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THE CONTROL SYSTEM FOR THE LINEAR ACCELERATOR AT THE EUROPEAN XFEL - STATUS AND FIRST EXPERIENCES

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Abstract

The European XFEL is a 3.4 km long X-ray Free-Electron Laser facility with a superconducting, linear accelerator and initially three undulator beam lines. First user run with two experiments has started in September this year at the first photon beamline while the final installation and commissioning of the other, two photon beam lines is well underway. This paper will focus on control system parts of the linear accelerator and highlight briefly its design and implementation. Namely the hardware framework based on the MTCA.4 standard, testing software concepts and components at real and virtual accelerator facilities. A well-established method for integrating high-level controls into the middle layer by means of a shot-synchronized data acquisition allows for rapid deployment and commissioning of the accelerator controls. Status of the final installations, of the commissioning phase and some first experiences from a technical and an operational point-of-view will be presented.

INTRODUCTION

The European XFEL (EuXFEL) is a 3.4 km long X-ray Free-Electron Laser starting in Hamburg, Germany, and ending south of Schenefeld, a city in the neighbourhood of Hamburg. It comprises of an injector, a linear accelerator section, a beam distribution system, undulators, photon beam lines and experimental stations. The geometry of the facility is basically a straight line with a northern and a southern branch in the last third for the undulator sections and photon beam lines. The injector produces an electron beam by extracting electron bunches with a laser beam from a photo cathode, which is focused and accelerated by a normal-conducting RF gun to beam energies of 5 MeV. The accelerator will provide up to 2700 electron bunches at repetition rates varying from 1 Hz to 10 Hz with 10 Hz being the default rate. The RF pulse length (flat top) is 600 µs long and the bunch charge can be chosen within a range of 0.02 – 1 nC.

A first cryogenic 1.3 GHz RF module accelerates the beam to 150 MeV followed by a 3.9 GHz module linearizing the energy profile. The beam is fed at a beam energy of 130 MeV into a 1.6 km long linear accelerator section with 96 cryogenic modules installed. These modules are utilizing superconducting RF-technology and accelerate the electron bunches up to 14 GeV and with four more modules installed eventually up to 17.5 GeV. Additionally, the linear accelerator section has two bunch compressor sections installed at locations corresponding to energies of 0.7 GeV and 2.4 GeV for maximizing peak currents. A collimation section followed by a flexible kicker system at the end of the linear accelerator section can distribute configurable bunch trains into two electron beam lines with undulator systems. On the northern branch two undulator sections with a tunable, planar undulator system and second tunable, helical undulator system will provide two different hard X-ray photon beams produced by the self-amplified spontaneous emission process (SASE). On the southern branch only one tunable, planar undulator system has been installed for now. Each of the three undulator sections will provide a photon beam for two experiments, serving six stations in total. The undulator sections are supposed to deliver photon pulses within a wavelength range of 0.05 – 0.4 nm, resp. 0.4 – 4.7 nm, a pulse length between 10 – 100 fs and a peak brilliance of 10^{32} – 10^{34} photons/s/mm^2/mrad^2/0.1% bandwidth. The schematic overview of the European XFEL accelerator is shown in Fig. 1.

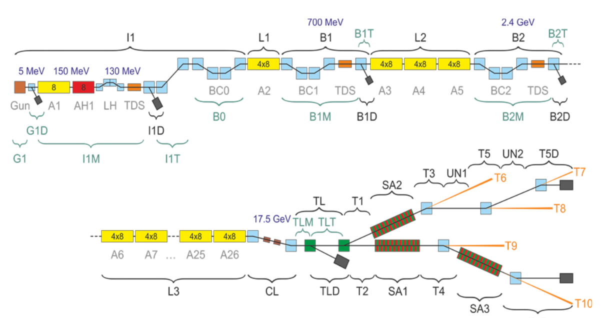

Figure 1: Schematic overview of the overall European XFEL accelerator with injector (I1), linear accelerator tunnel (L1 – L3), the collimation and distribution section (CL and TL) and the various SASE beam lines with its undulators (T1 – T10, SA1 – SA3).

The overall control system used at the EuXFEL facility is a common effort by of various groups at DESY

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THE FIRST OPERATION OF THE MAX IV LABORATORY SYNCHROTRON FACILITIES

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Abstract

On 21st of June 2016 the MAX IV Laboratory was inaugurated in the presence of the officials and has since then welcomed the first external researchers to the new experimental stations. The MAX IV facility is the largest and most ambitious Swedish investment in research infrastructure and designed to be one of the brightest source of X-rays worldwide. The current achievements, progress, collaborations and vision of the facility will be described from the perspective of the control and IT systems.

FIRST OPERATION

MAX IV Laboratory is a synchrotron based research facility which will operate one full energy linear accelerator at 3.2 GeV, two storage ring at 3 GeV and 1.5 GeV, and 14 beamlines (see Fig. 1).

The last 2 years most of the effort was made to bring the storages ring in operation while targeting at least 2 beamlines for user operation. The KITS group, being responsible for all IT infrastructure, information management, control system hardware/software and the scientific software, has supported all subsystem, beamline and accelerator scientists in their projects. The KITS has established a working guideline to balance the constraint of limited resources, in order to achieve this objective and help the stakeholder for their success.

Figure 1: The Machine Status web application accessible for the public, showing all accelerators and beamlines in operation.

Several milestones have been passed since the last report of the MAX IV status [1]. One of the major intermediate milestone happen end of 2015 when the 3 GeV ring could stack for the first time at 4 mA. This event has validated the new design of the 3 GeV ring and especially the optics parameters defined by simulation. As soon as the 3 GeV storage ring reach 50 mA, which is consider as the minimal to start the commissioning of the beamlines, the 3 GeV accelerator entered in operation mode. For the IT system it was the confirmation that the choice of technology, previously deployed for the Linac, could scale for the new accelerators. Some important date of the facility:

- 5 November 2015, the first synchrotron light of the 3 GeV was detected on the diagnostic beamline.
- 31 January 2016, the 3 GeV in operation.
- 9 June 2016, the first protein diffraction detected at Biomax; first light on the sample at Nanomax.
- 21 June 2016, the inauguration of the facility.
- 31 December 2016, the end of the MAXLAB building decommissioning.
- Dec 2016, the first expert users.
- Between March and June 2017, the first user
- June 2017, R1 commissioned.

The facility welcomed the first expert users at the end of 2017. Although 3 beamlines are already in operation not all the first phase beamlines of the original plan are commissioned, especially the 5 Soft X-Ray beamlines of the 1.5 GeV Ring. MAX IV will still continue to expand as well in the next 5 years to 14 beamlines. A project of Soft X-Ray Free Electron Laser, recommended by the Machine Advisory Council in Spring 2017, has now the necessary resource to propose a conceptual design before 2020.

ACCELERATOR STATUS

The commissioning of the 3 GeV have been achieved in 5 months, in spite of few unstable systems, especially the diagnostic. Meanwhile the total user experience of the control system improves quite a lot. Actually the system was made primary for the expert user in order to fine tune it or diagnose the system in details during the installation and subsystem test phases. With the coming operation mode the control system has quickly evolve to reduce the 300 000 parameters and signals of the Machine to a most comprehensive and high level view in order for the operator to quickly identify warning and fault of the equipment and recover as soon as possible for the beam delivery.

1.5 GeV Ring Commissioning

The R1 subsystem test went fast thanks to the experience acquired with the 3 GeV [1]. To reach high current was important to condition the ring. This process is slow and the important parameter is number of hours with beam, i.e.

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STATUS OF THE NATIONAL IGNITION FACILITY (NIF) INTEGRATED COMPUTER CONTROL AND INFORMATION SYSTEMS*

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Abstract

The National Ignition Facility (NIF) is the world's largest and most energetic laser experimental facility with 192 beams capable of delivering 1.8 megajoules of 500-terawatt ultraviolet laser energy to a target. The energy, temperatures and pressures capable of being generated on the NIF allow scientists the ability to generate conditions similar to the center of the sun and explore the physics of planetary interiors, supernovae, black holes and thermonuclear burn. This year concludes a very successful multi-year plan of optimizations to the control & information systems and operational processes to increase the quantity of experimental target shots conducted in the facility. In addition, many new system control and diagnostic capabilities have been commissioned for operational use to maximize the scientific value produced. With NIF expecting to be operational for greater than 20 years focus has also been placed on optimizing the software processes to improve the sustainability of the control system. This talk will report on the current status of each of these areas in support of the wide variety of experiments being conducted in the facility.

INTRODUCTION

The National Ignition Facility (NIF) [1] provides a scientific center for the study of inertial confinement fusion (ICF) and matter at extreme energy densities and pressures [2]. Each NIF experiment, or shot cycle, is managed by the Integrated Computer Control System (ICCS) [3], which uses a scalable software architecture running code on more than 2000 front end processors, embedded controllers and supervisory servers. The NIF control system operates laser and industrial controls hardware containing 66,000 control points (e.g. motors, calorimeters, etc) to ensure that all NIF's 192 laser pulses arrive at a target within 30 picoseconds of each other, are aligned to a pointing accuracy of less than 50 microns, and orchestrate a host of diagnostic equipment collecting experimental data in a few billionths of a second. Every NIF shot cycle [4] consists of approximately 1.6 million sequenced control point operations, such as beam path alignment, pulse shaping and diagnostic configuration and each cycle is typically conducted within 4-8 hours depending on the experiment complexity.

NIF has been a 24x7 operational facility since 2009 and has supported the advancement of understanding in various fields of study such as High Energy Density (HED) experiments for Stockpile Stewardship, Inertial Confinement Fusion (ICF), National Security Applications and Discovery Science. The facility and control system advancement has continued since becoming operational and many significant changes over occurred to increase its capabilities and efficiency since last reporting [5]. A summarization of the most recent enhancements is detailed in the following paper.

CONTROL SYSTEM STATUS

NIF Shot Rate Improvements

Over a two-year period, starting in 2014, the NIF facility and control system embarked on a large focused activity to improve the efficiency of shot operations with a goal to increase the number of shots performed annually thereby maximizing the experimental value obtained, all while keeping a flat funding level. Two significant goals of the activities were defined; 300 target shots in fiscal year 2015, and 400 target shots in fiscal year 2016, the latter goal representing greater than a 100% increase over the volume performed in 2014

Through a series of systems engineering analysis studies, optimizations were identified [6] and implemented in the areas of improved experiment scheduling, formalizing a 24x5 shot week and increasing the number of weeks utilized for shots during the year (by 10% to 44 weeks), and control system and operational process enhancements to reduce the shot cycle activity durations.

All optimizations have now been implemented and the results obtained (fig. 1) highlight that both goals were exceeded. As of August 2017, the facility is also on track for exceeding the fiscal year 400 target shot goal again (completes end September 2017). NIF also achieved another milestone in August this year when it successfully completed the 2000th target shot since becoming operational. The improvements made are now institutionalized and we believe that the capability to conduct similar annual target shots rates is sustainable.

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SwissFEL CONTROL SYSTEM – OVERVIEW, STATUS, AND LESSONS LEARNED

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Abstract

SwissFEL is a new free electron laser facility at the Paul Scherrer Institute (PSI) in Switzerland. Commissioning started in 2016 and resulted in first lasing in December 2016 (albeit not on the design energy). In 2017, the commissioning continued and will result in the first pilot experiments at the end of the year. The close interaction of experiment and accelerator components as well as the pulsed electron beam required a well thought out integration of the control system including some new concepts and layouts. This paper presents the current status of the control system together with some lessons learned.

OVERVIEW

The SwissFEL free electron laser facility [1] is the newest accelerator at the Paul Scherrer Institute (PSI) [2]. PSI already operates three large user facilities: a third-generation synchrotron radiation source (SLS), the continuous-beam spallation neutron source (SINQ), and the continuous-beam muon source (SμS). SINQ and SμS are driven by the high-intensity proton accelerator (HIPA) which also serves the particle physics program with pions, muons and ultra-cold neutrons (UCN). In addition to its research activities, PSI operates Switzerland's sole facility for the treatment of specific malignant tumours using protons (Proscan).

Based on the experiences from both the proton and the electron accelerators, the SwissFEL construction was preceded by an intense R&D period that included the temporary construction of the SwissFEL Test Injector Facility. The goal was to build the shortest possible XFEL facility with the lowest possible electron energy to allow reduced costs for both construction and support of the facility.

SwissFEL

A schematic drawing of SwissFEL is shown in Fig. 1. The accelerator is divided into an S-band injector, a C-band main linac (divided into three parts) and an undulator line called Aramis. The Aramis line will provide hard X-ray radiation, in the wavelength range from 0.1 - 0.7 nm, to two experimental stations with the possible extension of one more in the future. The overall length of the machine (from gun to experiment) is around 720 m and the beam pulses will have a repetition rate of 100 Hz.

The construction of the SwissFEL building started in spring 2013 and in summer 2015 the installation of first accelerator components began. In August 2016 the first electrons were produced, and in December 2016 the first lasing (at 380 MeV, 24 nm) was achieved. Since then more C-Band accelerating structures were put into operation, resulting in the start of photon optics commissioning in August 2017 with an FEL beam of 1620 MeV (1.3 nm wavelength).

Table 1: Key Design Parameters of SwissFEL

Overall Length (Gun – Experiment)	720 m
Maximum Electron Beam Energy	5.8 GeV
Repetition Rate	100 Hz
Nominal Wavelength in Aramis Line	0.1 - 0.7 nm
Number of Endstations in Aramis	2 + (1)
Expected Photon Pulse Length	0.2 – 20 fs

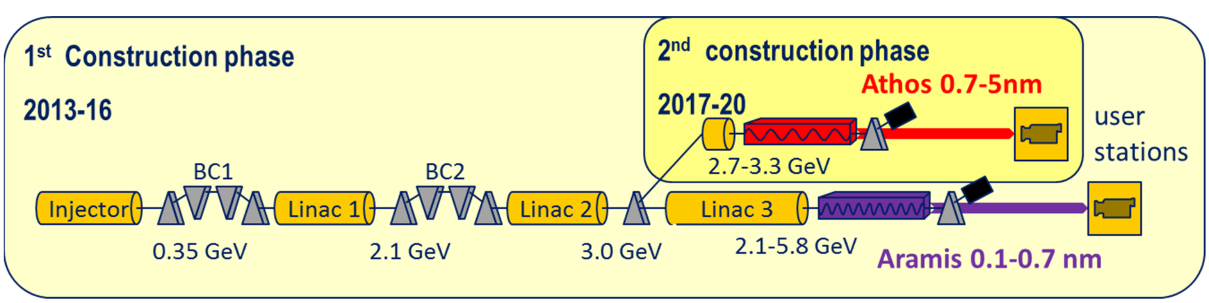

Figure 1: Schematic SwissFEL accelerator layout.

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EPICS 7 PROVIDES MAJOR ENHANCEMENTS TO THE EPICS TOOLKIT

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Abstract

The release of EPICS 7 marks a major enhancement to the EPICS [1] toolkit. EPICS 7 combines the proven functionality, reliability and capability of EPICS V3 with the powerful EPICS V4[2] extensions enabling high-performance network transfers of structured data. The code bases have been merged and reorganized. EPICS 7 provides a new platform for control system development, suitable for data acquisition and high-level services. This paper presents the current state of the EPICS 7 release, including the pvAccess network protocol, normative data types, and language bindings, along with descriptions of new client and service applications.

INTRODUCTION

EPICS 7 provides support for Data Acquisition, Experiment Control, and Data Analysis with new data representation and mechanisms in the protocol and data representation while preserving the robust, high performance, and easily extendible capabilities that are expected a control system. EPICS 7 is the merge of EPICS 3 and EPICS 4. The release includes both communication mechanisms running seamlessly, side by side. The new capabilities are provided by the EPICS 4 communication improvements in pvAccess and pvData, the next generation communication protocol and data representation. The new protocol provides structured data support and a remote procedure call (RPC). that support the integration of all data into microservices: including real time data from I/O Controllers (IOCs), processed data from data aggregation, and configuration data required for plant integration. The most significant improvement is that pvData provides the ability to define arbitrary data structures for more complex data sets and pvAccess is designed to transport those structures in the most efficient manner. The new EPICS 7 release enables the development of services on all real time, configuration, and aggregated data.

NO CHANGES REQUIRED TO USE EPICS 7

All the features of EPICS V3 work as is. The IOC process database, device support and drivers are used by both pvAccess/pvData and Channel Access/DBRTypes [3] seamlessly. Control System Studio (CS Studio) [4][5], Archive Appliance, run both pvAccess and Channel Access protocols. The IOC severs all data over both pvAccess and Channel Access. The pvAccess services provides the improved metadata for multidimensional arrays. All IOC data provides better support for time stamps and alarm information.

NEW FEATURES OF EPICS 7

The new capabilities overcome limitations of EPICS V3 that give EPICS users the ability to develop applications that can provide data through a network service and access data from any service on the control network. The communication mechanisms are provided to support a service oriented architecture for real time data, aggregation data, and configuration database backends. In conjunction with EPICS 7, services are available for real time data from the IOC and areaDetector, configuration data from a Directory Service and save set service (MASAR), and aggregated data from the Data Index Service. Complex control is supported with the new ability to communicate with devices (groups of PVs on an IOC) in an always-consistent, transaction type way. The new capabilities extend the scope of EPICS V3 from instrumentation and control (I&C) to data acquisition, image processing, data analysis, configuration management, data management and beyond.

STRUCTURED DATA

EPICS 7 can do everything EPICS V3 can do but better. It can construct pvData structures used in EPICS V3 as DBR types. For example, the equivalent of a DBR_TIME_DOUBLE would be the NTScalar structure in Figure 1. The improvements include:

```
NTScalar
        double value
        alarm_t alarm
                int severity
                int status
                string message
        time_t timestamp
                long secondsPastEpoch
                int nanoseconds
                int userTag
```

Figure 1: pvData equivalent of DBR_TIME_double.

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TANGO KERNEL DEVELOPMENT STATUS

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Abstract

The TANGO Controls Framework continues to improve. This paper will describe how TANGO kernel development has evolved since the last ICALEPCS conference. TANGO kernel projects source code repositories have been transferred from subversion on Sourceforge.net to git on GitHub.com. Continuous integration with Travis CI and the GitHub pull request mechanism should foster external contributions. Thanks to the TANGO collaboration contract, parts of the kernel development and documentation have been sub-contracted to companies specialized in TANGO. The involvement of the TANGO community helped to define the roadmap which will be presented in this paper and also led to the introduction of Long Term Support versions. The paper will present how the kernel is evolving to support pluggable protocols - the main new feature of the next major version of TANGO.

ROADMAP

TANGO is a mature and reliable toolkit to build distributed control systems for installations which need to run for the next 10 to 20 years. For this reason TANGO needs a roadmap which will ensure its future evolution and stay a good choice for the coming years. At the TANGO meeting in May 2015 held at Solaris in Krakow (Poland) the community gave their input on the essential features of the current roadmap. Input was provided via email and discussed during an interactive session. The results presented in [1], [2] and [3] are summarised here:

(1) Improve Documentation, (2) Move to Git, (3) Remove CORBA completely, (4) Grow the community, (5) REST API, (6) Web browser application, (7) Secure encryption, (8) Database performance, (9) Device class Marketplace, (10) Long Term Support, (11) TANGO Virtual Machine, (12) Auto-generate Unit tests, (13) SysML support, (14) Replace Boost.Python.

This paper will go through each point of the roadmap and present the current status (as of October 2017).

IMPROVE DOCUMENTATION

The highest priority point as defined in the roadmap in 2015 was to re-factor and consolidate the documentation and to write a cookbook of recipes and concepts. Until recently, the main TANGO documentation was *The TANGO Book*, a large pdf file of more than 250 pages and many other documents in various formats. *The Book* contains a lot of precious information but was hard to read. It was decided to combine all the available documentation into a single source in Sphinx format on readthedocs. In the spirit of Write-the-docs [4] a documentation camp was held in the Grenoble area in May 2017. The camp lasted 3 days with 2 days in a house rented especially for the event and located in a quiet mountain village. The event was dedicated to working on reviewing the new documentation available on read-the-docs [5] and identifying and writing missing documentation for TANGO.

The meeting was sponsored by the TANGO Controls Collaboration. Travel and accommodation were paid for by the Collaboration. 11 enthusiastic documentation writers from 7 different institutes/companies participated (see Fig. 1).

Figure 1: The write-the-docs team at work.

Here is a brief summary of the achievements: the documentation has been re-organized to be a coherent whole, almost all existing docs have been converted to sphinx, new diagrams have been produced and integrated. Some old ones have been updated. New Getting Started

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THE SKA TELESCOPE CONTROL SYSTEM GUIDELINES AND ARCHITECTURE

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Abstract

The Square Kilometre Array (SKA) [1] project is an international collaboration aimed at building the world's largest radio telescope, with eventually over a square kilometre of collecting area, co-hosted by South Africa, for the mid-frequency arrays, and Australia for the low-frequency array. Since 2015 the SKA Consortia joined in a global effort to identify, investigate and select a single control system framework suitable for providing the functionalities required by the SKA telescope monitoring and control. The TANGO Controls [2] framework has been selected and comprehensive work has started to provide telescope-wide detailed guidelines, design patterns and architectural views to build Element and Central monitoring and control systems exploiting the TANGO Controls framework capabilities.

INTRODUCTION

Spring 2015 representatives from eight SKA Consortia met in Trieste, Italy, for the SKA Local Monitoring and Control (LMC) Standardisation Workshop, with the purpose to explore some open source control system frameworks and define a procedure to select the best suited for SKA. The main criteria adopted for the final evaluation were:

- technical applicability, with particular respect to:
  - scalability
  - industry standards support and bespoke developments
  - modernity and roadmap
  - user support and documentation
- integration of precursors
- risk mitigation

The TANGO Controls framework turned out to be the best suited to fulfil the above criteria, especially with respect to it's modern architecture and strong roadmap for future developments. TANGO Controls has been selected as SKA monitoring and control common framework. A series of workshops have been scheduled in 2016, with the aim to improve commonality across the main sub-systems[1] control systems architecture. The TANGO LMC Harmonisation through telescopes workshops targeted at analysing the existing designs made by the Elements Consortia, identify commonalities, defining best practices and provide a path to LMC harmonisation beyond the selection of TANGO as control system framework. Building on the outcome of the harmonisation effort, the SKA Control System Guidelines document summarises generic design patterns and common approaches for monitoring and control harmonisation across SKA Elements, to maximise the benefit of the TANGO control system framework.

TERMINOLOGY

In a scenario where a worldwide community is involved in the Elements, and thus telescope, control system design, some clarifications about the adopted terminology helped better understanding. In particular, the SKA control system guidelines use the following definitions:

- **monitoring**: is used in the context of a higher-level component subscribing to updates of a TANGO Attribute with the purpose of evaluate its value/quality factor for a specific reason;
- **archiving**: is used in the context of gathering monitoring. information, e.g Attributes, from a TANGO device to save it to a monitoring archive;
- **logging**: is used in the context of additional information that may be emitted by components to support fault finding and engineering activities. No information that is expected to be used for operations or expected to be monitored by another component may be included only in logs. Logs can also be stored; this is referred as *log storage*;
- **failure**: occurs when an item is unable to provide the correct service and is unable to perform its required function according to its specification. Either hardware or software can fail, and the failure must be reported together with all the details required for a prompt and effective identification of the failed component;
- **fault**: is the cause of an error, or the condition that causes software to fail to perform its required function;
- **error**: refers to difference between actual autput and expected output;
- **state**: refers to the TANGO device State attribute;
- **health state**: represents the overall health of the component with respect to a set of monitoring points/reported failures applying a predefined metric;
- **alarm**: an audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring a timely response, as per the IEC 62682 standard.

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[1] Referred as *Elements* in the SKA project.

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MADOCA II DATA COLLECTION FRAMEWORK FOR SPring-8

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Abstract

MADOCA II (Message and Database Oriented Architecture II) is the next generation of the MADOCA control framework and has been implemented in accelerator and beamline control for the SPring-8 since 2014. In this paper, we report on the recent evolution in MADOCA II for data collection, which was missing in the past reports at ICALEPCS [1, 2]. To improve the management flexibility, we developed a data collection framework to manage various data collection types in SPring-8 with a unified method. All of the data collection methods (polling, event triggered type), data formats (such as point and waveform data) and platforms (UNIX, Embedded, and Windows including LabVIEW [3]) can be managed within the same framework. We also developed a signal registration procedure to facilitate the preparation for the data collection. In MADOCA, we managed all the parameters used in the data collections with an RDBMS, and requested the equipment manager to fulfil a Signal Registration Table (SRT) to update the data collection. However, this required an extensive work owing to inconsistencies in the SRT and the iteration of communications with the DB manager for the registration of the SRT into the RDBMS. In MADOCA II, we facilitated the signal registration procedure with a prior test of the data collection and a validity check in SRT with a web-based user interface. We started to implement the MADOCA II data collection into SPring-8 with 220 hosts and have confirmed stable operation since April 2016.

INTRODUCTION

MADOCA is a distributed control framework developed to control the SPring-8 accelerator and beamline. It has been adopted for this operation since 1997 [4]. Though we have experienced stable operation with MADOCA for more than 15 years, we have developed the next generation of MADOCA, called MADOCA II, which has been implemented to include new functions to cope with current requirements in the controls. MADOCA II has been adopted into the SPring-8 and SACLA DAQ system since 2014 [5, 6]. The schematic view of messaging control in MADOCA II is shown in Figure 1. MADOCA II performs text-based messaging controls with SVOC sentence structure for distributed controls, similar to MADOCA. However, much of the functionality has been implemented by introducing ZeroMQ [7] and MessagePack [8] as core messaging architectures. Flexibility in the messaging communication was improved to handle the capability to attach variable length data such as image data to the messages, and to add support for the Windows platform. Fast data logging was also archived by using NoSQL databases such as Redis [9] and Cassandra [10].

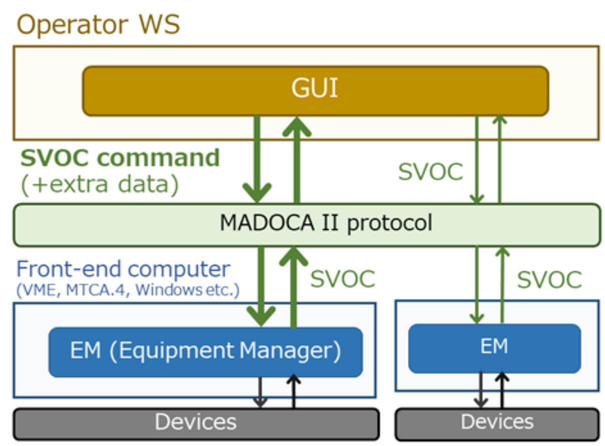

Figure 1: Schematic view of the software framework for messaging controls with MADOCA II.

At SPring-8, we operate data logging with about 500 hosts and 30 k signals. On average, about 9 k signals per second are collected, where intervals of data collections for signals vary from one second to 10 minutes. For the data logging, we archive the data for each signal with the signal name from the O/C in the SVOC command of MADOCA. For example, the signal name is set to “sr_mag_ps_a/voltage” for the signal data in the voltage of a power supply for a magnet in a storage ring.

Most of the data collections are operated with Poller/Collector applications [11]. The Poller/Collector periodically collects point data in several formats such as integers, or statuses with bit information and floats, which are applied to the data logging of vacuum pressure, temperature and voltage in magnet power supplies and so on. However, we have also encountered other data types in the data collection during the 20 years of operation at SPring-8. In a Linac accelerator, we encountered event triggered data collections synchronized in time with the injection beams of a different framework [11]. We also have other types of data collections such as bunch current measurements and closed orbit distortion (COD) in electron beams, which deal with the structure of the data format.

The schematic view of the data collection at SPring-8 is shown in Figure 2. We still use MADOCA for the data collection. However, data logging is upgraded to MADOCA II for high flexibility. Therefore, data collected with MADOCA is sent to the streamer in MADOCA II. After passing the data into the streamer, the data is archived into the NoSQL database through writers. These applications in

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HOW TO DESIGN & IMPLEMENT A MODERN COMMUNICATION MIDDLEWARE BASED ON ZeroMQ

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Abstract

In 2011, CERN's Controls Middleware (CMW) team started a new project aiming to design and implement a new generation equipment access framework using modern, open-source products. After reviewing several communication libraries [1], ZeroMQ [2] was chosen as the transport layer for the new communication framework. The main design principles were: scalability, flexibility, easy to use and maintain. Several core ZeroMQ patterns were employed in order to provide reliable, asynchronous communication and dispatching of messages. The new product was implemented in Java and C++ for client and server side. It is the core middleware framework to control all CERN accelerators and the future GSI FAIR [3] complex. This paper presents the overall framework architecture; choices and lessons learnt while designing a scalable solution; challenges faced when designing a common API for two languages (Java and C++) and operational experience from using the new solution at CERN for 3 years. The lessons learnt and observations made can be applied to any modern software library responsible for fast, reliable, scalable communication and processing of many concurrent requests.

INTRODUCTION

A control system needs a performant communication infrastructure offering a reliable exchange of data between distributed processes. Each process acts either as a client or as a server, or even both. The communication capability is provided by a middleware software framework, composed of client & server parts, exposing a public API to the application layer.

Technology Evolution

For the needs of the CERN accelerator control system, a middleware framework called RDA (Remote Device Access) [4] was designed and its first version was implemented in 2000. Initially, RDA was built on top of the CORBA transport layer. However, after using the CORBA based solution for more than 10 years, a number of outstanding issues were identified: poor scalability and heavy use of system resources (CPU & memory). In 2011, it was decided to perform a market survey [1], aiming to find a modern transport library, replacing completely CORBA and providing the required scalability and performance levels. The review process selected ZeroMQ as a transport library for the new, major version of RDA, called subsequently RDA3.

Requirements for RDA3

A set of functional & technical requirements was formulated for RDA3. All major functional requirements remained the same as for the previous RDA2. However, based on the operational experience, certain technical aspects (e.g. asynchronous transport) became obligatory for the new RDA3.

Here are the most important functional requirements:

- Support for required data types: scalars, strings, data structures, multi-dimensional arrays of scalars/strings/data structures
- Access to remote resources based on the device-property model
- Provide sync & async *Get* call (read data)
- Provide sync & async *Set* call (write data)
- Provide *Subscribe* call (monitor data changes)
- Guaranteed, ordered execution of requests on the server-side and ordered reception of results
- Consistent implementation for C++ and Java

Additionally, equally important technical requirements:

- Fully asynchronous communication
- Good scalability, exceeding by far RDA2
- Quality of Service (QoS): timeout management, message queues, thread management policies
- Low usage of memory and system resources
- Portable solution, with minimal external dependencies, which can be easily adopted to any platform
- Intuitive, extendable, safe and easy to use public API.

RDA3 Overview

In the CERN context, RDA3 as the middleware framework, provides transparent access to equipment, following the device-property model used at CERN (i.e. the means to access remote resources) [4]. In this model access points are represented as device-property pairs. A device is an abstraction of the underlying equipment. A property represents an operation that can be performed on the device.

The framework supports two communication paradigms:

- *request/reply*: client can either read from (*Get* call) or write to (*Set* call) an access point.

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EXPERIENCES WITH LASER SURVEY INSTRUMENT BASED APPROACH TO NATIONAL IGNITION FACILITY DIAGNOSTIC ALIGNMENTS

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Abstract

The National Ignition Facility (NIF) uses powerful lasers to compress targets for the study of high energy density physics. Sophisticated diagnostics are placed close to the targets to record the results of each shot. The placement of these diagnostics relative to the target is critical to the mission, with alignment tolerances on the order of 500 microns. The integration of commercial laser tracker instruments into the NIF control system has improved diagnostic alignment in many ways. The Advanced Tracking Laser Alignment System (ATLAS) project incorporates commercial Faro laser tracker instruments into the diagnostic factory and the target chamber, providing flexibility and improved alignment accuracy. The system uses multiple retroreflectors mounted on each of the diagnostic assemblies. These are measured with the tracker and the location of the diagnostic hardware is interpreted as a 6 DoF (degrees of freedom) position in the NIF target chamber volume. This enables a closed loop alignment process to align each diagnostic such that the instrument line of sight intersects the aim point on the target. This paper provides an overview of how the laser tracker is used in diagnostic alignment and discusses challenges met by the control system developers to achieve this integration.

OVERVIEW

The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) is the world's most energetic laser system for experimental research in Inertial Confinement Fusion (ICF) and high-energy-density (HED) physics. The NIF laser system consists of 192 laser beams which are focused inside a 10-meter Target Chamber (TC), delivering up to 1.8 MJ of ultraviolet light onto the mm to cm scale target.

The NIF has several Diagnostic Instrument Manipulators (DIMs) mounted to the target chamber, each of which can be used to place diagnostic instruments inside the target chamber for up-close viewing of the shot-time physics. Each DIM can extend up to 6 m, allowing the diagnostics to be positioned as close as 100 mm from the NIF target. Each DIM supports a variety diagnostics payloads, and based on the shot schedule, these payloads are frequently reconfigured. Each shot requires that the DIMs be precisely aligned to the NIF target.

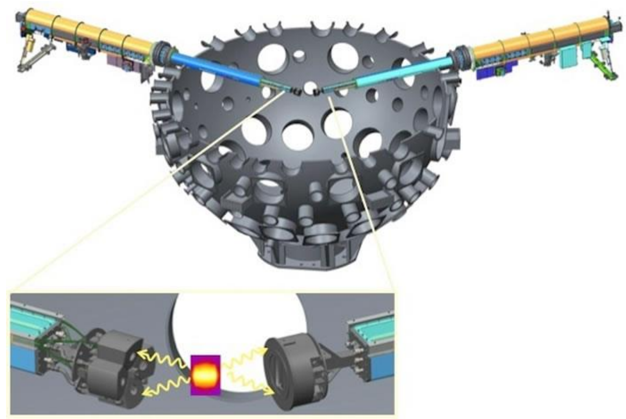

Figure 1: Two NIF Diagnostic Instrument Manipulators.

THE NEED FOR IMPROVED ALIGNMENT TOOLS

Prior to the introduction of the Advanced Tracking Laser Alignment System (ATLAS) system in NIF, all diagnostic alignments were performed using custom systems consisting of digital cameras, complex optics and lighting, and human interpretation of images as feedback for the alignment. Due to the narrow field of view of the optical systems, a dedicated optical system was required per diagnostic location [1,2]. NIF originally had three DIMs, and in conjunction with the ATLAS project there was a plan to add two more. The optical alignment system model would have led to five dedicated systems to maintain, and additional, sequential, manual alignments.

The many camera systems have to be removed for each high neutron yield NIF shot, and then reinstalled afterwards. Each of these systems also requires a clear view through the center of the target chamber, which constrained the sequence for alignment of the NIF experiment. Improving the alignment process flexibility and speed translates into cost savings and more experiments within a given period [3]. The main goals of the ATLAS project were:

- Have a single device to support alignment of multiple diagnostics
- Be easy to remove, re-install and recalibrate
- Not require visual interpretation of images for the alignment process

After an extensive evaluation and feasibility study of three different technologies and review of multiple laser tracker make and models, the Faro laser tracker was selected to be basis for this new alignment system.

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PROFINET COMMUNICATION CARD FOR THE CERN CRYOGENICS CRATE ELECTRONICS INSTRUMENTATION

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Abstract

The ITER-CERN collaboration agreement initiated the development of a PROFINET® communication interface, which may replace the WorldFIP interface in non-radiation areas. The main advantage of PROFINET® is a simplified integration within the CERN controls infrastructure that is based on industrial Programmable Logic Controllers (PLCs).

CERN prepared the requirements and subcontracted the design of a communication card prototype to the Bern University of Applied Sciences (BFH). The designed PROFINET® card prototype uses the netX Integrated Circuit (IC)© for PROFINET® communication and a FPGA to collect the electrical signals from the back-panel (electrical signals interface for instrumentation conditioning cards).

CERN is implementing new functionalities involving programming, automation engineering and electronics circuit design. The communication between the card and higher layers of control is based on the Open Platform Communications Unified Architecture (OPC UA™) protocol. The configuration files supporting new types of instrumentation cards, which are being developed and are compatible with the SIEMENS© SIMATIC automation environment. Some minor changes to PROFINET® PCB electronics card will be performed before launching a small series production.

It is worth to mention that all required data calculations (for example interpolation, calibration) and protocol handling (PROFINET®, OPC UA™) are performed using a multithreading application, which runs on a single netX50 chip. It allows to simplify the architecture of the control system, because there is no need for additional computing nodes in the network to execute all required calculations of the process.

INTRODUCTION

System Overview

The control system in radiation areas is shown in Figure 1. It is based on the CRATE (equivalent to a remote IO), PLC, Front End Computer (FEC), Cryogenics Instrumentation Expert Tool Supervisory Control and Data Acquisition (CIET SCADA) and Cryogenics Supervisory Control and Data Acquisition (CRYO SCADA). CIET SCADA and CYRO SCADA are connected to the DB Log (database for data logging – long term archiving and cloud data analysis). CRYO SCADA is also connected to DB Sensor (database for sensor and heater cards parameters) [1], [2], [3]. This architecture is also used in non-radiation areas.

In order to simplicity the architecture the whole functionality of the FEC was moved to the crate which is now smart device able to calculate, transform the raw input data and communicate directly with the PLC (see the Figure 2). Due to the fact that the WorldFIP protocol is not recommended for new installations the Ethernet based PROFINET® protocol is used. The communication between CIET SCADA and CRATE runs through OPC UA™, as this protocol is going to be available in the netX51 chip. OPC UA™ also allows direct connection between the CRATE and cloud data analysis module.

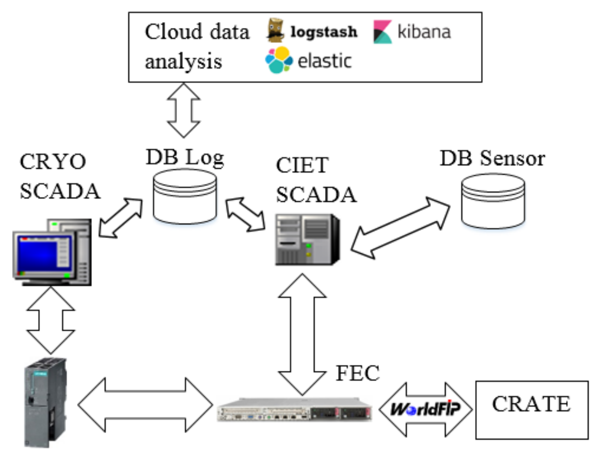

Figure 1: Current architecture overview.

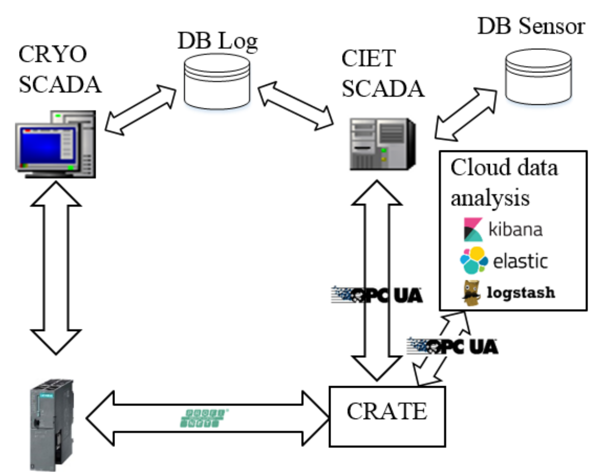

Figure 2: New architecture overview.

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LTE/3G-BASED WIRELESS COMMUNICATIONS FOR REMOTE CONTROL AND MONITORING OF PLC-CONTROLLED MOBILE VACUUM DEVICES

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Abstract

All particle accelerators and most experiments at CERN require high (HV) or ultra-high (UHV) vacuum levels. Contributing to vacuum production are two types of mobile devices: Turbo-Molecular Pumping Groups and Bakeout Racks. During accelerator stops, these PLC-controlled devices are temporarily installed in the tunnels and integrated in the Vacuum SCADA, through wired Profibus-DP. This method, though functional, poses certain issues which a wireless solution would greatly mitigate. The CERN private LTE/3G network is available in the accelerators through a leaky-feeder antenna cable which spans the whole length of the tunnels. This paper describes the conception and implementation of an LTE/3G-based modular communication system for PLC-controlled vacuum mobile devices. It details the hardware and software architecture of the system and lays the foundation of a solution that can be easily adapted to systems other than vacuum.

INTRODUCTION

The extensive network of particle accelerators and experiments at CERN, the European Centre for Nuclear Research [1], features the largest operational vacuum system in the world [2]. These accelerators, represented in Figure 1, have extremely strict pressure requirements.

In order to minimize the interaction between the particle beam and any residual air molecules, pressure in the beam pipes must be kept below 10^{-10} mbar (UHV). The superconductive magnets and RF cavities in the LHC, together with the helium distribution lines, require vacuum for thermal insulation of the associated cryogenic system. This is typically maintained between 10^{-6} and 10^{-8} mbar (HV). Such low-pressure levels are created and maintained using a wide array of methods and technologies.

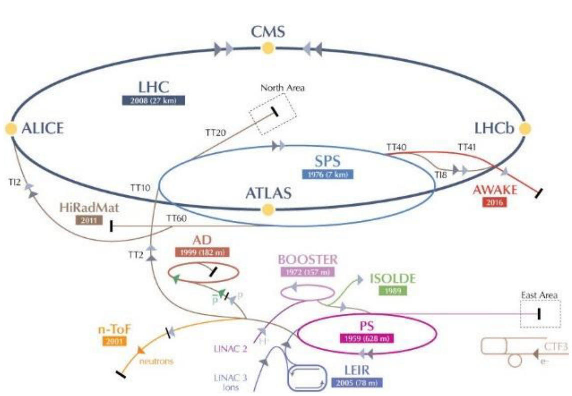

Figure 1: The CERN Accelerator Complex.

These include turbo-molecular pumping, baking of the vacuum vessels, and techniques such as NEG, ionic, cryogenic and sublimation pumping [3] [4]. Most of the equipment required to create and maintain HV and UHV is permanently fixed in place.

Several hundred pumping groups are installed throughout all accelerators in the complex, for both beam and insulation vacuum purposes. The same can be said for NEG, ionic, cryogenic and sublimation pumps, which can be found by the hundreds in most of the accelerators. In several sections, the inside of the beam pipes is actually coated with a NEG, which essentially acts as a pump by adsorbing molecules. In others, the pipes are cryogenically cooled in order to condense certain gases on their walls, further reducing pressure.

Though most of this is achieved with fixed equipment, two types of mobile devices contribute to the creation and management of vacuum: Turbo-Molecular Pumping Groups (VPGMs) and Bakeout Racks. VPGMs (Figure 2) are trolley-mounted pumping groups, containing one primary rotary-vane pump and one turbo-molecular pump, along with all required valves and some additional equipment. These PLC-controlled groups are temporarily installed at necessary locations, to either perform the initial pump down from atmospheric pressure (the LHC, for example, has no fixed pumping groups on the beam pipe) or to complement the other pumping methods.

Figure 2: Turbo-Molecular Pumping Group.

Bakeout Racks (Figure 3) also play a major role in reaching low pressures. Prior to accelerator operation, the beam pipes and several elements of the vacuum system are baked, by being heated to temperatures in excess of 200ºC for over 24 hours. Baking these vacuum vessels evaporates molecules that may have condensed on their inner walls

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ECMC, THE OPEN SOURCE MOTION CONTROL PACKAGE FOR EtherCAT HARDWARE AT THE ESS

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Abstract

The open standard EtherCAT is well established as a real-time fieldbus for largely distributed and synchronised systems. Using EtherCAT hardware for digital and analogue I/Os, Diamond Light Source (DLS) and the Paul Scherrer Institut (PSI) introduced open source solutions for the bus master in scientific installations. The European Spallation Source (ESS) decided to use EtherCAT systems for mid-performance data acquisition and motion control on accelerator applications.

In this contribution we present the motion control software package ECMC developed at the ESS using the open source Etherlab master to control the EtherCAT bus. The motion control interfaces to the EPICS Motor Record with a model 3 driver. It supports functionalities like positioning, jogging, homing and soft/hard limits. Advanced features of the ECMC package include full servo-loop feedback, a scripting language for custom synchronisation of different axes, virtual axes, externally triggered position capture and interlocking. We will illustrate the synchronisation feature on the example of a 2-axis slit set and present different CPU hardware platforms and EtherCAT slave modules for the ECMC framework.

INTRODUCTION

Since it's introduction in 2003, the field bus EtherCAT established itself as an industrial standard for distributed and synchronised applications. Beckhoff Automation GmbH [1] established the bus on the market, and hundreds of manufacturers followed, coordinated in the EtherCAT Technology Group [2]. The group is collecting all users and suppliers of EtherCAT hardware and applications and maintains the open bus standard.

EtherCAT Field Bus

EtherCAT is a real time field bus based on Ethernet infrastructure (100 Mbit/s, full-duplex). It uses a one master/n-slaves model with standard CAT5 connections in line, star or ring topologies. It supports synchronised distributed clocks (DC) in all bus components with a synchronisation error <100ns and bus cycle times <50µs.

The bus master is able to run on any computer hardware with Ethernet ports. Beckhoffs Windows-based TwinCAT [1] is the most common commercial software solution. Since the bus master is not restricted to dedicated hardware virtually any hardware/OS combination can be used to implement the bus master functionality.

Slaves are running on dedicated hardware and are available as motor drives, I/O-terminals, sensors, actors or even as complete robotic systems.

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ESS Controls Strategy

EtherCAT systems are part of the chosen controls hardware strategy at ESS [3, 4] being the medium performance platform for data acquisition and control as shown in Fig. 1.

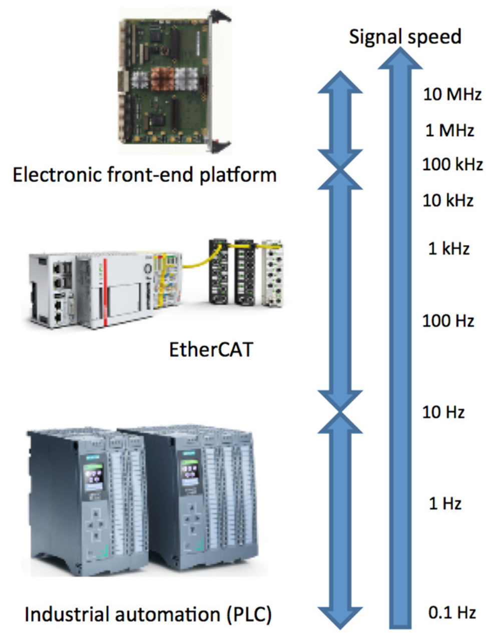

Figure 1: ESS hardware performance levels [5].

A particularly advantageous setup for the accelerator applications at ESS is the combination of a bus master for the high level electronic front-end platform, an EtherCAT master and the associated EPICS IOCs on the same hardware (e.g. a µTCA-CPU). As all ESS IOC's will run on Linux OS, an Open Source EtherCAT master is needed here.

Previous Work at Research Facilities

Currently several open source EtherCAT master are available in the community. The most popular is the Open Source EtherCAT Master introduced by the company IgH as part of their EtherLab package [6]. The Diamond Light Source (DLS) used this master in a project aiming to replace the first generation VME-based DAQ system to an EtherCAT based distributed digital and analog I/O and control system [7, 8].

More recently also the Paul Scherrer Institut (PSI) took an approach with the same bus master for simplified hardware configuration and higher bus cycle rates [9].

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MARWIN: A MOBILE AUTONOMOUS ROBOT FOR MAINTENANCE AND INSPECTION

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Abstract

MARWIN is a mobile autonomous robot platform designed for performing maintenance and inspection tasks alongside the European XFEL accelerator installation in operation in Hamburg, Germany. It consists of a 4-wheel drive chassis and a manipulator arm. Due to the unique Mecanum drive technology in combination with the manipulator arm the whole robot provides three degrees of freedom. MARWIN can be operated in a pre-configured autonomous as well as a remotely controlled mode. Its operation can be supervised through various cameras. The primary use case of MARWIN is measuring radiation fields. For this purpose MARWIN is equipped with both a mobile Geiger-Mueller tube mounted at the tip of the manipulator arm and a stationary multi-purpose radiation detector attached to the robot's chassis. This paper describes the mechanical and electrical setup of the existing prototype, the architecture and implementation of the controls routines, the strategy implemented to handle radiation-triggered malfunctions, and the energy management. In addition, it reports on recent operations experiences, envisaged improvements and further use cases.

INTRODUCTION

The mobile robotic system was developed in a collaboration of the "hochschule 21" and DESY, which provides autonomous measurement tasks in the new research facility European XFEL. The project is a proof-of-concept for the recording of robot-based radiation measurements in accelerator systems. Among other things, it has to be clarified to what extent such a system can operate reliably under the given radiation load. The hardware used mostly comes from the consumer sector and is not protected against radiation.

Motivation

The need for automated systems and autonomous robot systems is steadily growing. This shows above all the current development in the field of (semi-) autonomous systems towards autonomous UAVs for parcel delivery (see [1]), self-propelled cars (see [2]) or the guideless train and bus in public transport (see [3]). Furthermore, accelerators such as, for example, PETRA III or FLASH (both at the DESY) are generally overbooked, so that beam time for researchers is limited. As the accelerators must be serviced, it is important to hold the maintenance time to a minimum.

But what must happen before a maintenance team can enter an accelerator tunnel? After switching off the accelerator, the radiation safety personnel has to measure the radiation level in the tunnel. This means that the specialists use measuring probes to control the complete tunnel at predetermined measuring points. If there is no residual radiation, maintenance can be carried out. Needless to say, the process of measuring requires time which is not available to the researchers for experiments. A useful solution is to minimize the inspection time, by automating the radiation measurements.

In addition to the time consuming aspects of the radiation measurements, there are also both physiological and psychological aspects which are usually of concern to the radiation safety personnel. A robot is unaffected by such considerations, and additionally, a measurement task performed by a robot will lead to better and to more reproducible measuring results.

Conditions

In order to increase the availability and efficiency of maintenance, repairs, inspections and fault diagnostics of scientific accelerator-based light sources, a mobile robot system is to be developed, which enables inspections without interruption of accelerator operation.

Because the spatial conditions are difficult to access, the robot platform is to be equipped with a manipulator which allows measurements and inspections to be carried out on the accelerator components. The robot is used in the European XFEL tunnel. On a route of about 3.2 km, the radiation should be measured without human intervention. As far as possible, a monitoring center should be able at all times to monitor the current status of the robot system and, if necessary, perform a manual intervention. The robot system will offer two scenarios within the project:

- Scenario 1: The accelerator is to be routinely measured by (partially) autonomous and automatic driving along the accelerator as well as carrying out radiation measurements at predefined measuring positions. Appropriate personnel carry out the configuration of the measuring positions and other parameters via a remote access.
- Scenario 2: By manually approaching certain measuring positions, the operator can perform remotely controlled and punctual measurements on the accelerator.

The switch between the scenarios should be possible at any time via remote access. The measurement data are recorded and processed by the measuring device.

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THE INTEGRATED ALARM SYSTEM OF THE ALMA OBSERVATORY

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Abstract

ALMA is composed of many hardware and software systems each of which must be properly functioning to ensure the maximum efficiency. Operators in the control room, follow the operational state of the observatory by looking at a set of non-homogeneous panels. In case of problems, they have to find the reason by looking at the right panel, interpret the information and implement the counter-action that is time consuming so after an investigation, we started the development of an integrated alarm system that takes monitor point values and alarms from the monitored systems and presents alarms to operators in a coherent, efficient way. A monitored system has a hierarchical structure modelled with an acyclic graph whose nodes represent the components of the system. Each node digests monitor point values and alarms against a provided transfer function and sets its output as working or non nominal, taking into account the operational phase. The model can be mapped in a set of panels to increase operators' situation awareness and improve the efficiency of the facility.

ARCHITECTURE PRINCIPLES

During the development study, we have found that each monitored system has a hierarchical structure that can be modelled with an acyclic graph whose nodes represent the components of the system [1]. Each node, or component, of the monitored system can be working properly or be in a non-nominal state. In the latter case, the error could or could not generate an alarm to catch the attention of the operator or engineer. In fact, depending on the particular operational phase, an error could be safely ignored without distracting the operators. This is for example the case of the failure generated by a non-operational antenna during the maintenance. This case shows that having an error does not correspond 1-to-1 to an alarm: the monitor points in input to a component must be elaborated against a user provided heuristic to decide case by case if a non-nominal value in one or more of them is enough to produce an alarm for the operator. The model graph in the right side of Figure 1, shows the nodes that are working well in green and those in a non-nominal state in orange or red. Such information can be used to map the information in the model in the panels for engineers and operators as shown in the left side of the same Figure 1.

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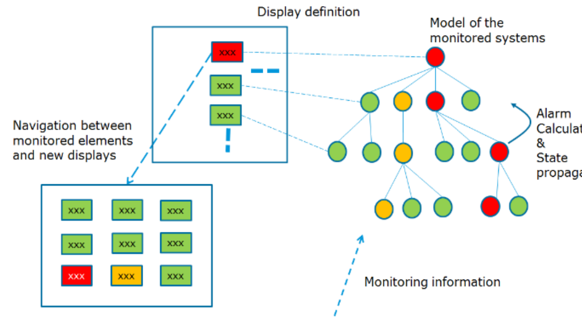

Figure 1: The schema of the alarm system.

The inputs of the IAS come in the form of values from monitor points like a temperature sensor, or alarms generated by other alarm sources such as specialized software systems like for example the ALMA Common Software (ACS) or the control system of a power plant. The set of inputs is therefore very heterogeneous: the IAS must be able to elaborate each type of input independently of its format and the software system who provides it. In the scope of this document, we will call the input to the IAS Integrated Alarm System Input/Output (IASIO), regardless if they are the values of monitor points or alarms, and without distinction of the software source that produces them.

Distributed Alarm System Unit

The core of the IAS [2] is a distributed software system composed of Distributed Alarm System Units (DASU) that concurrently evaluate the IASIOs in input and, if appropriate, produce one or more alarms. Sometimes when the translation of IASIOs into alarms is very complex or several IASIOs must be correlated, the DASU produces an intermediate value instead of an alarm. We call such temporary value a synthetic parameter. Typically, a DASU represents the IAS model of a particular subsystem of the observatory. For more complex subsystems, it can also make sense to break them down into a hierarchy of DASUs, most likely following the natural hierarchy of the subsystem.

The output produced by a DASU being an alarm or a synthetic parameter can be, in turn, the input to another DASU, as shown in Figure 2. This design follows the principle that the software systems that produce the IASIOs in input to the IAS can or cannot be completely separated. It is a central concept of this architecture the concept that the values coming from the remote systems and those produced by the DASU are indistinguishable.

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REPLACING THE ENGINE IN YOUR CAR WHILE YOU ARE STILL DRIVING IT – PART II*

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Abstract

Two years ago, at the 2015 ICALEPCS conference in Melbourne Australia, we presented a paper entitled "Replacing The Engine In Your Car While You Are Still Driving It" [1]. In that paper we described the mid-point of a very ambitious, multi-year, upgrade project involving the complete replacement of the low-level RF system, the timing system, the industrial I/O system, the beam-synchronized data acquisition system, the fast-protect reporting system, and much of the diagnostic equipment. That paper focused mostly on the timing system upgrade and presented several observations and recommendations from the perspective of the timing system and its interactions with the other systems. In this paper, now nearly three quarters of the way through our upgrade schedule, we will report on additional observations, challenges, recommendations, and lessons learned from some of the other involved systems.

INTRODUCTION

To briefly re-cap the previous paper, we compared the installation/operations schedule to driving through mountainous terrain on a road with many peaks and valleys. When you start down a valley, you shut down your engine, replace as much of it as you can, then try to get it running again before you have to start up the next peak. At the bottom of each valley there is a relatively flat stretch of road representing the "start-up period" – during which you mostly coast while you discover how your changes affected the machine's operation (for good or for ill).

The installation and operation schedule is shown below in Figure 1. The green blocks represent the operating periods, the red blocks represent the installation and maintenance periods, and the yellow blocks represent the start-up periods. The durations of the operation, maintenance, and start-up periods vary as the project progresses. The first three years of the schedule call for longer operational periods (seven to nine months), shorter upgrade periods (four months), and shorter start-up periods (one month). The middle three years – during which the most complex upgrades take place – have longer maintenance periods (four to five months), longer start-up periods (three months), and shorter operational periods (three to four months). During the last three years, things theoretically get easier and we go back to longer operations, shorter maintenance, and shorter start-up periods. This is the point where we are currently at in the schedule.

Figure 1: Installation and operation schedule.

OBSERVATIONS AND RECOMMENDATIONS

In the previous paper, we presented three observations and two recommendations. The observations were:

1. You can't replace the whole system at once.
2. Some compatibility must be maintained between the old and new systems.
3. You will be surprised.

The two recommendations were:

1. Always have a way to fall back
2. Have sympathy for the operations staff.

This paper amplifies on the three observations and includes one new recommendation.

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VIRTUAL CONTROL COMMISSIONING FOR A LARGE CRITICAL VENTILATION SYSTEM: THE CMS CAVERN USE CASE

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Abstract

The current cavern ventilation control system of the CMS experiment at CERN is based on components which are already obsolete: the SCADA system, or close to the end of life: the PLCs. The control system is going to be upgraded during the LHC Long Shutdown 2 (2019-2020) and will be based on the CERN industrial control standard: UNICOS employing WinCC OA as SCADA and Schneider PLCs. Due to the critical nature of the CMS ventilation installation and the short allowed downtime, the approach was to design an environment based on the virtual commissioning of the new control. This solution uses a first principles model of the ventilation system to simulate the real process. The model was developed with the modelling and simulation software EcosimPro. In addition, the current control application of the cavern ventilation will also be re-engineered as it is not completely satisfactory in some transients where many sequences are performed manually and some pressure fluctuations observed could potentially cause issues to the CMS detector. The plant model will also be used to validate new regulation schemes and transient sequences offline in order to ensure a smooth operation in production.

INTRODUCTION

During the past 6 years, the CERN Cooling and Ventilation (CV) group has been gradually migrating their existing control systems and deploying all the new ones using the CERN industrial control standard: UNICOS employing WinCC OA as SCADA and either Siemens or Schneider PLCs. This work already covers nearly 200 PLCs, and is deployed on 10 production WinCC OA servers, running around 35 WinCC OA projects, being monitored 24hr/day by the technical infrastructure operators in the CERN Control Centre.

The two remaining major HVAC (Heating, Ventilation and Air-Conditioning) systems using a legacy and now virtually obsolete SCADA system (Wizcon) are the ATLAS and CMS caverns plants. These systems are large, complex ventilation units, covering multiple buildings, across multiple PLCs, which are scheduled to be upgraded during the first half of the LHC Long Shutdown 2 (LS2), beginning in 2019. This will bring these control systems into the CERN standard, and will guarantee their functioning through the next 15 years of operation, during the future upgrade phases of the LHC.

Since these ventilation systems are critical to the operation of the two largest detectors of the LHC, CMS and ATLAS, they are critical to the operation of the LHC accelerator itself, since any failures can impact the beam availability. In order to ensure a smooth and quick upgrade of the control system, as well as allowing engineers and operators to achieve improved control system performance, a virtual commissioning of the CMS ventilation cavern will be performed, using a dynamic model that has been developed.

Current Ventilation System

The current ventilation system for the CMS experimental cavern was designed and installed during the period of the LHC installation between 2000 and 2005. It has been in operation for nearly 10 years, since the start-up of the LHC in 2008, and the SCADA system is obsolete, and the PLCs are close to the end of their operational lifetime. Furthermore there has been no major improvement made since the LHC began operation considering that the application is critical, and cannot be stopped for long. During the upgrade any potential performance or maintenance issues will be addressed as well, based on experiment and HVAC plant operator input.

CERN Industrial Control Standard

The CERN industrial control standard for continuous processes, the UNICOS CPC framework [1], has been discussed in detail in previous publications. This standard provides many advantages for the development, operation and maintenance of the control applications. Therefore, given the aforementioned need to upgrade the ventilation system, the CERN UNICOS CPC standard will be used to migrate during the next possible upgrade window: the Long Shutdown 2 of the LHC, scheduled to begin in 2019. Since the CMS ventilation system is critical, it is preferable to be able to do a virtual commissioning of the system, with a first principles model, prior to the deployment in-situ.

PROCESS MODELLING

In order to apply a model-based approach for the virtual commissioning of an existing plant, the process must be analysed, from a global level down to each individual component. During this phase two complementary data sources were used: CV group internal documentation and the Electronic Documents Management System (EDMS), which is a global CERN documentation storage location. The CV data provided "As-Built" HVAC sub-contractor project

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EXPERIENCE UPGRADING CONTROL SYSTEMS AT THE GEMINI TELESCOPES

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Abstract

The real-time control systems for the Gemini Telescopes were designed and built in the 1990s using state-of-the-art software tools and operating systems of that time. These systems are in use every night, but they have not been kept up-to-date and are now obsolete and also very labor intensive to support. This led Gemini to engage in a major effort to upgrade the software on its telescope control systems. We are in the process of deploying these systems to operations, and in this paper we review the experience and lessons learned through this process and provide an update on future work on other obsolescence management issues.

INTRODUCTION

The Gemini Observatory consists of twin 8.1-meter diameter optical/infrared telescopes, which provide full sky coverage from their locations on Maunakea in Hawaii (first light 1999) and Cerro Pachón in Chile (first light 2000). Most of the control systems for these telescopes were developed in the late 1990s using the technology and techniques of that time.

The overall software architecture for both telescopes is identical, and organized in five logical groups: Observatory Control System (OCS), Adaptive Optics Systems (AO), Telescope Control System (TCS), Instrument Systems and the Data Handling System (DHS) as shown in Fig. 1.

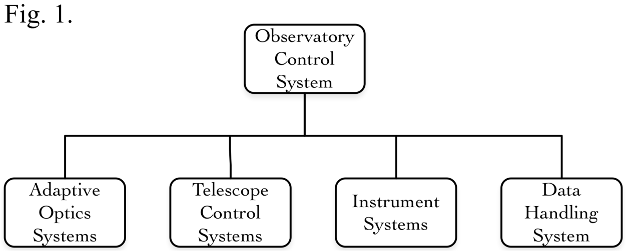

Figure 1: Gemini Software Architecture.

This architecture includes both the hardware and software necessary to operate the telescopes and its instruments, coordinated through the Observatory Control System (OCS) [1].

The Experimental Physics and Industrial Control System (EPICS) [2] was adopted as the standard control framework in which to run the facility subsystems, specifically for real-time control. A Standard Instrument Controller [3] on Versa Module Europa bus (VME) hardware was developed to ensure conformity between externally developed subsystems.

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A more detailed view of the Telescope Control System and its components for both telescopes is shown in Fig. 2.

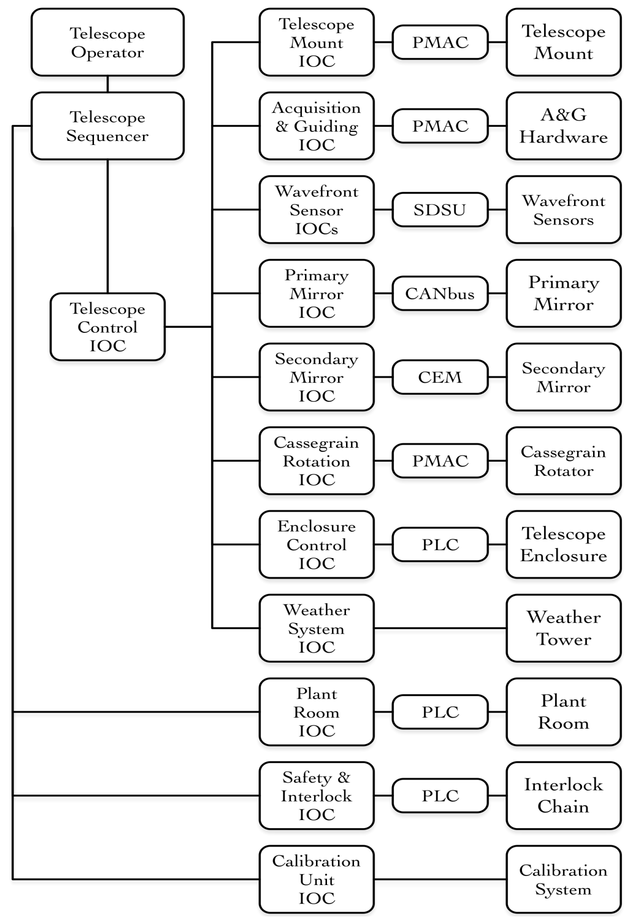

Figure 2: Gemini Telescope Control Architecture.

The Gemini software model makes a clear distinction between the low level software that directly controls and coordinates the telescope and instrument hardware and the high level software that interfaces with the users and sequences this hardware to perform queue scheduled science observations. All low-level Gemini software applications are classified as real-time even though the application may not have any hard real-time performance requirements.

While the high-level software has evolved over the years, the real-time control software has, with the exception of minor modifications to add features and fix problems, remained relatively unchanged. The real-time software development environment used to maintain these systems is likewise rooted in the 1990s. It has evolved organically over time, consisting of many different build processes; code repositories; development operating sys-

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FRAMEWORK UPGRADE OF THE DETECTOR CONTROL SYSTEM FOR JUNO*

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Abstract

The Jiangmen Underground Neutrino Observatory (JUNO) is the second phase of the reactor neutrino experiment. The detector of the experiment was designed as a 20k ton LS with a Inner diameter of 34.5 meters casting material acrylic ball shape. Due to the gigantic shape of the detector there are approximate 10k monitoring point of temperature and humidity. There are about 20k channels of high voltage of array PMT, electric crates as well as the power monitoring points. Since most of the first phase software of the DCS was developed on the framework based on windows, which is limited by operation system upgrade and commercial software, the framework migration and upgrade are necessary for DCS of JUNO. The paper will introduce the upgrade framework of the DCS based on EPICS (Experimental Physics and Industrial Control System) running Linux OS. The implementation of the IOCs of the high-voltage crate and modules, stream device drivers, and the embedded temperature firmware will be presented. The software realization and the remote control method will be presented as well as the development of the GUIs by CSS (Control System Studio). The upgrade framework can be widely used in the project with the similar hardware and software interfaces.

INTRODUCTION

The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose neutrino experiment. It was proposed in 2008 for neutrino mass hierarchy (MH) determination by detecting reactor antineutrinos from nuclear power plants (NPPs). The site location is optimized to have the best sensitivity for mass hierarchy determination, which is at 53 km from both the Yangjiang and Taishan NPPs. The experiment is located in Jinji town, Kaiping city, Jiangmen city, Guangdong province, CHINA. The neutrino detector is a liquid scintillator (LS) detector with a 20 kton fiducial mass, deployed in a laboratory 700 meters underground. JUNO consists of a central detector, a water Cherenkov detector and a muon tracker. The central detector is a LS detector of 20 kton fiducial mass. The central detector is submerged in a water pool to be shielded from natural radioactivities from the surrounding rock and air. The water pool is equipped with PMTs to detect the Cherenkov light from muons. On top of the water pool, there is another muon detector to accurately measure the muon track [1]. See Figure 1 schematic view.

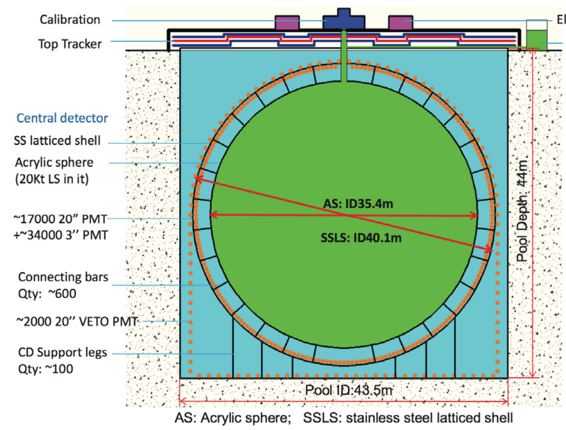

Fig. 1: A schematic view of the JUNO detector.

The main task of the detector control system (DCS) is to probe the parameters affecting the performance of the detector for long-term monitoring and control. Since JUNO is the second phase of the reactor neutrino experiment. Before that the DCS of DayaBay Reactor Neutrino Experiment was developed to support the running neutrino-oscillation experiment. The experiment has been taking data for almost 3 years and making steady progress. And the first results have already been released. And most of the first phase framework of the DCS was developed based on windows, which is limited by operation system upgrade and commercial platform upgrade. The framework of DCS migration and upgrade are necessary. The DCS of JUNO will implement by open source framework based on Linux.

REQUIREMENTS AND FRAMEWORK DESIGN

The detector of the experiment was designed as 20k ton LS with an Inner diameter of 34.5 meters casting material acrylic ball shape. Due to the gigantic shape of the detector there are approximate 1k monitoring point of temperature and humidity, 20k channels of high voltage of

*Manuscript received May 30, 2016. This work was supported in part by the Jiangmen Underground Neutrino Observatory (JUNO) experiment. It was proposed in 2008 for neutrino mass hierarchy (MH) determination by detecting reactor antineutrinos from the nuclear power plant (NPP).
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LIGHTWEIGHT ACQUISITION SYSTEM FOR ANALOGUE SIGNALS

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Abstract

In a complex machine such as a particle accelerator there are thousands of analogue signals that need monitoring and even more signals that could be used for debugging or as a tool for detecting symptoms of potentially avoidable problems. Usually it is not feasible to acquire and monitor all of these signals not only because of the cost but also because of cabling and space required.

The Radio Frequency system in the Large Hadron Collider (LHC) is protected by multiple hardware interlocks that ensure safe operation of klystrons, superconducting cavities and all the other equipment. In parallel, a diagnostic system has been deployed to monitor the health of the klystrons.

Due to the limited amount of space and the moderate number of signals to be monitored, a standard approach with a full VME or Compact PCI crate has not been selected. Instead, small embedded industrial computers with Universal Serial Bus (USB) oscilloscopes chosen for the specific application have been installed.

This cost effective, rapidly deployable solution will be presented, including existing and possible future installations as well as the software used to collect the data and integrate it with existing CERN infrastructure.

OVERVIEW OF AVAILABLE SOLUTIONS

As a large organization CERN has multiple different systems for data acquisition. Some of them are older and being phased out and some are still developed and new hardware support is added. Much of the data acquisition is performed directly in the equipment groups' hardware and available via associated software. In this section we focus on standalone systems that can be used to sample signals that are not digitized by other means.

The biggest and most well known acquisition system for analogue signals at CERN is Open Analog Signals Information System (OASIS) [1] created and supported by the Controls Group of the Beams Department. OASIS supports many different hardware platforms (mostly VME crates and Kontron's PCs), digitizers from different vendors, analogue multiplexers and provides a software that allows configuring acquisition and plotting acquired traces.

This system is highly specialized and allows operators and experts to monitor all critical signals in the accelerator complex and correlate them using the system-wide triggers based on the CERN Central Timing. With use of wideband multiplexers it is possible to reuse the same precise and expensive digitizers for multiple signals. This system is perfectly suited for permanent and frequently used installations. The initial deployment cost is high but it can benefit from the scale.

From a technical point of view OASIS uses standard Front-End Computers (FECs), the Front-End Software Architecture (FESA) [2] framework and an abstraction layer for hardware. It is well integrated into the Control System and it is possible to read out values using standard tools.

On the other side of the spectrum from this central service there are acquisition systems built into devices developed by the equipment groups themselves. The Radio Frequency Group has a common way of retrieving diagnostic information from all the cards designed in-house via a standardised hardware and a set of FESA device properties. This solution, although always available, is not flexible. If a parameter was not designed to be acquired a change of hardware and/or firmware would be needed to make it accessible.

There is another acquisition system designed by the RF Group — the ObsBox [3]. It is a high throughput system that is able to monitor the longitudinal and transverse positions of bunches in a bunch-by-bunch manner and is a crucial part of the LHC Transverse Damper. The acquisition cards are connected using gigabit serial links to a powerful server fitted with a large amount of RAM.

There are many other domain specific acquisition systems which are often tightly coupled with domain specific hardware.

The Lightweight Acquisition System for Analogue Signals described here started as one of these custom solutions.

THE LIGHTWEIGHT ACQUISITION SYSTEM FOR ANALOGUE SIGNALS

The system started as a custom tool built for monitoring the health of the LHC klystrons. The sixteen klystrons are arranged in four groups, each consisting of four klystrons powered using a separate power converter installed on the surface. There are four airtight bunkers underground, from which the power is distributed to the klystrons.

Klystrons are sensitive devices and can be easily damaged by for example an electric arc. To protect against such situations the distribution point in the bunker monitors the current consumed. When the protection is triggered it switches off the power supply and fires the crowbar, which short circuits the smoothing capacitor and the power supply output to ground using a large thyristor stack in order to remove their residual stored energy and prevent damage to the klystron. After each such event the gathered data is analysed and the reasons for the fault are determined.

The first version of the system consisted of a pair of PicoScope 6000 series oscilloscopes triggered in parallel with the thyristor. The scopes were then connected via a USB-over-Ethernet bridge to a remote PC running Windows XP. On this machine LabView would read out the acquired data. The reliability of the acquisition chain was quite low and often people trying to investigate cause of a crowbar would find the PC to be off or with no data available. It was decided

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HOW LOW-COST DEVICES CAN HELP ON THE WAY TO ALICE UPGRADE

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Abstract

Cheap, ready to install and simple to configure, minicomputer and microcontroller boards have been in use in ALICE for a few years for specific, non-critical tasks, like integrating the environment sensors network in the experimental site, and to monitor and analyse clock signals. These systems have also been installed inside the ALICE experiment, in the presence of magnetic field and radiation, and subjected to a functionality test. While the major part of these devices proved to work correctly even under the experiment conditions, finally some weaknesses were revealed, thus excluding this class of devices from usage in the production setup.

They have also played a role in the realization of scaled systems for the ALICE upgrade. With them, we have been able to simulate the presence of Front-End cards which are not yet available, allowing to proceed in the development of the software framework, of libraries and interfaces, in parallel with the production and validation of the hardware components. Being off-the-shelf and available everywhere in the world, they can be installed in remote institutes and laboratories participating to the collaboration.

Some of the systems have been realised by students and trainees hosted at CERN for short periods of time. As well as being cheap and easy to procure, they proved to be a great didactic tool, allowing young collaborators to realise a complete system from scratch, integrate into a complex infrastructure and get a hands-on approach to modern control systems.

INTRODUCTION

The ambitious upgrade plan of the ALICE experiment[1, 2] expects a complete reformulation of its data flow after the LHC shutdown scheduled for 2019. The continuous read-out of large size events at an interaction rate of 50 kHz Pb-Pb and 200 kHz pp, resulting in an impressive 3.4 TBytes/s data flow and 100 GBytes/s data-to-storage rate[3], requires the development of brand new electronic modules, together with the redesign of the trigger and online computing systems[4].

The electronics development phase started a few years ago and has already made a lot of progress. However, access to the prototypes is at present very limited and full scale prototypes of new devices are expected only very close to the time of their installation in the experiment. The lack of real hardware has a negative impact on developments of the supervision systems, including the Detector Control System (DCS)[5, 6].

To overcome the limitations caused by the lack of realistic hardware, the ALICE DCS team started building small-scale prototypes of the Front-End cards, based on low-cost commercial components: Raspberry Pi, Arduino, Intel Edison, etc.

These systems are commonly used in ALICE for environmental monitoring and to check simple electronic components and sensors. During 2016 and 2017, some of these devices have been configured and installed in the experiment areas around and inside the ALICE detector, where they were left for several months, in the presence of beam and magnetic field.

While the developments continue on the electronics part and on the overall design, these small-scale prototypes demonstrate their helpfulness to simulate the final system, allowing to understand and optimise the separation of roles, and target tools and protocols for the communications. Lastly, they represent a rather inexpensive, but realistic, laboratory, to exercise the developers' tools and environment, and to plan the deployment and integration phases.

FROM PRESENT INSTALLATIONS TO THE ALICE UPGRADE

Operational since 2014, the first minicomputer setup was installed to monitor the alignment of the LHC clocks (Fig. 1), replacing an expensive oscilloscope.

Figure 1: LHC clock monitor, able to detect misalignments of 100 ps.

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MicroTCA GENERIC DATA ACQUISITION SYSTEMS AT ESS

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Abstract

The European Spallation Source (ESS) is a Partnership of 17 European Nations committed to the goal of collectively building and operating the world's leading facility for research by use of neutrons by the second quarter of the 21st Century. The strive for innovation and the challenges that need to be overcome in order to achieve the requested performances pushed towards the adoption of one of the newest standards available on the market. ESS has decided to use MicroTCA as the standard platform for systems that require high data throughput and high uptime. The implications of this choice on the architecture of the systems will be described with emphasis on the data acquisition electronics.

INTRODUCTION

For many years VME has been the preferred choice in the accelerator and science community for data acquisition systems. The availability of many manufacturers, who developed either crates or boards, the reliability of the platform, proven in both industrial and research environments, and the established knowledge base of the system acquired during the years by many engineers made the selection of this standard a safe choice.

In the last decade quite a few new standards started to challenge VME for both scientific and industrial applications, a few examples could be the ATCA for telecommunications, OpenVPX for military and aerospace, PXI and MicroTCA for measurement and automation applications. All of these new standards share the characteristic of replacing the old parallel architecture of the buses with newer ones based on serial interconnects, like PCIe and SRIO, leveraging the technological advances and the increasing availability of multi-gigabit transceivers in many silicon devices including FPGAs.

MicroTCA Capabilities

MicroTCA is defined as a complimentary standard to ATCA (Advanced Telecommunications Computing Architecture) and its purpose is to address cost sensitive and physically smaller applications while still retaining most of the underlying philosophy, interconnect topologies and management features [1, 2].

MicroTCA infrastructure is designed to provide high availability, the standard itself claims that its goal is to achieve an up-time requirement of 99.9%. This characteristic is achieved through the integration of features for resiliency, redundancy, serviceability and manageability. MicroTCA uses IPMI with the addition of PICMG specific commands to manage the system components. The MicroTCA Carrier Hub (MCH) features a MicroTCA Carrier Management Controller (MCMC) whose role is to monitor and control the Advanced Mezzanine Cards (AMCs) that are part of a shelf by means of the IPMB-L bus as well as presence detect and enable signals. By interacting with the MCH it is possible to disable and start any specific Field Replaceable Unit (FRU) in the crate and to monitor the sensors provided on each card. According to the standard the management section shall be able to supervise the available supply voltage levels and the temperatures of critical areas on the PCB like those close to the air inlet and outlet and core components. In addition to these sensors it is also possible to monitor the connectivity status of each card, both on the Fat Pipe Region and on the GbE interface. Thresholds can be set for each of the cards to allow the MCMC to take actions and warn the user if a monitored parameter is drifting away from its nominal value.

The use of AMCs, the same equipment that can be used with certain restrictions in the ATCA environment by means of ATCA carrier cards, as the basic building blocks of the MicroTCA system allows migration between the two platforms. The manageability, modularity and hot-swap capabilities provided by the infrastructure allow the standard to be flexible, by configuring diverse AMCs in a MicroTCA shelf many different application architectures can be realized. The availability of infrastructure components that provide switching capabilities for different protocols like PCIe, Ethernet and Serial Rapid IO further expand the range of applications that can be covered by this standard [3].

MicroTCA makes provision for up to 4 telecommunication clocks on the backplane, plus one additional fabric clock to be used as the reference for the aforementioned interconnection standards, and up to 20 full-duplex ports (differential TX and RX links) that can be used to move data amongst the different AMCs or towards external systems. Common backplane implementations provide redundant Gigabit Ethernet (GbE) communication links on AMC ports 0 and 1 and direct board to board connections on ports 2 and 3 (ie. SAS/SATA). The main communication channel, called Fat Pipe, uses ports 4 to 7 whereas the Extended Fat Pipe, which is used when redundancy or higher bandwidth is required, is implemented on ports 8 to 11. Ports 12 to 20, exception made for port 16, are the so called Extended Options Region and are further divided into two sets. Ports 12 to 15 are usually reserved for additional direct AMC to AMC connections whereas a M-LVDS bus implementation uses ports 17 to 20. Port 16 is used for two out of the four total telecommunication clocks.

Figure 1 shows an overview of an implementation of a MicroTCA backplane used at ESS.

ESS has adopted a multi-layer strategy for implementing the data acquisition and control systems with different architectures covering complimentary input signal frequencies and response time. For the majority of applications with

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PORTING VME-BASED OPTICAL-LINK REMOTE I/O MODULE TO A PLC PLATFORM - AN APPROACH TO MAXIMIZE CROSS-PLATFORM PORTABILITY USING SoC

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Abstract

The optical-link remote I/O system called "OPT-VME system" that consists of a VME master and several kinds of slave boards is widely used in SPring-8 and SACLA. As the next generation low-end platform instead of the outdated VMEbus, a Linux PLC such as Yokogawa e-RT3 has been considered. We have developed an e-RT3-based master module OPT-PLC to fully utilize a large number of existing remote boards.

In the original system, low-level communication is performed by FPGA and high-level communication procedures are handled in the Solaris device driver on a VME CPU board. This driver becomes a barrier to port the system to the e-RT3 platform. OPT-PLC should be handled by the e-RT3 standard driver in the same manner as other e-RT3 I/O modules. To resolve the difficulty, OPT-PLC was equipped with Xilinx SoC and the high-level communication procedures were implemented as application software on ARM Linux in the SoC. As a result, OPT-PLC can be controlled through the standard e-RT3 driver. Furthermore, the system will be ported to other platform like PCI Express by replacing the bus interface block in the PL part.

This paper reports on our development as an approach to maximize cross-platform portability using SoC.

INTRODUCTION

The control system of the SPring-8 accelerator complex employs a large amount of optical-linked remote I/O systems that consist of master and slave boards to efficiently control the widely distributed accelerator equipment in the large site from the front-end computers. Originally, four different kinds of optical-linked remote I/O systems were used. We have consolidated them into two through the update of the control system. One is an "RIO system" developed by Mitsubishi Electric Co. and over 1,400 RIO slave boards are employed since 1997. The other is an "OPT-VME system" [1] developed by SPring-8 and over four hundred slave boards are used since 2001. Since the RIO system has been discontinued already, we have completed the preparation to replace it with the OPT-VME system. The master boards using the RIO system and the OPT-VME system are based on VMEbus.

Meanwhile, VME is already out-of-date and we are considering the next-generation alternative platforms. As a high-end platform, MicroTCA.4 [2] is the best candidate at present. On the other hand, a Linux-based PLC such as e-RT3 [3] by Yokogawa Electric Co. is considered as a low-end platform. Several e-RT3s are applied as the front-end computer in both SPring-8 and SACLA.

In order to effectively utilize the resources of the large amount of OPT-VME slave boards, we have developed the e-RT3 based new master module named OPT-PLC for slow control applications such as magnet power supplies. In the development, we have considered maximizing the portability of the developed FPGA logic to other platforms such as the PCI Express based platform, for example, MicroTCA.4 as the next-generation high-end platform.

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OPT-VME SYSTEM

The OPT-VME system consists of two types of master boards, "OPT-VME" (Fig.1) and "OPT-CC" (Fig. 2), and ten types of slave boards (Fig. 3). OPT-VME is a single-slot 6U VME board with four optical channels and OPT-CC is a dual-slot 6U VME board with twelve optical channels. TOSLINK [4] is used for all the optical channel connectors of the OPT-VME system. The communication protocol between a master board and a slave board is "OPT-Protocol 2006" [5] also developed by SPring-8 and one slave board can be connected to one optical channel of the master board. The main specification of the OPT-VME system is summarized in Table 1.

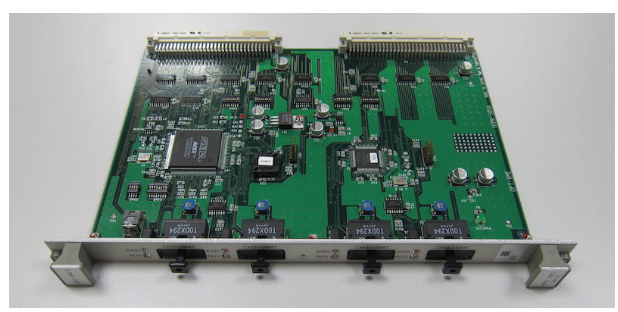

Figure 1: Photo of the OPT-VME board.

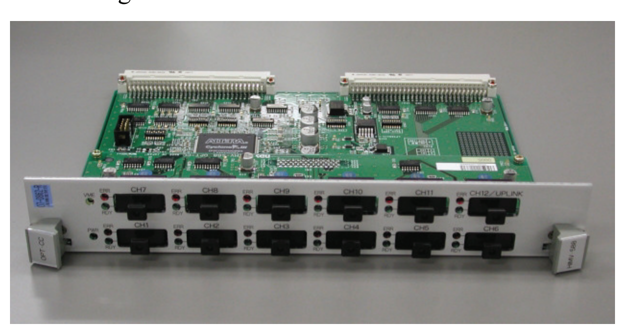

Figure 2: Photo of the OPT-CC board.

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SOLVING VENDOR LOCK-IN IN VME SINGLE BOARD COMPUTERS THROUGH OPEN-SOURCING OF THE PCIE-VME64X BRIDGE

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Abstract

VME is a standard for modular electronics widely used in research institutes. Slave cards in a VME crate are controlled from a VME master, typically part of a Single Board Computer (SBC). The SBC typically runs an operating system and communicates with the VME bus through a PCI or PCIe-to-VME bridge chip. The de-facto standard bridge, TSI148, has recently been discontinued, and therefore the question arises about what bridging solution to use in new commercial SBC designs. This paper describes our effort to solve the VME bridge availability problem. Together with a commercial company, MEN, we have open-sourced their VHDL implementation of the PCIe-VME64x interface. We have created a new commodity which is free to be used in any SBC having an FPGA, thus avoiding vendor lock-in and providing a fertile ground for collaboration among institutes and companies around the VME platform. The article also describes the internals of the MEN PCIe-VME64x HDL core as well as the software package that comes with it.

INTRODUCTION

The VME (Versa Module Europa) modular electronics standard emerged from the VME bus electrical standard and the Eurocard mechanical form factor. The former is a parallel communication bus developed in the 1980's. The latter defines the dimensions of Printed Circuit Boards (PCBs) as well as the mechanics of a rack hosting multiple cards. VME usually comes as a multi-slot chassis with a power supply and a fan tray (Fig. 1). Depending on the needs of a particular application, various types of VME crates are available in the market, starting from the smallest 1U, 2-slots to 9U, 20-slots with a possibility of having Rear Transition Modules (RTMs). These are the boards that are plugged to the slots at the back of a typical VME crate. They don't have direct access to the VME bus in the backplane, but instead connect to the corresponding modules installed in the front slots of a crate. Usually an RTM would be a quite simple board routing signals from cables connected in the back of the crate, to a front VME Slave board. The front module, on the other hand, is a more complex PCB with for example ADCs and an FPGA to process inputs and/or generate outputs going to a controlled system. A typical VME crate is deployed with one or multiple VME Master cards controlling several Slave cards. The Master module is very often a Single Board Computer (SBC). This is in fact a miniaturized PC running some operating system (e.g. Linux) and communicating with higher layers of the control system over an Ethernet link.

Figure 1: VME chassis example.

Despite, the availability of more modern standards, like MicroTCA or PXIe, VME is still a widely used solution for not only control systems in research facilities, but also in industrial and military applications. The reason behind that is all the already existing investment in the technology and the usual long lifetime of modular electronics in the fields mentioned above. People are reluctant to upgrade their critical systems and redesign their application-specific boards, once they have spent a long time to make them robust and reliable. For all these applications also the VME bus performance is very often sufficient, which delays modernization plans even further. Taking the CERN accelerators case as an example, we currently have almost 900 VME crates installed in various operational and lab systems. Out of those, about 50 new crates were installed only in 2016. We still plan to install about 200 new VME crates in various renovations during Long Shutdown 2 in 2019-2020.

VME BUS

VME bus was originally developed in the 1980's for Motorola 68k processors as a multi drop, parallel bus with big endian byte ordering [1]. It is organized as a master-slave architecture, where master devices can transfer data to and from slave cards. In practice, the majority of setups use a single master, multiple slaves configuration. It is a quite slow communication bus for today's standards. For the base specification, it can reach 80MB/s throughput. An absolute

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Em# ELECTROMETER COMES TO LIGHT

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Abstract

Em# project is a collaboration project between MAX IV Laboratory and ALBA Synchrotron to obtain a high performant four-channel electrometer. Besides the objective of accurate current measurements down to the picoampere range, the project pursues to establish a reusable instrumentation platform with time stamped data collection able to perform real time calculations for flexible feedback implementations.

The platform is based on a FPGA responsible of acquisition and synchronization where a real-time protocol between the modules has been implemented (Harmony) [1]. The data acquired is transmitted via PCIe to a Single Board Computer with an embedded Linux distribution where high level processing and synchronization with upper levels of Control System is executed.

In this proceeding, the reasons that lead to start a complex instrument development instead of using a Commercial On the Shelf (COTS) solution will be discussed. The results of the produced units will be analysed in terms of accuracy and processing capabilities. Finally, different Em# applications in particle accelerators will be described, further widening the functionality of the current state-of-the-art instrumentation.

INTRODUCTION

Instrumentation development for low current measurements is one of the key activities in the Computing Division of ALBA Synchrotron. Em# project is the evolution of previous project ALBA Em, which established a knowledge background important to fulfil new equipment requirements.

Background – ALBA Em

In 2011 ALBA Em was developed, a four channel electrometer that allowed low current measurements for X-Ray beam diagnostics or experiment applications since the first day of operation at ALBA Synchrotron [2]. More than 40 units have been used with good acceptance from scientific users.

ALBA Em was composed of four units of in-house developed ALBA Current Amplifier and one commercial Rabbit RCM4200 micro-controller core. This microcontroller core has a custom interface connector that, when connected to a custom designed board is able to control the four current amplifiers. The firmware code running in the microcontroller core was developed using proprietary IDE.

The good performance in current measurement led to continued use of ALBA Em as a standard electrometer for new beamlines in the following construction phases of ALBA Synchrotron. Unfortunately the production of new units was not possible since the microcontroller core was declared obsolete on 2013. This impediment together with the new functionality needs in experimental end stations forced an equipment redesign in 2013.

New requirements for upcoming development project were stated following scientific user needs. The most important requirement was to increase the ADC resolution, as the embedded ADS7870 ADC in the microcontroller core was just 11 bits in single-ended configuration. Another limiting parameter to be improved was the sampling rate of the same ADC which was limited to 1 kS/s. The possibility to isolate the detector ground of equipment from the facility ground in order to avoid ground loops and reduce induced current due to electromagnetic noise was another must for the new development. Yet another new requirement, also related to the ground loop break, was the possibility to make current measurements with detector's ground voltage-biased respect to equipment and facility ground, in order to avoid the loss of generated charges in the detector by applying an electric field to it.

The Em# (Fig. 1) development has been framed in a collaboration agreement between MAX IV Laboratory and ALBA Synchrotron. The collaboration is not closed to other institutes and facilities, although the project is already at the production phase and the pending development tasks are related to gateware and software.

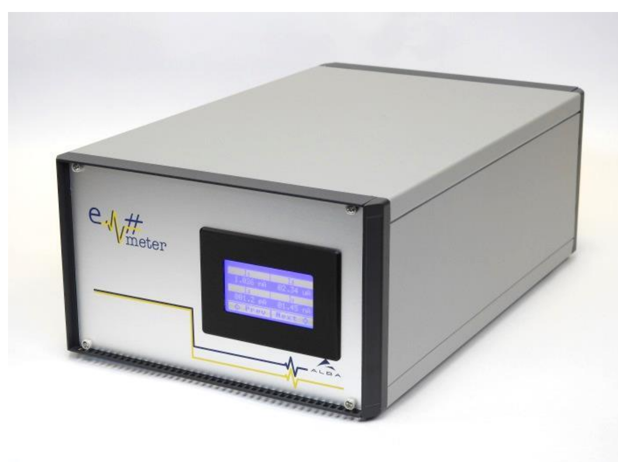

Figure 1: Em# first production unit.

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PANDABOX: A MULTIPURPOSE PLATFORM FOR MULTI-TECHNIQUE SCANNING AND FEEDBACK APPLICATIONS

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Abstract

PandABox is a development project resulting from a collaboration between Synchrotron SOLEIL and Diamond Light Source started in October 2015. The initial objective driving the project was to provide multi-channel encoder processing for synchronizing data acquisitions with motion systems in experimental continuous scans. The resulting system is a multi-purpose platform well adapted for multi-technique scanning and feedback applications. This flexible and modular platform embeds an industrial electronics board with a powerful Xilinx Zynq 7030 SoC (Avnet PicoZed), FMC slot, SFP module, TTL and LDVS I/Os and removable encoder peripheral modules. In the same manner, the firmware and software framework has been developed in a modular way to be easily configurable and adaptable. The whole system is open and extensible from the hardware level up to integration with control systems like TANGO or EPICS. This paper details the hardware capabilities, platform performance, framework adaptability, and the project status at both sites.

PROJECT INTRODUCTION

PandABox (Position and Acquisition Box) was initiated to overcome obsolescence problems and technical limitations in Synchrotron SOLEIL and Diamond Light Source concerning their in-house designed products SPIETBOX (SOLEIL) and ZEBRA (Diamond); two products that have been integral to beamline operations to synchronize various equipments and for position capture.

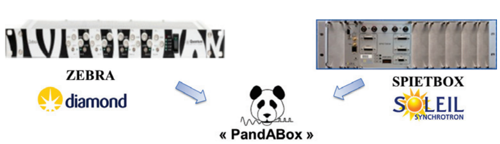

Figure 1: PandABox, a collaboration project between Diamond and SOLEIL.

The collaboration [1] proved efficient in sharing leadership and experience between both synchrotrons in hardware, firmware, and software developments. Along the development process, the two institutes have worked closely to review and validate the design at each step: 2 prototypes have been designed and improved within the scope of the project and the PandABox is now validated for production. The firmware and software have been improved and are now stable for EPICS or TANGO control system interfacing. The project is also available on the Open Hardware Repository (OHWR) to share with other institutes.

The PandABox project [2] had four repositories were created: PandABox-gw, PandABox-hw, PandABox-sw, and PandABox-tst (giving acces to the official releases of the firmware, TCP server, webserver and hardware source files). All documentation is accessible such as Hardware user guides and FPGA development Kits for PandABox firmware. Although the initial deliverables of the project are complete, both institutes still do collaborative work to improve the platform based on their own experience with the PandABox.

HARDWARE DESIGNS

PandABox is packaged in a 19” 1U rack which integrates several PCB boards: one detachable front panel board, one carrier board holding 4x encoder daughter modules and 1x PicoZed SOM (System-On-Module) module. The connection between the front panel and the carrier board is made through 2x FFC cables. On the carrier board, an FMC (FPGA Mezzanine Connector) slot is using an LPC (Low Pin Count) connector that can optionally receive an FMC mezzanine card to extend the hardware functionalities and I/O capabilities. [3]

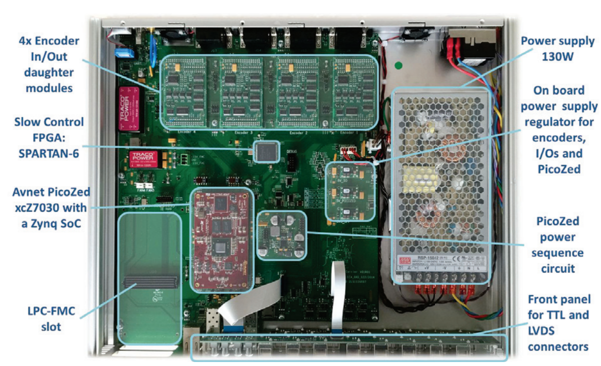

Figure 2: PandABox internal hardware top view.

The hardware was designed to meet the requirements for simultaneous and multi-technique scanning applications with support for a wide range of encoder protocols. The architecture presented in Fig. 3 was developed to be modular and flexible in order to enable the maximum number of applications.

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CRYOMODULE-ON-CHIP SIMULATION ENGINE*

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Abstract

The Cryomodule-On-Chip (CMOC) simulation engine is a Verilog implementation of a cryomodule model used for Low-Level RF development (LLRF) for superconducting cavities. The model includes a state-space model of the accelerating fields inside a cavity, the mechanical resonances inside a cryomodule as well as their interactions. The implementation of the model along with the LLRF controller in the same FPGA allows for live simulations of an RF system. This allows for an interactive simulation framework, where emulated cavity signals are produced at the same rate as in a real system and therefore providing the opportunity to observe longer time-scale effects than in software simulations as well as a platform for software development and operator training.

INTRODUCTION

The CMOC simulation engine has been used throughout the design process of a SRF cavity controller, first for the Next Generation Light Source (NGLS) proposal at LBNL [1] and then for the Linear Coherent Light Source Linac (LCLS-II) [2]. LCLS-II is an X-ray Free Electron Laser (FEL) under construction at SLAC, driven by a superconducting RF Linac [2]. The electron beam quality will directly translate to the quality of the X-ray beams produced in undulators and used for scientific research in the end stations; hence strict requirements have been placed on the stability of the accelerating cavity fields. An initial stability goal of 0.01° in phase and 0.01% amplitude has been set for the main Linac, composed of 280 nine-cell 1300 MHz superconducting cavities [3].

The difficulty resides in providing the ability to reject disturbances from the cryomodule, which is incompletely known as it depends on the cryomodule structure itself (currently under development at JLab and Fermilab) and the harsh accelerator environment. Previous experience in the field and an extrapolation to the cavity design parameters (relatively high $Q_L \approx 4 \times 10^7$, implying a half-bandwidth of around 16 Hz) suggest the use of strong RF feedback to reject the projected noise disturbances, which in turn demands careful engineering of the entire system.

MOTIVATION

LBNL has developed tools to first perform analytical stability analysis using basic control theory, software [4] for the numerical analysis and CMOC. CMOC takes the design of a SRF cavity controller one step closer to the final result, which is its implementation in an FPGA. It runs the actual cavity controller in a live FPGA and provides the capability of exercising the functionality of the controller as it interacts with a SRF cavity model, also implemented in the FPGA.

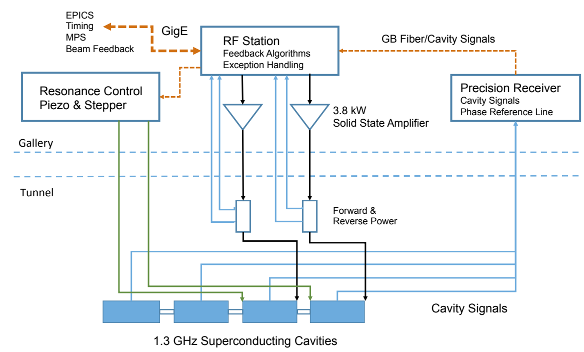

Figure 1: System hardware configuration supporting half of a cryomodule (one of two RF Station chassis shown).

Waveform display and user interaction with CMOC demands for communication logic with software, which is included in CMOC to extract cavity waveforms and to set configuration parameters for both the cavity controller and the models. This communication link is the same used in operations and can be used to build the software infrastructure for the LLRF installation. The physically meaningful live waveforms being generated by CMOC and its ability to provide the user with the same level of interactivity as when operating a real cavity make it useful for several purposes: initial tests of the cavity controller for FPGA designers, a complete environment to exercise the communications between the FPGA and a control system (both on the FPGA and control system ends) and as a training platform for students, non-LLRF experts and operators.

Figure 1 shows a the hardware configuration supporting half of a cryomodule (one of two RF Station chassis shown) for the LCLS-II LLRF system. CMOC includes provisions to include the cavity controller (in the RF Station), a model of the RF plant (RF amplifier saturation and cavity models), the cavity probe sensing through the Precision Receiver and a mechanical model of the cryomodule as well as its interactions with the cavities' electrical properties through ponderomotive forces. The resonance control logic is not integrated in CMOC at the moment but an emulation of a piezo actuator is possible from software for cavity tuning purposes.

CAVITY MODEL

The cavity model responds to a multi-cell cavity structure, with couplings to the RF source, a cavity field probe and the beam. The cavity field is decomposed in its eigenmodes, where each mode is represented by the traditional RLC par-

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CERN CONTROLS CONFIGURATION SERVICE – A CHALLENGE IN USABILITY

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Abstract

Complex control systems often require complex tools to facilitate daily operations in a way that assures the highest possible availability. Such a situation poses an engineering challenge, for which system complexity needs to be tamed in a way that everyday use becomes intuitive and efficient.

The sensation of comfort and ease of use are matters of ergonomics and usability - very relevant not only to everyday equipment but especially software applications, products and graphical user interfaces.

The Controls Configuration Service (CCS) is a key component in CERN's data driven accelerator Control System. Based around a central database, the service provides a range of user interfaces enabling configuration of all different aspects of controls for CERN's accelerator complex.

This paper describes the on-going renovation of the service with a focus on the evolution of the provided user interfaces, design choices and architectural decisions paving the way towards a single configuration platform for CERN's control systems in the near future.

INTRODUCTION

For a long time, the subject of ergonomics and usability in the software domain was mainly attributed to consumer products. Business products and industry-oriented software in particular received less attention to such aspects, often being considered as secondary or optional with respect to the core functional needs. This situation is gradually changing due to gaining a better understanding of the importance of usability as well as advancements in modern software technologies aimed at easy and efficient development of user-friendly interfaces. In general, Control Systems used in particle accelerators and large experiments can be perceived as industrial installations where stability, efficiency and reliability are primary concerns (including user-interfaces and software applications). However, in the case of scientific experiments and installations there is no hiding the fact that the primary mission is not monetary profit but rather the pursuit of greater ideas and fundamental understanding. This mission is often conducted by personnel for whom the task to control complex installations via software application is performed in addition to their principle scientific or engineering background. This aspect should be seen as a motivator for Control System designers and engineers to provide not only reliable and efficient solutions, but also ergonomic and usable software applications to facilitate their usage as the primary tools for daily work.

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The CERN accelerator Control System has evolved together with the accelerator complex. Certain software applications and user interfaces have roots going back to the early 1990's. This situation naturally poses a challenge with respect to maintenance and further evolution of the software. The first basic graphical user interfaces provided by the Controls Configuration Service (CCS) were developed in the mid–1990's and have evolved ever since [1]. The specificity of the CCS service in the CERN accelerator Control System is its centralised role making it a hub of configuration data among all Control System layers. Having this role, together with a broad scope spanning many domains, with a large number of users (~500) – creates a major challenge in providing and maintaining usable, user-friendly interfaces without imposing unnecessary constraints on the user community.

The challenges to design and provide ergonomic and user-friendly Controls applications, practical strategies and design concepts and an overall discussion of usability aspects with respect to centralised core Control systems services like the CCS are discussed further in this paper. The practical experience gained during development of the new generation of CCS tools serves to reflect on how Controls applications can be designed and developed such that long-term maintenance and user satisfaction are not conflicting goals. In addition, technical highlights about deliberately selected software technologies bring insights on how graphical user interfaces can be rapidly developed without sacrificing responsiveness or ergonomics.

USABILITY

Generally speaking, the term *usability* expresses facility of use or ease of learning for a given man-made object; let it be a tool or a device [2]. In a world of software engineering the term usability represents the degree to which a piece of software can be used by its end-users in a satisfactory, effective and efficient manner. A given user-interface can be considered intuitive when it does not require intense training and exhibits a natural workflow for which it was designed. The subject of usability is widely acknowledged in the software industry world and is formalised by dedicated ISO standards: ISO/TR 16982:2002 and ISO 9241-210:2010.

Software applications, specifically graphical user interfaces (GUI) are by no means mere tools facilitating daily work. Their sole purpose is to establish an interface between human users and "machines", specifically the internal implementation of a system. This point is especially important – one of the common failures of some GUIs is an inherent lack of abstraction between system internals, (e.g. a database structure) and its

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TAURUS BIG & SMALL: FROM PARTICLE ACCELERATORS TO DESKTOP LABS

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Abstract

Taurus is a popular solution for rapid creation of Graphical User Interfaces (GUIs) for experiment control and data acquisition (even by non-programmers) [1]. Taurus is best known for its ability to interact with the Tango and Epics control systems, and thus it is mainly used in large facilities. However, Taurus also provides mechanisms to interact with other sources of data, and it is well suited for creating GUIs for even the smallest labs where the overhead of a distributed control system is not desired. This scalability together with its ease-of-use and the uncontested popularity of Python among the scientific users, make Taurus an attractive framework for a wide range of applications. In this work we discuss some practical examples of usage of Taurus ranging from a very small experimental setup controlled by a single Raspberry Pi, to large facilities synchronising an heterogeneous set of hundreds of machines running a variety of operating systems.

INTRODUCTION

Taurus [2] is a framework for creating user interfaces (both GUIs and command-line based) to interact with scientific and industrial control systems as well as with other related data sources. Its main strength is that fully-functional GUIs can be created with minimum effort even by non-programmers, while still allowing full control and the possibility of extending its capabilities by more advanced developers.

Taurus is a free, open source, multi-platform pure Python module (it uses PyQt [3] for the GUI). It uses a Model-View approach to building the GUIs where the complexities of lower-level access to the data sources or control libraries is abstracted away by a set of plugins that provide Taurus model objects. The graphical components of a GUI just need to be provided with one or more model names in order to display and/or control the data represented by the model(s), allowing the creation of fully functional GUIs in a few minutes without programming [1].

These characteristics, combined with the popularity of Python in scientific environments made Taurus the preferred framework for GUI creation at many facilities.

Taurus was originally developed at the ALBA synchrotron within the Tango Collaboration [4] and therefore the first data source to be supported was the Tango Distributed Control System (DCS), but it is not limited to it. Other DCSs such as Epics as well as generic data sources such as "python evaluation" or hdf5 files are supported via "scheme" plugins. Since Taurus version 4, the architecture for new user-contributed scheme plugins was simplified and the Taurus core was made completely scheme-agnostic (i.e. Tango support is implemented just as another scheme plugin). The main widgets provided with Taurus (forms, plots, labels, edit boxes, etc.) are also scheme-agnostic, allowing the implementation of GUIs that integrate one or more sources of data, as shown in Fig. 1.

In the following sections we describe the different strategies for integrating a given data source into Taurus and we discuss how this allows Taurus to be used in a wide range of contexts, from large facilities with thousands of controllable parameters to single-instrument laboratories.

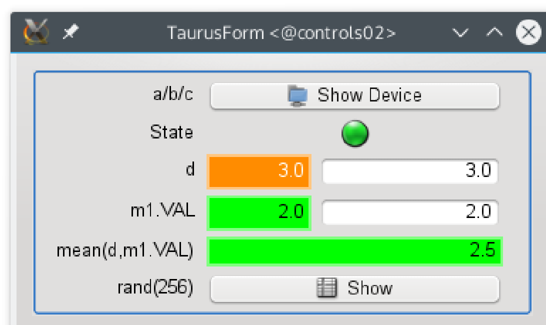

Figure 1: TaurusForm widget attached to models from *tango*, *epics* and *evaluation* schemes.

ACCESSING DATA SOURCES FROM A TAURUS APPLICATION

As already mentioned, the scheme plugins provide Taurus model objects which are used by the Taurus widgets to enable the interaction with the experimental setup and data sources. A scheme plugin implements specific Taurus model objects, which can be of one of three types: Attribute (a model that provides a value and related metadata), Device (a stateful model that may execute actions, or may be a natural aggregator of Attributes) and Authority (a model that provides a context for Devices and Attributes). A Taurus model has a unique name in the form of a Unified Resource Identifier (URI)

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PANIC AND THE EVOLUTION OF TANGO ALARM HANDLERS

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Abstract

The PANIC Alarm System is a python based suite to manage the configuration, triggering and acknowledge of alarms and automated actions in a Tango control system. The suite was developed at ALBA in 2007 and since then it has been adopted by several other facilities and installations such as Synchrotron light sources and large telescopes, integrating in the process a large set of community-requested features.

Its scalability is based on the stand-alone PyAlarm engines, that operate distributed across the control system; and the PANIC python API and user interfaces, that centralize the operation and configuration of the system. Each PyAlarm engine performs polled or event-triggered evaluation of alarm rules, complex logical operations and regular expression searches. The activation, recovery or reset of any alarm in the system can trigger actions like email, SMS, audible messages, local/remote logging, database insertion or execution of tango commands.

This paper describes the evolution of the suite, its compatibility with other alarm handlers in Tango, the current state-of-the-art features, the compliance with Alarm Management standards and the future needs.

INTRODUCTION

According to IEC 62682:2014 [1], the primary function of an Alarm System will be to notify abnormal process conditions or equipment malfunctions and support the operator response. The alarm system shall include mechanisms for communicating the alarm to operators via HMI or annunciators, as well as additional functions like event logs, alarm historian, automated actions and performance metrics.

Alarm Systems in Tango

The *Tango Control System* framework [2] is the result of a growing international collaboration to develop a modern open-source object-oriented control system that empower sharing control software development between institutions.

Three alarm systems are currently available in Tango:

- *Tango Alarm Handler*, by Elettra[3]: a centralized, event-based system evaluating syntax-rich formulas with high performance (C++), uses external devices as annunciators.
- *Alarm Archiving Database*, by Soleil Synchrotron: a centralized alarm logging database (Java), uses existing alarm configurations in Tango DB instead of formulas, records quality changes using polling.
- *PANIC*, by ALBA Synchrotron[4]: a distributed system that evaluates Python formulas, focused on flexibility has limited support for events, provides multiple annunciator types and automated actions.

Having several options is at the same time an advantage and an impediment if they are not complementary or able to interact. Thus, an effort to standardize the tools have been started based on the recommendations of the *IEC 62682 standard.*

The IEC 62682:2014 Standard

The *"Management of alarms sytems for the process industries"* standard (IEC 62682:2014) addresses the development, design, installation and management of alarm systems in the process industries. It defines the terminology and models to develop an alarm system and the work processes to effectively maintain the alarm system throughout the life cycle. It is based on ISA-18.2-2009 as well as previous documents reported by EEMUA [5] association.

As an standard, IEC 62682 provides a minimum set of rules and a guide for unifying criteria amongst countries/institutions. It provides recommendations on alarm systems design, implementation, and prevention of *alarm floods* (guarantee 12 < alarms/operator/hour). It also establishes that it is the responsibility of the operation group and the whole institution to ensure that all the procedures and stages of the standard are enforced, not relying only in the tools to do so.

THE PANIC ALARM SYSTEM

PANIC project was initiated during the construction phase (2007-2010) of the ALBA Synchrotron [6] to provide remote control of the several installed equipments on site (vacuum, Linac) while no operators were permanent on-site. In comparison with already existing alarm systems, PANIC is an scalable decentralized system that can aggregate hundreds of alarms from multiple Tango control systems or just run as a single process in an isolated IOC. Since 2013, PANIC has been adopted by several members of the Tango collaboration (Maxlab, Solaris, SKA).

PANIC Architecture

The PANIC Alarm System is based on two main entities: the *Alarm* object, keeping settings and state of each single alarm, and the *PyAlarm* device, a Tango device server on charge of evaluating a sub-set of alarms with a common configuration (on/off times, event count, annunciators setup, error management, ...).

PyAlarm device servers are deployed on the server side, loading each of them a list of alarms from an *AlarmAPI* collection (Fig. 1). Each PyAlarm device is an

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STREAMLINING THE TARGET FABRICATION REQUEST AT THE NATIONAL IGNITION FACILITY (NIF)

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Abstract

The NIF Shot Data Systems (SDS) team developed the Target Request Tool (TRT) Web application for facilitating the management of target requests from creation to approval. TRT provides a simple-to-use and user-friendly interface that allows the user to create, edit, submit and withdraw requests. The underlying design uses the latest Web technologies such as Node.js, Express, jQuery and JavaScript. The overall software architecture and functionality will be presented in this paper.

INTRODUCTION

National Ignition Facility (NIF) targets are complex engineering marvels in tiny packages. Creating them requires interplay among target designers, materials scientists, and precision engineers. The laser drives a target capsule inward at nearly a million miles an hour. Because the targets are subjected to extreme temperatures (greater than those in the Sun) and pressures (similar to those found in the core of Jupiter) during experiments, the targets must be designed, fabricated, and assembled with extreme precision [1].

The target production lifecycle begins with submission of a formal target request. Experimentalists and project engineers create the target feature definition based on dozens of existing and/or new parameters determined by the physics requirements and the type of shot. When the shot calls for an existing target, a previous target fabrication request can be duplicated. However, when it calls for a new type of target, a new request must be created. And in those cases, supporting documentation must be provided describing the custom parts that will be needed in the target build.

Before the commissioning of this project, experimentalists, project engineers and target fabrication team members ("users") first utilized a tool developed in Apex (Oracle Application Express). This application was developed as part of an existing tool suite called Production Optics Reporting and Tracking (PORT). The PORT-based target request tool had three major limitations: underlying data architecture precluded future automation in target order processing, data was usually duplicated, and page loading times were very slow.

Given the above limitations of the PORT-based tool, and with an estimated 500 targets needed to be produced each year, it became clear that users urgently needed a new tool. The decision was made to develop a completely new application versus modifying the existing one.

APPLICATION REQUIREMENTS

A brief description of the core requirements for the TRT is provided below:

1. Allow the requester to link the target request with an experimental planning ID called Facility and Laser Integrated Planning (FLIP) ID. This feature is critical since every target that is built must be destined for use on an experiment.
2. Display shot planning data. These data include metadata about the experimental team, diagnostic instrumentation, and target fielding parameters.
3. Allow the requester to select target features from a menu. Feature selection can either be started from a blank template or with a pre-populated set of features that the requester chooses.
4. Allow the requester to enter custom target features. Allow the user to select 'Other' from the options and enter a comment to describe the customized feature.
5. Provide the ability to upload attachments.
6. Provide target request status. Inform the user on the status of the request and drive when specific panels of the application can be edited.
7. Implement roles and permissions. Enable or disable UI capabilities (e.g., changing a field, modifying target request (TR) status) given the user role.
8. Provide target orders search capability (with filters). Provide a list of all orders and ability to filter by certain parameters, e.g., TR number, status, requester, etc.

CHOICE OF TECHNOLOGY

The needs from the Target Fabrication organization resulted in a schedule that allowed for only four months of development time. This limited development time was a key factor when selecting the technologies for this project. We decided to work with modern Web technologies that were familiar to the team and that would allow for reuse of software from other SDS tools.

Node.js

We chose Node.js for the back-end because it is fast to implement, is modern technology, and is supported by a large community of developers. It also pairs well with Web technologies we currently use and allows us to seamlessly connect to existing databases. Node.js is an open-source, cross-platform JavaScript run-time environment for executing JavaScript code server-side [2].

It has the following characteristics:

- Uses V8 engine by Google.
- Is a good fit for real-time applications.
- Is suitable for non-CPU-intensive operations.
- Provides an effective single codebase with JavaScript in server and client, making it easy to send and synchronize data between these two points.

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MXCuBE3 - BRINGING MX EXPERIMENTS TO THE WEB

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Abstract

Originally conceived at ESRF and first deployed in 2005 MXCuBE, Macromolecular Xtallography Customized Beamline Environment, has with its successor MXCuBE2, become a successful international collaboration. The aim of the collaboration is to develop a beamline control application for macromolecular crystallography (MX) that are independent of underlying instrument control software and thus deployable at the MX beamlines of any synchrotron source. The continued evolution of the functionality offered at MX beamlines is to a large extent facilitated by active software development. New demands and advances in technology have led to the development of a new version of MXCuBE, MXCuBE3, The design of which was inspired by the results of a technical pre-study and user survey. MXCuBE3 takes advantage of the recent development in web technologies such as React and Redux to create an intuitive and user friendly application. The access to the application from any web browser further simplifies the operation and natively facilitates the execution of remote experiments.

INTRODUCTION

MXCuBE is a control software developed for Macromolecular Crystallography beamlines. Since its first version, deployed in 2005 at The European Synchrotron (ESRF), MXCuBE has continuously evolved to facilitate user experiments by hiding the complexity of the beamline hardware and low-level control environment. In 2013 MXCuBE2 succeeded the original version and became the core of an international collaboration. MXCuBE2 was completely redesigned to permit the operation of new hardware, with particular relevance given to sample changer robots and new generation X-ray detectors. The development further enabled the automation of MX beamlines and maximised sample throughput [1]. Since then, the constant evolution of MX data collection methods and the increasing popularity of remote data collection, created new demands on the control and acquisition software, that converged into a new graphical user interface. This paper presents the architecture, preliminary usage feedback, and experiences learned from the development of the next version of MXCuBE, version 3. MXCuBE3 takes advantage of the recent development in web technologies such as ECMAScript 6 (ES6), React and Redux which the authors believe provides an environment suitable for implementing a complex web application such as MXCuBE3.

ORGANIZATION

The MXCuBE collaboration currently consist of eight institutes (ESRF, Soleil, MAX IV, HZB, EMBL, Global Phasing Ltd., DESY and ALBA) actively developing the software. A few further institutes are currently considering becoming full members of the collaboration. Developers and scientists meet in joint scientific and development workshops twice every year to share their respective progress and agree on the future goals of the collaboration. The collaboration enhances and speeds up the development of MXCuBE, many sites share similar needs and instruments and can thus quickly adapt to already existing solutions. Users of all MXCuBE sites are further presented with a familiar user interface, which decreases the learning curve and increases the portability of experiments across the different facilities.

A Memorandum of Understanding (MoU) has been signed by the partners in the collaboration. The collaboration comprises steering-, scientific- and a developer's committees. The development of MXCuBE3 was promoted and supported by the collaboration, however the development and deployment effort for MXCuBE3 is being jointly made by ESRF and MAX IV. Development started in September 2015 with a comprehensive roadmap and specific goals established during an initial meeting. The project uses an agile, scrum like, process. Planning meetings are held every two weeks and development workshops every three months. The project is available on GitHub [2].

BACKGROUND

MXCuBE 2 has become the leading software used to collect data for MX-experiments at European synchrotrons [3]. As the MXCuBE project is an international collaboration and the software is used on different sites across the world, the aim of the project is to provide user friendly software which is easy to adapt to various control systems and hardware environments.

The evolution of MX beamlines, the increase in sample throughput and the introduction of new collection procedures, have introduced new demands on the software [4-7]. The application and its interface have grown increasingly more complex to be able to handle the new requirements, as a side effect decreasing usability of the application [8]. At the same time key software libraries used in the User Interface (UI) are getting outdated and difficult to maintain. Efforts to update these

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THE GRAPHICAL USER INTERFACE OF THE OPERATOR OF THE CHERENKOV TELESCOPE ARRAY

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Abstract

The Cherenkov Telescope Array (CTA) is the next generation gamma-ray observatory. CTA will incorporate about 100 imaging atmospheric Cherenkov telescopes (IACTs) at a southern site, and about 20 in the north. Previous IACT experiments have used up to five telescopes. Subsequently, the design of a graphical user interface (GUI) for the operator of CTA poses an interesting challenge. In order to create an effective interface, the CTA team is collaborating with experts from the field of Human-Computer Interaction. We present here our GUI prototype. The back-end of the prototype is a `Python` Web server. It is integrated with the observation execution system of CTA, which is based on the Alma Common Software (ACS). The back-end incorporates a `redis` database, which facilitates synchronization of GUI panels. `redis` is also used to buffer information collected from various software components and databases. The front-end of the prototype is based on Web technology. Communication between Web server and clients is performed using `Web Sockets`, where graphics are generated with the `d3.js Javascript` library.

INTRODUCTION

The Cherenkov Telescope Array (CTA) [1] is the next generation observatory for very high-energy gamma-rays (γ-rays). CTA will be sensitive to photon energies from 20 GeV, up to a few hundred TeV. As they impact the atmosphere, γ-rays induce particle showers. A part of these cascades is Cherenkov radiation, which is emitted as charged particles travel faster than the speed of light in the atmosphere. The Cherenkov radiation can be detected by imaging atmospheric Cherenkov telescopes (IACTs) [2]. Using multiple telescopes together, the particle showers can stereoscopically be reconstructed. This allows one to derive the properties of the initial γ-ray that initiated the shower.

CTA will include three types of primary instruments. These correspond to three telescope sizes, large-, mid- and small-size, respectively called LSTs, MSTs, and SSTs. The different telescope types will be sensitive to different γ-ray energy ranges, where smaller mirror areas correspond to higher energies. CTA telescope arrays will be deployed in two sites in the southern and northern hemispheres, respectively consisting of ~ 100 and ~ 20 telescopes. This represents a substantial increase in the number of instruments compared to existing IACT experiments (H.E.S.S. [3], VERITAS [4], and MAGIC [5]), which incorporate between two to five telescopes.

The focus of this paper is the graphical user interface (GUI) for the operator of a CTA site. As mentioned above, CTA will include a large number of telescopes. In addition, several variations of SST and MST designs will be used. This further increases the diversity of hardware which needs to be controlled by an operator. The complexity of CTA makes for an interesting challenge in designing an effective user interface. In the following, the development process of the operator GUI is detailed. We describe the way in which the GUI is foreseen to be integrated with other CTA systems. In addition, we showcase a few of the features of the current prototype implementation[1].

DESIGN AND DEVELOPMENT PROCESS

Nominally, on-site observing operations with CTA will be automated. The purpose of the operator GUI can therefore be summarised as follows:

1. start and end observations;
2. override the automated scheduled operations in order to perform a specific task, or for safety reasons (could require manual control over instruments);
3. monitor the state of the array during operations, including hardware status and simple scientific metrics;
4. identify, diagnose, and if possible resolve, problems with specific systems or processes.

The development process of the GUI is inspired by the model used by the Atacama Large Millimeter/submillimeter Array (ALMA) [6]. ALMA is an astronomical interferometer of radio telescopes in the Atacama desert of northern Chile. It is similar in complexity to CTA, comprising 66 radio antennas of three general types. One of the main lessons learned from ALMA, is that it is important to take into account advances in Human-Computer Interaction (HCI) when designing an interface [7].

The design process is thus driven by participatory workshops. These bring together several groups of people: experts from the field of HCI; experienced telescope operators; control software experts; and astroparticle physicists. The purpose of the workshops is to refine the requirements on the GUI; to better understand what the GUI should enable users

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[1] Media resources illustrating panels from the prototype are available at https://www-zeuthen.desy.de/~sadeh/ .

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THE EVOLUTION OF COMPONENT DATABASE FOR APS UPGRADE*

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Abstract

The purpose of the Advanced Photon Source Upgrade (APS-U) project is to update the facility to take advantage of the multi-bend achromat (MBA) magnet lattices, which will result in narrowly focused x-ray beams of much higher brightness. The APS-U installation has a short schedule of one-year. In order to plan and execute a task of such complexity, a collaboration between many individuals of very diverse backgrounds must exist. The Component Database (CDB) has been created to aid in documenting and managing all the parts that will go into the upgraded facility. After initial deployment and use, it became clear that the system must become more flexible, as the engineers started requesting new features such as tracking inventory assemblies, supporting relationships between components, and several usability requests. Recently, a more generic database schema has been implemented. This allows for the addition of more functionality without needing to refactor the database. The topics discussed in this paper include advantages and challenges of a more generic schema, new functionality, and plans for future work.

GENERIC DATABASE SCHEMA

The initial version of the CDB software [1] was based on a database schema designed around concepts like "component" and "design" (a design being made up of several components). As new use cases emerged for tracking and managing different sets of objects, it became clear that a new set of similar database tables had to be created every time there was a need to support a new type of object. Illustrated in Fig. 1 is a simplified conceptual design representation of how the set of tables had to be recreated for components, component instances, designs, and design elements. All of these entities had a set of standard attributes, such as a name, ownership information, description, properties, logs, and some have additional connections. This means that every time a new entity was added, it needed a set of standard associative tables to go along with it as well as any additional entity specific tables.

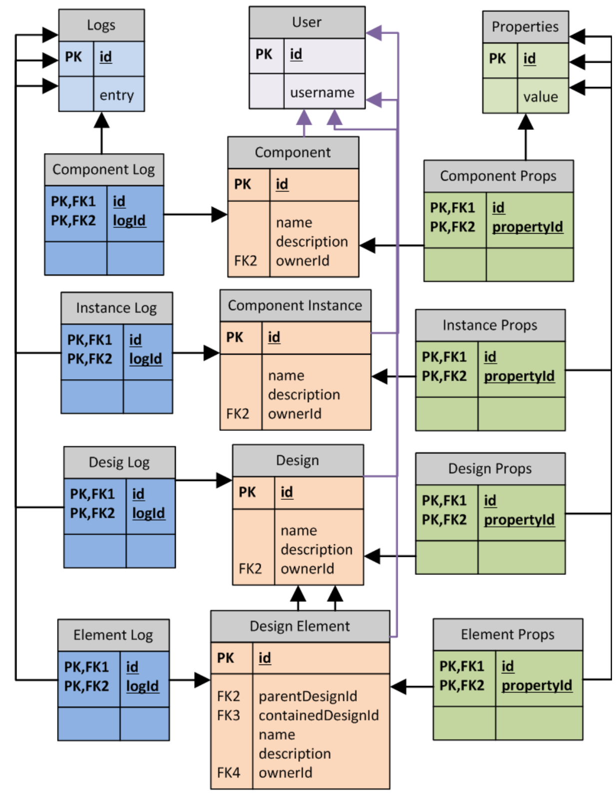

Figure 1: Conceptual simplified example of the old non-generic schema design.

Moving to a generic schema resulted in having generic tables for items and item elements (see Fig. 2). Each item now has a "self element" that represents the connections of that item. An item may also have a hierarchical structure by having more elements. All items are assigned a domain, which are similar to the previous component, component instance, etc. The assigned domain determines the possible associations of a particular item.

Advantages

The main benefit of the new schema design is that it fully supports existing application functionality in a completely generic approach. This enables us to quickly and easily add support for tracking and managing new types of objects without changing the underlying database structure.

Another aspect of the new approach is support for generic relationships. In the old schema, location could be specified only for component instances. Location information was stored in a specific location entity. A foreign key for location was referenced from the component instance table. The new schema does not have a location table, instead it has a location domain. The same required information is

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MONITORING THE NEW ALICE ONLINE-OFFLINE COMPUTING SYSTEM

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Abstract

ALICE (A Large Ion Collider Experiment) is a particle detector designed to study heavy-ion collisions and the physics of strongly interacting matter and the quark–gluon plasma at the CERN LHC (Large Hadron Collider).

ALICE has been successfully collecting physics data since 2010. Currently, it is in the preparations for a major upgrade of the computing system, called O^2 (Online-Offline) and scheduled to be deployed during Long Shutdown 2 in 2019–2020.

The O^2 system will consist of 268 FLPs (First Level Processors) equipped with readout cards and 1500 EPNs (Event Processing Node) performing data aggregation, calibration, reconstruction and event building. The system will readout 27 Tb/s of raw data and record tens of PBs of reconstructed data per year.

To allow an efficient operation of the upgraded experiment, a new Monitoring subsystem will provide a complete overview of the O^2 computing system status, detect performance degradation or component failures. The ALICE O^2 Monitoring subsystem will collect and receive up to 600 kHz of metrics. It will consist of a custom monitoring library and a toolset to cover four main functional tasks: metric collection, metric processing, storage, visualization and alarming.

This paper describes the Monitoring subsystem architecture and the feature set of the monitoring library. It also shows the results of multiple benchmarks, essential to ensure that the processing and storage performance requirements are met. In addition, it presents the evaluation of pre-selected tools for each of the functional tasks, including Collectd, Apache Flume, Apache Spark, InfluxDB and Grafana. It concludes by describing the next steps towards the final subsystem.

INTRODUCTION

The ALICE Experiment

ALICE (A Large Ion Collider Experiment) [1] is a heavy-ion detector designed to study the physics of strongly interacting matter (the Quark–Gluon Plasma) at the CERN Large Hadron Collider (LHC). ALICE consists of a central barrel and a forward muon spectrometer, allowing for a comprehensive study of hadrons, electrons, muons and photons produced in the collisions of heavy ions. The ALICE collaboration also has an ambitious physics program for proton–proton and proton–ion collisions.

After a successful Run 1 ALICE has been taking data in Run 2 since the beginning of 2015. In the end of 2018 the LHC will enter into a consolidation phase – Long Shutdown 2. At that time ALICE will start its upgrade to fully exploit the increase in luminosity.

The upgrade foresees a complete replacement of the current computing systems (Data Acquisition, High-Level Trigger and Offline) by a single, common O^2 (Online-Offline) system.

The ALICE O^2 system

The ALICE O^2 computing system [2] will allow the recording of Pb–Pb collisions at 50 kHz interaction rate. Some detectors will be read out continuously, without physics triggers. Instead of rejecting events the O^2 system will compress the data by online calibration and partial reconstruction.

The first part of this process will be done in dedicated FPGA cards that receive the raw data from the detectors. The cards will perform baseline correction, zero suppression, cluster finding and inject the data into the memory of the FLP (First Level Processors) to create a sub-timeframe. Then, the data will be distributed over EPNs (Event Processing Node) for aggregation and additional compression.

The O^2 facility will consist of 268 FLPs and 1500 EPNs. Each FLP will be logically connected to each EPN through high throughput links. The O^2 farm will receive data from the detectors at 27 Tb/s, which after processing will be reduced to 720 Gb/s.

OBJECTIVES DEFINITION

The Monitoring subsystem is part of O^2 and provides comprehensive functionality in metric collection, processing, storage, visualization and alarming as shown in Fig. 1. Three already short-listed solutions are being evaluated: MonALISA [3], Modular Stack (see MODULAR STACK section) and Zabbix [4]. This paper aims to provide details and performance measurements of the Modular Stack.

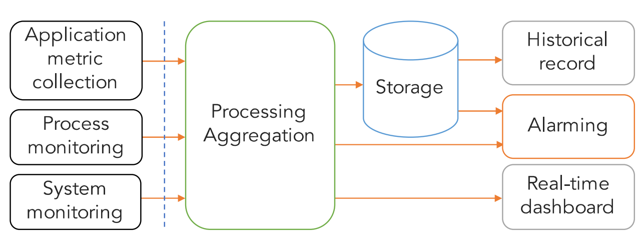

Figure 1: Functional architecture of the Monitoring subsystem.

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DATABASE SCHEME FOR UNIFIED OPERATION OF SACLA/SPring-8

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Abstract

For a reliable accelerator operation, it is essential to have a centralized data-handling scheme, such as unique equipment IDs, archived and online data from sensors, and operation points and calibration parameters for restoration upon a change in operation mode. Since 1996, when SPring-8 began operation, a database system has been utilized for this role. However, as time has passed, the original design has become outmoded, and new features equipped upon request have increased the maintenance costs. For example, through the start of SACLA in 2010, we introduced a new data format for shot-by-shot synchronized data. In addition, the numbers of tables storing operation points and calibrations have increased with various formats. Facing project upgrades on-site, it is now time to overhaul the entire scheme. In this project, SACLA will be a high-quality injector for a new storage ring while in operation as the XFEL user machine. To handle multiple shot-by-shot operation patterns, we plan to introduce a new scheme wherein multiple tables inherit common parent table information. In this paper, we report a database design for a project upgrade and the transition status.

INTRODUCTION

The SPring-8 complex has been leading the synchrotron radiation community for almost two decades. SACLA [1], the XFEL facility, has been in operation since 2010, and SXFEL beamline [2] as a soft X-ray source has recently been added.

To help the community evolve, a project upgrade (SPring-8-II project) is under way, in which the oldest SPring-8 storage ring (SR) will be rebuilt into a fourth-generation X-ray source of a low-emittance beam in the early 2020s [3][4]. With this project, SACLA has been given an additional role as an injector into the new SR with its high-quality beam. Omitting the existing linac and 8-GeV booster synchrotron will also contribute to energy saving.

In terms of the control system, a large-scale overhaul for the SPring-8-II project is needed [5]. Currently, local evolutions exist in SPring-8 and SACLA, and in SPring-8 in particular, which has a long operation history, patches and roundabouts have accumulated.

This paper focuses on the database aspect. The rest of the paper is organized as follows. First, we describe the role of the database system at the site. Then, for the two main topics, a log database and parameter database, we describe the current status and its problem, followed by the new scheme we plan to replace it with. Before concluding, we show a transition strategy for the running facility. The SXFEL accelerator complex was selected as the first migration test location this summer.

DATABASE OF SACLA/SPRING-8

From the early design stage of the site, the database was set as the core technology of the control system [6]. The role of a database can be divided to three parts. First, the log database stores time-series data that are sent from each subsystem. Log data are mostly point signals, although some 1D and 2D data are also included. Next, the parameter database provides an intermediate location between applications. An example is the alarm system where a monitoring process goes around log data and keep the judges in the database, and a display process responds to them. The final part is used for management. For example, it manages the signal names and corresponding information.

LOG DATABASE

Current Scheme

There are three different systems currently running at this site in terms of data logging. Figure 1 shows a schematic of these systems.

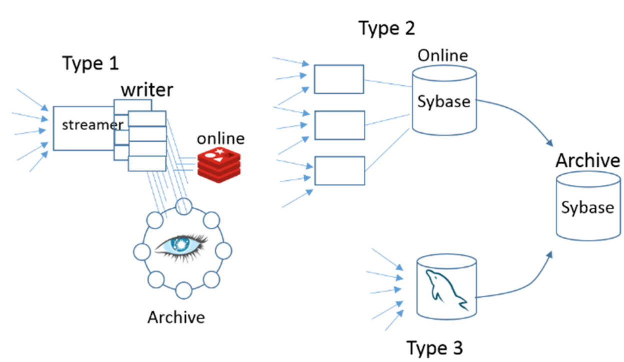

Figure 1: Current log data streams.

Type 1 [7]:

Data are stored in a NoSQL database (Cassandra). Multiple writer processes are connected to the NoSQL database, and all frontend equipment send data through the streamer. The connection between the equipment and streamer is based on ZeroMQ PUSH/PULL mode. To help with quick access to the data, an in-memory database (Redis) is running to keep the most recent data.

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THE MAX IV LABORATORY SCIENTIFIC DATA MANAGEMENT

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Abstract

The Scientific Data Management is a key aspect of the IT system of a user research facility like the MAX IV Laboratory. By definition, this system handles data produced by the experimental user of such a facility. It could be perceived as easy as using an external hard drive to store the experimental data to carry back to the home institute for analysis. But on the other hand the "data" can be seen as more than just a file in a directory and the "management" not only a copy operation. Simplicity and a good User Experience vs security/authentication and reliability are among the main challenges of this project along with all the mindset changes. This article will explain all the concepts and the basic roll-out of the system at the MAX IV Laboratory for the first users and the features anticipated in the future (Fig. 1).

DO RESEARCHERS NEED SUPPORT TO MANAGE THEIR DATA?

In short yes, there is a growing consensus spanning the European commission, research infrastructures, higher education and research groups that services need to be improved for researchers. While being owners of the data, they are not able to dedicate enough focus to data management while the amount of data generated is rapidly growing. Within facilities such as MAX IV Laboratory, the handling of users is split into many groups which handle different parts of the workflow. This results in visiting researchers needing to access many internal tools and systems as they follow the facility experimental visit workflow from proposing to do an experiment, planning a visit, following safety procedures and using the beam line computer systems, data storage and computation and finally obtaining data and results. Without any internal integration of these systems, the user is normally obliged to carry information (login details, experimental context and history of the events) between different systems, in their heads, on paper or in their own electronic log formats. They must try to keep a track of the relevant information needed at each step and be able to take what is needed away from the facility. The Scientific Data Management (SDM) is designed to create links across all systems which permits each component to dialogue information without the researcher having to do it. The result is that each system can implement a smoother, less detailed workflow, increasing effectiveness while more easily allowing more complexity to be added, such as meta-data acquisition during the experiment, automated data processing workflows and even automated migration to destined remote data centres. It is important that the SDM workflows appear simple and reliable to build trust in using them, instead of the current trust in using portable physical disks as a way of transferring data which makes it virtually untrackable once it leaves the facility. In addition, the new high data volume experiments are too much data for this method to be feasible.

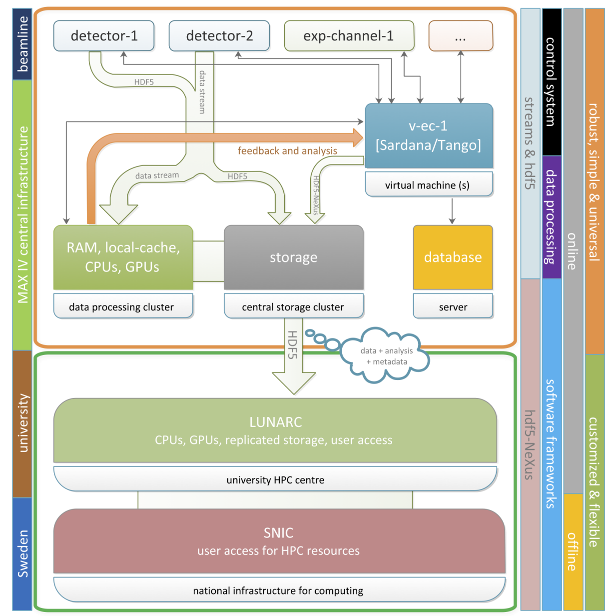

Figure 1: The MAX IV imaging concept. [1]

SCIENTIFIC DATA MANAGEMENT

History

The project started in 2013 with a White Paper trying to describe the need for managing the data at the new MAX IV Laboratory. This was distributed for feedback, both internally and at the MAX-lab 2013 user meeting. In order to address the resource issue, including both hardware and personel, a collaboration was initiated with Lund University Centre for Scientific Computing (LUNARC [2]) after a meeting with representatives from the Swedish National Infrastructure for Computing (SNIC [3]).

To verify the content of the White Paper, a prototype project was launched in early 2014 and was finished by summer the same year. The prototype tried to address all aspects and provide more information for the continuation of the project. In particular, it provided valuable insight in terms of technical requirements, staffing needs and hardware costs. The prototype report has been published in 2016 [4]. In late summer 2014, MAX IV was asked by SNIC (on behalf of the the Swedish Research Council (VR)) to provide a report on our future e-infrastrucutre needs. Using the information from the prototype project and with new estimates from the

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HIGH THROUGHPUT DATA ACQUISITION WITH EPICS*

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Abstract

In addition to its use for control systems and slow device control, EPICS provides a strong infrastructure for developing high throughput applications for continuous data acquisition. Integrating data acquisition into an EPICS environment has many advantages. The EPICS network protocols provide for tight control and monitoring of instrument operations through an extensive set of tools. As part of a facility-wide initiative at the Spallation Neutron Source at Oak Ridge National Laboratory, EPICS-based data acquisition and detector control software has been developed and deployed to a growing number of neutron scattering instruments. The software interacts with in-house detector electronics using fast optical channels for bi-directional communication and data acquisition, and is built around "asynPortDriver," which allows the passing of arbitrary data structures between software plugins. This completely modular design enables versatile configuration of data pre-processing plugins, as dictated by the neutron detector type and various instrument requirements. After 3 years of experience capturing average data rates of 1.5 TB per day, this system shows exemplary results of efficiency and reliability.

INTRODUCTION

The Spallation Neutron Source (SNS) [1] provides the most intense pulsed neutron beam in the world for scientific research and industrial development. Up to 20 distinct neutron scattering instruments utilize this beam for scientific research. Coupled with high-resolution detectors, SNS instruments offer unprecedented performance for the neutron-scattering analysis of a variety of materials, ranging from "liquid crystals to superconducting ceramics, from proteins to plastics, and from metals to micelles to metallic glass magnets." [2] While the high neutron flux enables more efficient scientific research, it also represents a big challenge for developing a reliable data acquisition system. The SNS instruments continuously capture data, on the order of tens of millions of events per second (aggregate bandwidth), with some individual beamlines approaching 5 to 10 million events per second locally, and producing about 1.5 TB of pre-processed raw experiment data overall per day.

Reliability and data integrity are also crucial at the SNS, given the megawatts of power required to generate and maintain the neutron beam, and the fact that users travel from all around the world, for limited time frames, to perform their experiments. The users' proposals are carefully evaluated and tightly scheduled to efficiently use the neutron beam. Any failure or downtime from the data acquisition system wastes the users' time (and the facility's beam power) and detracts from important investigations.

Given these stringent constraints, and the breadth of data acquisition hardware and instruments at SNS, a new data acquisition software system has been developed to target these demanding requirements for high-throughput and reliable data collection. This software is called "neutron Event Distributor" (nED). It enables SNS instruments to quickly and completely acquire valid detector events from the neutrons scattered by the users' unique sample materials. Ensuring efficiency and reliability in capturing and storing these experimental data empowers users to focus on optimizing experimental/sample parameters for maximal scientific (or industrial) impact.

Besides efficiency and reliability, a main requirement for this updated data acquisition software was integration with the EPICS control system. An internal feasibility study conducted in 2014 recommended that EPICS should be used for instrument data acquisition and controls. In early 2015 nED was first put into production at a neutron scattering instrument. This instrument is one of the highest data throughput instruments at SNS. The deployment of nED was fully successful. Even with an un-attenuated beam, nED was able to reliably and completely collect the full data rate of neutron events at the start of commissioning. In mid-2017, 70% of SNS neutron instruments have been converted to use nED and are collecting more data than ever before.

SYSTEM ARCHITECTURE

The data acquisition system at the SNS consists of sensors, data acquisition measurement hardware, communication hardware and a computer with data acquisition software (Fig. 1). Neutron detector hardware is connected to read-out electronics that are responsible for detecting electrical signals from detectors, applying discriminator settings and baseline correction, calculating detector "pixel" positions and measuring the time of flight relative to the beginning of the pulse. Given the pulsed beam, capturing the time when each event occurs is a critical component in reconciling the relationships among these events. Digitized events from multiple read-out electronics are sent to a concentrator that groups events into structured data packets. In addition to collecting neutron events, the concentrator also connects to fast meta-data sources to acquire non-neutron events, like pulse magnets used to apply high magnetic fields to the sample, load frames to apply compression on the sample and other sample environment devices. Each group of neutron and meta-data events is packetized by the concentrator, completed with corresponding beam pulse information and sent over the fast optical channel for processing.

Every SNS instrument provides unique scientific capabilities and they require different neutron detector setups.

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SCALABLE TIME SERIES DOCUMENTS STORE

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Abstract

Data indexed by time is continuously collected from instruments, environment and users. Samples are recorded from sensors or software components at specific times, starting as simple numbers and increasing in complexity as associated values accrue e.g. status and acquisition times. A sample is more than a triple and evolves into a document. Besides variance, the volume and veracity also increase and the time series database (TSDB) has to process hundreds of GB/day. Also, users performing analyses have ever increasing demands e.g. in <10s plot all target coordinates over 24h of 64 radio telescope dishes, recorded at 1 Hz. Besides the many short term queries, trend analyses over long periods and in depth enquiries by specialists around past events e.g. critical hardware failure or scientific discovery, are performed. This paper discusses the solution used for the MeerKAT radio telescope under construction by SKA SA in South Africa. System architecture and performance characteristics of the developed TSDB are explained. We demonstrate how we broke the mould of using general purpose database technologies to build a TSDB by rather utilising technologies employed in distributed file storage.

OVERVIEW

This paper describes the updated Katstore [1], the storage system developed to store the values, status and other information about sensors in the MeerKAT [2] Control And Monitoring (CAM) system [3]. Sensors and the CAM system are described in more depth in the Data Acquisition section.

Software components in CAM will send data points (samples) to Katstore to save and make available for analysis. All the samples received by Katstore are keyed on time and sensor name. This makes Katstore a time series database (TSDB); it is purposely built to have a fixed index on time. The data in Katstore is immutable and only grows over time, no update on a sample is allowed. It can be seen as an append-only database and samples do not need to arrive in chronological order.

For flexibility and ease of implementation, the samples are packed as JavaScript Object Notation (JSON) [4] objects by the software components that collected the samples. Any valid JSON is accepted. Katstore only requires that each sample contains the keys *name* and *time*, where *name* is the sensor name and *time* is the time in Coordinated Universal Time (UTC). The sample structure is discussed in the Samples section. These semi-structured samples, as JSON objects, are generally referred to as a document in database systems. Document storage has been popularised in recent years with the NoSQL movement, with document orientated databases such as CouchDB, Elasticsearch, and MongoDB. Making each sample a document removes the need for application knowledge in Katstore and future-proofs the implementation. New fields can be added and removed without requiring changes to Katstore and there is no fixed schema for a sensor sample.

The software components that collect the samples will publish the samples to the message bus [5] at intervals that can be configured per sensor. Katstore will subscribe to the per sensor archive subject on the message bus and store the published samples. The samples are first written to a buffer and will at a later stage be written to the archive. This buffer and the archive system are described in more detail in sections Samples Buffer and Samples Archive respectively.

Katstore has a query interface that supports several ways to access the stored samples. This is discussed in more detail in the section Query Interface. Samples are fetched from the buffer and/or archive when the user queries the system; this is done transparently to the user.

In the Performance section we describe the initial performance evaluation of the Katstore system.

DATA ACQUISITION

The detail of the MeerKAT CAM system was well described in 2015 by Marais [3] and the sensor sample data acquisition was illustrated in the same year by Slabber et al. [6]. Since then some changes to where sensor samples are collected from and how samples are transported have been implemented, these changes are explained by Joubert et al. [5].

An abridgement of that work is given here for completeness. MeerKAT CAM has many software components some components connect to hardware devices and others connect to software components. All inter-component communication is done with Karoo Array Telescope Communication Protocol (KATCP) [7]. Components can call requests on connected components for control purposes. A KATCP request is analogous to method or command calls of other platforms. For monitoring purposes KATCP, provides the concept of sensors. For the purpose of archiving the components that make up the MeerKAT CAM system publish sensor samples to different subjects on the message bus, the publish rate is controlled by the system configuration. Katstore subscribes to the archive subjects and store the samples to the buffer.

Sensors

A sensor is a fundamental concept in KATCP [7] and a rich collection of sensor types are available. The following types are currently supported *integer*, *float*, *boolean*, *timestamp*, *discrete*, *address* and *string*. Sensors always have

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REFURBISHMENT OF THE ESRF ACCELERATOR SYNCHRONISATION SYSTEM USING WHITE RABBIT

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Abstract

The ESRF timing system, dating from the early 90's and still in operation, is becoming obsolescent and needs complete refurbishment. The White Rabbit timing system -developed by CERN- offers many attractive features for the implementation of a synchrotron synchronisation and timing system, the key one being the possibility to carry RF over the White Rabbit optical fibre network. CERN having improved the feature to provide network-wide phase together with frequency control over the distributed RF, the whole technology is now mature enough to propose a White Rabbit based solution for the replacement of the ESRF system, providing flexibility and accurate time stamping of events. The paper provides details on the renovation project and describes the WHIST instrument that is being designed to that purpose.

ESRF SYNCHRONISATION SYSTEM

The current accelerator synchronisation system was developed at the construction phase of the ESRF, and is still in operation. This very reliable system is built around a centralized Radio Frequency (RF) driven sequencer distributing synchronization signals along copper cables. The analogue RF clock is broadcast over a separate copper network. The main characteristics of the ESRF accelerators are provided in Table 1.

Characteristics	
Radio Frequency (RF)	352 MHz ; 2.84 ns period
Booster	352 buckets; 1 MHz revolution frequency
Storage Ring (SR)	992 buckets; 355 kHz revolution frequency
Injection Sequences	4 Hz; 10 Hz

Table 1: ESRF Accelerator Characteristics.

This centralized "Bunch Clock" system (Figure 1), based on a top-down architecture, ensures the correct operation of the accelerators, delivering distributed triggers following a specific sequence which is basically detailed below.

The whole sequence is initiated with a so-called T0 trigger, generated by the Booster magnet power supply at start of ramping.

The RF synchronised Bunch Clock then provides sequentially:

- A programmable delay (1 ms minimum) to align the booster magnet energy to the LINAC output energy.
- A "gun trigger" (1) to generate an electron bunch at the LINAC input.
- An "Injection trigger" (2), to transfer a bunch from the Linac into the Booster. Optionally up to 5 bunches, properly spaced, can be launched in a row.
- An "Extraction trigger" (3), to extract the bunch from the Booster into the Storage Ring at the end of acceleration. A precise synchronization occurs in order for the bunch to be transferred at the programmed position in the SR (4).
- The whole sequence starts again at the reception of a new T0 trigger.

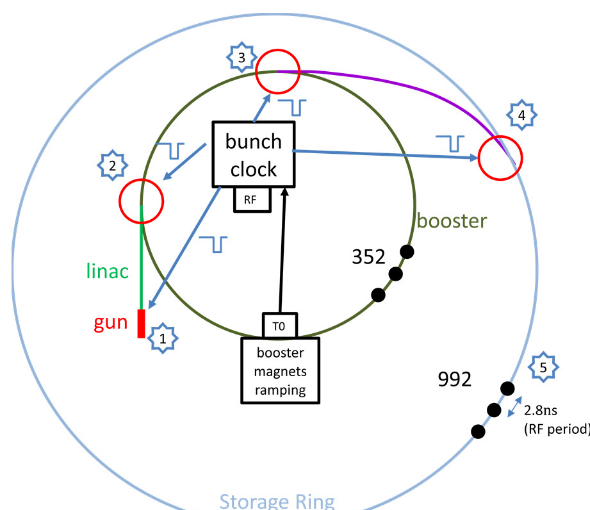

Figure 1: ESRF – Synchronisation system.

The system also provides additional triggers and clocks such as SR revolution frequency, that can be used for Diagnostic purposes and also by the Beamlines.

SYSTEM REFURBISHMENT GOALS AND CHALLENGES

The present system is stable, proven to be highly reliable but is becoming obsolescent. It also shows several heavy technical limitations. Based on a cabled logic centralized sequencer, it offers almost no possibility to add new features. The fixed copper cable distribution of signals makes combinations, as simple as gating, very difficult to implement. The addition of new signals to the existing architecture is impossible without adding cables, contributing to increase complexity of the system and, to a certain point, downgrade its maintainability.

The system by itself does not offer precise time-stamping capability, while the demand for such a feature

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SYNCHRONIZED TIMING AND CONTROL SYSTEM CONSTRUCTION OF SuperKEKB POSITRON DAMPING RING

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Abstract

A KEK electron/positron injector linac delivers beams for particle physics and photon science experiments. A damping ring has been constructed at the middle of the linac to generate a positron beam with sufficiently low emittance and to support 40 times higher luminosity in the SuperKEKB asymmetric collider than the previous project of KEKB. A timing and control system at the damping ring has been constructed to enable the timing synchronization and beam bucket selection among the linac, the positron damping ring and the SuperKEKB main ring. It should manage precise timing down to several picoseconds for the beam energy and bunch compression systems. Besides precise timing controls to inject and extract positron beams, it has to meet local analysis requirements owing to measure beam properties with changing RF frequency. The timing control system is constructed with MRF modules.

INTRODUCTION

SuperKEKB, electron/positron assynmetric collider, is being constructed for flavour physics experiment of elementary particles. It aims at a luminosity of 8×10^{35} cm^{-2}s^{-1}, 40 times higher than that of previous KEKB project by squeezing the beams at the collision point. To achive this luminosity, a Damping Ring(DR) was constructed for making lower emmitance positron beams. It is located at the middle of the injector Linac as shown in Fig.1. The main beam parameters are listed in Table1.

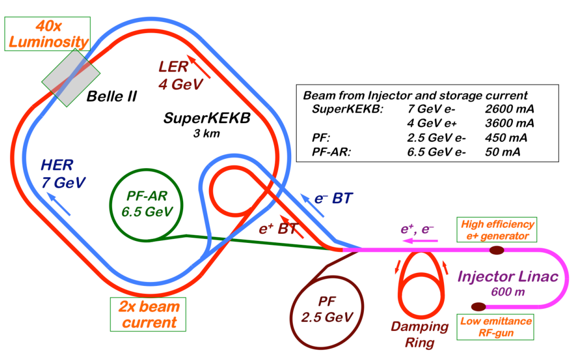

Figure 1: SuperKEKB accelerator.

The emmittance of positron beam is gone down to 92 μm at DR in the case of strage time of 40 ms. The DR can accumlate 2-pulses × 2-bunches, and need to keep more than 100 ns between pulses because of rising and falling time of Kicker magnets. Ideal bunch position is shown in Fig.2.

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Table 1: Parameters of the Damping Ring

Parameters	Value	Unit
Energy	1.1	GeV
Repetition frequency	50	Hz
Length	135.5	m
RF frequency	508.9	MHz
Harmonic Number	230	
Number of bunches	2	
Bunch spacing	96	ns

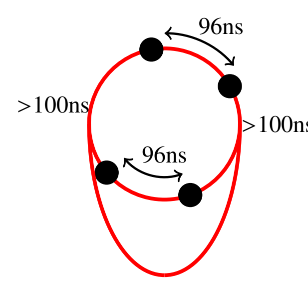

Figure 2: The storage configuration of 2-bunch, 2-pulse at Damping Ring.

EVENT TIMING CONTROL SYSTEM

Overview

The control system of injector linac is required very complex system to operate such a several rings (SuperKEKB electron/positron ring and two light source rings) with several parameters. One of the important technologies is Pulse-to-Pulse Modulation (PPM). The PPM enables to inject simultaneously the top-up filling operation to four rings. To identify which ring will be injected, Event Timing Control system is introduced. This system delivers not only timing signal but also PPM information as an "Event" to beam line devices. We introduced event timing system produced by MRF [1] company to satisfy our requirement. MRF's event timing system consists of an "Event Generator (VME-EVG-230)" and an "Event Receiver (VME-EVR-230RF)". The protocol is based on 8B10B encoded characters. 2 byte of characters are transmitted to EVR on event clock cycle. The event clock cycle is used with 114.24 MHz RF frequency. The first encoded byte is an event code and the second encoded byte is shared by the distributed bus and synchronous data buffer. The system is worked on EPICS [2] IOC in the version of 3.14.12, and operated with the device/driver version of mrfioc2.

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SwissFEL TIMING SYSTEM: FIRST OPERATIONAL EXPERIENCE

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Abstract

SwissFEL timing builds on Micro Research Finland (MRF) event system products. Requirements for performance and new features have pushed MRF timing components to its newest generation (300 series) providing active delay compensation, conditional sequence events, topology identification and other interesting added features. However employing available hardware functionalities to implement complex and varying operational demands and provide them in the control system is its own challenge. In this paper after brief introduction to the new MRF hardware, we concentrate on operational aspects of the SwissFEL timing and related control system applications. We describe a new technique for beam rate control and explain how we provide assistance to machine protection system (MPS) using the same technique. We show how a well thought software design supports a clear interface between software layers and allows the use of the low level abstraction in different applications with reduced development effort. We also discuss our pulse marking (timestamping) method and its interface to beam synchronous data acquisition system. Further we share our experience in timing network installation, monitoring and maintenance issues during commissioning phase of the facility.

INTRODUCTION

SwissFEL [1] is a 740 m long FEL facility with final energy of 5.4 GeV, currently under commissioning at Paul Scherrer Institute in Switzerland. The first pilot experiment is scheduled before end of 2017. The nominal repetition rate of the SwissFEL machine is 100 Hz. A large number of various devices and systems distributed across the facility require precise timing to achieve synchronous controls and data acquisition. The SwissFEL timing system uses with MRF [2] timing modules. Two different kinds of modules exist: Event Master (EVM) modules and Event receiver (EVR) modules. EVM modules can be used as an event generator and as a fan-out. These timing modules are connected in a tree structure where one EVM is used as root node (top level event generator) and other EVMs are used as branch nodes (fan-outs). EVRs are used on the leaves of the tree. The nodes are connected via fibre optic links. The root node EVM generates global events and synchronous data and sends them down the tree. EVRs decode received event stream and use them to generate hardware triggers and/or process software objects. A reference clock at 142.8 MHz synchronizes the event system with the master oscillator of the accelerator.

OPERATIONAL REQUIREMENTS

Beam Rate Control

In order to have stable beam operation at reduced rates (below 100 Hz), subsystems such as RF and lasers must be triggered at all machine pulses. Reduced beam rates are achieved by delaying the actual triggers of those subsystems typically by a few microseconds in selected machine pluses. For RF systems this added delay stops acceleration in that machine pulse. As illustrated in Fig. 1, RF event is distributed at every machine pulse independent of the beam rate. The trigger to the RF subsystems is generated after a specified local delay. The delay value T at machine pulse N causes the acceleration (Fig. 1 on the left) and generates beam. Delay value T_d instead, is specified relative to the RF phase such that it stops acceleration which leads to the machine pulse with no beam (Fig.1 on the right).

This is the principle for beam rate control in all machine timing modes. This method also avoids acceleration of dark current and keeps the systems' operation stable by continuous triggering.

MPS Assistance

Machine protection at SwissFEL has its own implementation which is independent of the timing system. However timing system assists MPS as a second level protection. The requirement is that upon generation of certain MPS alarms beam rate should be instantly reduced to a configurable value. In other cases the beam must be completely stopped. This avoids destroying expensive devices such as undulators or screen monitors. The method to stop beam or reduce its rate is the same technique as for beam rate control that we explained in the previous subsection. The difference is that the information to delay RF trigger is not known ahead of time. This information can become available at any time during the machine pulse and it needs instant reaction on changing the delay value. Therefore it cannot be achieved by a software method (i.e. reprogramming of the delay value) and requires a hardware solution.

Flexible Event Rates

Already at the time of collecting requirements it became clear that we should maintain several event rates since not all systems will run at full rate during the commissioning or later for other machine setups like machine development, etc. A good example is RF subsystem where new RF stations are being commissioned while other stations are already in their routine operation. The new stations require independent repetition rate settings and usually are operated at lower rates for some time. There also several other examples such as slow diagnostics devices, etc.

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VERIFICATION OF THE FAIR CONTROL SYSTEM USING DETERMINISTIC NETWORK CALCULUS

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Abstract

The FAIR control system (CS) is an alarm-based design and employs White Rabbit time synchronization over a GbE network to issue commands executed accurate to 1 ns. In such a network based CS, graphs of possible machine command sequences are specified in advance by physics frameworks. The actual traffic pattern, however, is determined at runtime, depending on interlocks and beam requests from experiments and accelerators. In 'unlucky' combinations, large packet bursts can delay commands beyond their deadline, potentially causing emergency shutdowns. Thus, prior verification if any possible combination of given command sequences can be delivered on time is vital to guarantee deterministic behavior of the CS. Deterministic network calculus (DNC) can derive upper bounds on message delivery latencies. This paper presents an approach for calculating worst-case descriptors of runtime traffic patterns. These so-called arrival curves are deduced from specified partial traffic sequences and are used to calculate end-to-end traffic properties. With the arrival curves and a DNC model of the FAIR CS network, a worst-case latency for specific packet flows or the whole CS can be obtained.

INTRODUCTION

Non-functional aspects of large distributed systems often define the most safety-critical properties of such systems. For instance, the avionics sector employs x-by-wire applications with strict reliability and safety requirements [1]. Another area where formal verification is an important part of the development and operation are industrial facilities [2, 3]. Their uninterrupted operation is subject to fulfilment of predefined performance metrics, foremost w.r.t. to their control system (CS). This also holds true for the *GSI Helmholtz Centre for Heavy Ion Research*, a particle accelerator facility in Darmstadt, Germany. Its largest component, the *Facility for Antiproton and Ion Research (FAIR)*, will contain 3.5 kilometres of piping [4], several kilometres of cabling and more than 2000 endpoints [5]. Part of the development of FAIR has been the introduction of a highly accurate, low-latency CS system employing *White Rabbit* [6] time synchronization over Gigabit Ethernet [7]. The FAIR CS demands that, at any given time of operation, messages sent to any end point can reach their destination within 500 microseconds despite the presence of further messages in the network. While viable machine command sequences are specified in advance by physics frameworks, they might translate into a vast number of different traffic patterns. These are only determined at runtime and depend on interlocks and beam requests from experiments and accelerators. In the worst case, this might result in messages being delayed beyond their respective deadline, potentially causing emergency shutdowns of the entire system. To verify that the given timing constraint invariantly holds, all possible message sequences for an experiment need to be verified. For this, traffic specifications in a graph-based format as shown in Figure 1 were introduced.

The Deterministic Network Calculus (DNC) [8] has been used to verify deadlines in distributed avionics systems for quite some time [9]. DNC is an application-agnostic mathematical framework for worst-case modelling and analysis of distributed systems. More recently, it has also been applied to large industrial systems [10]. In this paper, we will provide its application to the FAIR CS. Among DNC's two parts, modelling and analysis, the latter has seen most attention. The literature set its focus on improving the accuracy of worst-case bounds on the end-to-end delay as well as computational aspects of deriving them (see [11] for recent and comprehensive results). In contrast, we extend the system modelling capabilities of DNC. To be precise, we contribute a method to convert the graph-based specification of possible machine command sequences to the deterministic upper bound on traffic flows at the location they enter the system. The DNC analysis takes the network topology, forwarding capabilities of the network, flows' path and these bounds, so-called arrival curves, to bound worst-case message delays. Arrival curves have been derived from input specifications before, however, such approaches often required explicit generation of compliant traffic traces that were then transformed into the arrival curves [12]. As these traces are finite, the domain of the resulting curves is finite, too. This may impact the validity of derived performance bounds and needs to be handled with care [13]. We avoid these problems by directly deriving arrival curves from the specification such that these are valid for indefinite length of operation of the system.

The remainder of this paper is structured as follows: A background section presents the basics on DNC, the FAIR traffic specification and a formalization that we use for derivation of arrival curves. The derivation is contributed in the subsequent section. We aim for most accurate arrival curves, resulting in pseudo-periodic shapes. Yet, tools providing automated DNC analysis, foremost the DiscoDNC [14, 15], may be restricted to aperiodic arrival curves. Thus, we provide a concave hull algorithm to convert to arrival curves with a finite amount of piecewise affine segments. We present practical considerations concerning our generic algorithm and parameter ranges found in a FAIR traffic spec-

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DATA ANALYSIS SUPPORT IN KARABO AT EUROPEAN XFEL

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Abstract

We describe the data analysis structure that is integrated into the Karabo framework to support scientific experiments and data analysis at European XFEL. The photon science experiments have a range of data analysis requirements, including online (i.e. near real-time during the actual measurement) and offline data analysis. The Karabo data analysis framework supports execution of automatic data analysis for routine tasks, supports complex experiment protocols including data analysis feedback integration to instrument control, and supports integration of external applications. The online data analysis is carried out using distributed and accelerator hardware (such as GPUs) where required to balance load and achieve near real-time data analysis throughput. Analysis routines provided by Karabo are implemented in C++ and Python, and make use of established scientific libraries. The XFEL control and analysis software team collaborates with users to integrate experiment specific analysis codes, protocols and requirements into this framework, and to make it available for the experiments and subsequent offline data analysis.

INTRODUCTION

The European X-ray Free Electron Laser (XFEL) is a facility providing X-ray and laser excited imaging to wide range of science users. The generated X-ray pulses are extremely brilliant (peak brilliance $\sim 5 \cdot 10^{33}$ photons/s/mm^2/mrad^2/0.1% band width), ultra-short (<100 fs) pulses of spatially coherent X-rays with wavelengths down to 0.1 nm. X-rays are delivered in 10 trains of pulses per second, where up to 2700 pulses form a train in which the pulse separation is 222 ns [1].

Measurement data obtained during experiments are analysed both during the experiment – to guide the experimental work during beam time – and subsequently to fully understand and exploit the data taken. The complexity of the experimental setup and high data rates of the order of 10-15 GB per second per detector at European XFEL [2] demand an efficient concurrent approach of performing experiments and data analysis: Data analysis must already start whilst data is still being acquired and initial analysis results must immediately be usable to feedback into and re-adjust the current experiment setup. The Karabo control system [3] has been developed to support these requirements.

In this paper, we describe European XFEL's provision for data analysis during and after the experiment. We start by defining rapid, online and offline data analysis, then describe the architecture of relevant frameworks at European XFEL for rapid-feedback and online analysis, offline data analysis, further user support, and close with a brief summary.

Rapid Feedback, Online and Offline Analysis

We distinguish three different data analysis scenarios:

(i) *rapid-feedback* (or near-realtime) data analysis, which we interpret as data analysis during the experiment to optimise and maintain the experiment conditions and parameters. Key requirements here are low latency in provision of data analysis results: the shorter the latency, the easier it is during the experiment to interpret and understand the effect of an intervention. For example, the adjustment of the sample position to bring it into the X-ray beam can be done the more rapidly, when integrated data analysis automatically provides the feedback if and when the beam has hit the sample. A low feedback latency is required for more effective conducting of experiments, as is well known in photon science facilities [4–9]. One aims for near real-time feedback with latency of the order of seconds or below.

(ii) *online* data analysis: data analysis to be carried out during the experiment (thus including rapid-feedback) but not requiring the same low latency. This includes analysis that is acceptable to be carried out minutes and hours after the data has been acquired.

(iii) *offline* data analysis, which summarises all remaining data analysis that takes place after the beam time has concluded. In contrast to the online data analysis, which is focused on fast and consequently often somewhat approxi-

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LEVERAGING SPLUNK FOR CONTROL SYSTEM MONITORING AND MANAGEMENT

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Abstract

The National Ignition Facility (NIF) is the world's largest and most energetic laser experimental facility, with 192 beams capable of delivering 1.8 megajoules (MJ) and 500-terawatts of ultraviolet light to a target. To aid in NIF control system troubleshooting, the commercial product Splunk was introduced to collate and view system log files collected from 2,600 processes running on 1,800 servers, front-end processors, and embedded controllers [1]. We have since extended Splunk's access into current and historical control system configuration data, as well as experiment setup and results. Leveraging Splunk's built-in data visualization and analytical features, we have built custom tools to gain insight into the operation of the control system and to increase its reliability and integrity [3]. Use cases include predictive analytics for alerting on pending failures, analyzing shot operation critical paths to improve operational efficiency, performance monitoring, project management, and analyzing and monitoring system availability. This talk will cover the numerous ways we have leveraged Splunk to improve and maintain NIF's integrated control system.

INTRODUCTION

The National Ignition Facility at Lawrence Livermore National Laboratory (LLNL) is the world's most energetic laser system for experimental research in inertial confinement fusion (ICF) and high-energy-density (HED) physics. The NIF laser system consists of 192 laser beams, which are focused inside the 10-meter Target Chamber (TC), delivering up to 1.8 MJ of ultraviolet light onto the target.

Since 2013, the NIF Information Technology (IT) and Integrated Computer Control System (ICCS) organizations have been relying on Splunk for collecting, managing and analyzing computer log files [2]. Splunk is a commercial software system for processing unstructured log files into a centralized indexed database with powerful search, data processing, and visualization capabilities.

Based on the positive experience and value of the analytics insights, Splunk monitoring of the NIF control system has been extended and now includes all logs generated for one year. The production NIF control system generates 20-50 GB of logs per day, which constitutes 20-25% of total NIF Splunk daily volume. Control system log storage is currently 3.4 TB, while total NIF Splunk data size is 15.1TB.

Splunk's ability to process unstructured log files is of key importance for a specialized control system such as ICCS. Many log analytics systems are fine-tuned for a specific IT application: webserver logs, database logs, firewalls, etc. The majority of ICCS software is developed in-house and is unique to NIF – there is no commercial vendor or a market to develop analysis tools for our control system. With Splunk, there is a simple setup step of configuring log data sources: where they are coming from and the general format: timestamp, hostname and text body. Once sources are configured, the body of the log message is not constrained; any text will be imported, indexed and stored. There is no fixed data schema –- search, data extraction, analysis, and visualizations can be performed on any part(s) of the log messages.

In addition to its primary indexed log file storage, Splunk supports connectivity to external data sources and databases. For controls system applications, Splunk is connected to ICCS configuration and NIF Archive Oracle databases. For data-driven project management, Splunk is connected to NIF enterprise management and problem tracking systems, IT inventory, and monitoring databases and Jira issue-tracking software.

Since deployment, Splunk has become the primary tool for ICCS log analysis, and we have retired the previously used "snapshot" log capture system [2]. Splunk online training materials have helped to introduce ICCS developers to Splunk and its Search Processing Language (SPL). Many developers have progressed into advanced courses to achieve Splunk Power User certification [5]. ICCS software expertise is in the server-side and embedded control applications, not in the Web visualizations. With Splunk and SPL, our software engineers can create visualizations and dashboards without Web development skills and with minimal overhead. To encourage developers' adherence to best logging practices, we have placed ICCS development and test environments under Splunk monitoring. By making Splunk available early in the development cycle, we have assured that all interesting data are logged, developers practice their SPL skills, and Splunk dashboards are developed and tested well before production deployment.

CONTROL SYSTEM MONITORING

Performance Monitoring and Alerts

One of the traditional applications of the system monitoring tools is to observe "vitals" at the Operating System (OS) level: CPU load, memory utilization, and swap use. In a large distributed control system such as ICCS, visualization of this information coming from hundreds of computer hosts presents a challenge. If shown individually there are too many screens, and it is unclear what is normal and what is not. Combining all hosts into one screen creates a noisy, unusable chart.

The readability and usefulness of ICCS performance monitors greatly improved after we configured a custom Splunk dashboard which segments the "vitals" into several groups of comparable hosts: framework servers (Solaris),

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EXPERIENCE WITH MACHINE LEARNING IN ACCELERATOR CONTROLS *

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Abstract

The repository of data for the Relativistic Heavy Ion Collider and associated pre-injector accelerators consists of well over half a petabyte of uncompressed data. Some of this data is viewed and analyzed in the course of accelerator operations. Other data has been retrospectively analyzed offline. However, a large fraction of that data has never been analyzed. Even data that has been analyzed may contain additional useful information that did not come to the surface during initial processing. We will describe in this paper our efforts to use machine learning techniques to pull out new information from existing data. Our focus has been to look at simple problems, such as associating basic statistics on certain data sets and doing predictive analysis on single array data. The tools we have tested include unsupervised learning using TensorFlow™, multimode neural networks, and hierarchical temporal memory techniques using NuPIC.

INTRODUCTION

Statistical machine learning uses automated techniques for predictive modeling [1]. What distinguished these approaches from classical statistical methods is they are data driven. No linear or specific structure is imposed on the interpretation of the data. Machine learning is focused on developing efficient algorithms to optimize a predictive model.

In our business, we put much effort into real-time processing of data, in order to present to operators, engineers, and scientists results that allow them to either diagnose the health of the system or have a signal on which to perform some optimization process. For example, most of us monitor (on some comfort display in the main control room) the beam current or intensity in the accelerator in real time. People become "trained" in recognizing when these signals are doing the wrong thing. For example, operators get to be extremely good at making the very abstract connection of the behavior in the beam current signal to particular fault conditions in the accelerator.

Our job, here, is to ask whether we can use machine learning to recognize (or train, if you like) in software what a person is able to detect visually. An advantage to such an approach is the computer can be looking all the time, while people tend to get distracted. Also, a computer can, possibly, react much more quickly than a person, if a learned response is given to the algorithm.

We break up machine learning for accelerator controls into two domains; recognizing anomalies (true anomalies and outlier values) and developing learned "responses". One example of a learned response is to consider the use of machine learning for correcting the beam trajectory in a beam line. This highlights well how machine learning uses no model but just learns the statistics of a signal and adapts a response based on setting target statistical values (e.g., bring a given signal to within n sigma of a target value of x by adjusting parameter a).

RELATED WORK

Machine learning, as a field, has grown out of advances in Artificial Intelligence research, particularly in the areas of pattern recognition and computational learning theory. The term, coined by Arthur Samual, IBM, goes back to 1959, where the idea was to give "computers the ability to learn without being explicitly programmed" [2]. The *Machine Learning* journal has been in publication since 1986. So there is a long and interesting history to this field.

For particle accelerators, the use of Machine Learning techniques goes back as far as 1987, when T. Higo, H. Shoaee, and J. E. Spencer, SLAC, discussed applications of artificial intelligence to problems in accelerators [3]. In 1989, J. E. Spencer, SLAC, discussed using Neural Networks techniques in accelerator controls [4]. Two years later, D. Nguyen, M. Lee, R. Sass, and H. Shoaee, SLAC, used Neural Network techniques to develop a dynamic feedback system for beam line controls [5].

More recently, A. L. Edelen, et al., have been experimenting with the use of machine learning techniques for RF gun temperature control [6]. At the SwissFEL, A. Rezaeizadeh, T. Schilcher, and R. Smith, PSI, used a model-free iterative learning approach to produce flat-topped RF pulses. The method iteratively updated the input pulse shape to generate the desired output pulse shapes in the RF system [7].

At Los Alamos, Sung-il Kwon, et al., used iterative learning techniques for modeling the SNS SRF cavity feedback controls [8].

At TRIUMF, M. Laverty and K. Fong used an iterative learning feedforward LLRF controller to improve the beam stability in the e-linac [9].

The use of machine learning for orbit control goes back to the work at SLAC, but has been investigated by many others over the years. In 2012, E. Meier, Australian Synchrotron, studied the use of neural networks for orbit correction [10]. Going back further in time, in 1994 E. Bozoki and A. Friedman, BNL, studied the use of neural networks for orbit control in the National Synchrotron Light Source [11].

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MODEL LEARNING ALGORITHMS FOR ANOMALY DETECTION IN CERN CONTROL SYSTEMS

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Abstract

The CERN automation infrastructure consists of over 600 heterogeneous industrial control systems with around 45 million deployed sensors, actuators and control objects. Therefore, it is evident that the monitoring of such huge system represents a challenging and complex task.

This paper describes three different mathematical approaches that have been designed and developed to detect anomalies in any of the CERN control systems. Specifically, one of these algorithms is purely based on expert knowledge; the other two mine the historical generated data to create a simple model of the system; this model is then used to detect faulty sensors measurements.

The presented methods can be categorized as dynamic unsupervised anomaly detection; “dynamic” since the behaviour of the system and the evolution of its attributes are observed and changing in time. They are “unsupervised” because we are trying to predict faulty events without examples in the data history. So, the described strategies involve monitoring the evolution of sensors values over time in the historical data. Indeed, consistent deviations from the historical evolutions can be seen as warning signs of a possible future anomaly; these warning signs have been used to trigger a generic anomaly alarm for the specific incoherent sensors, requiring further checks by system experts and operators. The paper also presents some results, obtained by the application of this analysis to the CERN Cryogenics systems.

Finally, the paper briefly describes the deployment of Spark and Hadoop platform into the CERN industrial environment to deal with huge datasets and to spread the computational load of the analysis across multiple hosts.

INTRODUCTION

The performance of the CERN Large Hadron Collider (LHC) relies on the operation of a multitude of heterogeneous industrial control systems. More than 600 industrial Supervisory Control and Data Acquisition (SCADA) systems have been deployed for the supervision and monitoring of CERN accelerators chain, detectors and technical infrastructure. Currently the stored data volume produced by the different industrial control systems exceeds the 100 terabytes per year; nevertheless, the volume of the controls data is actually much higher since multiple filters (deadbands both in time and value) are applied both at the SCADA systems and at the control level (PLCs and Front-End Computers) in order to reduce the data flow.

The generated controls data, after a proper analysis, constitutes a source of useful information about the current state of the processes, their performance, stability and overall behaviour. Obviously, an extensive analysis of this massive data flow requires specialized frameworks to handle big datasets and cannot be achieved by operators through manual operations.

The detection of anomalies and disturbances in an industrial process represents a key factor in the quality of the overall system [1, 2]. Nevertheless, an anomaly, if not properly handled, could lead to a system failure, therefore causing a downtime of the entire system. In our scenarios, the anomaly detection is strictly connected to the ability to identify sensors’ measurements which do not conform to the expected patterns; this explains the use of machine learning techniques to extract patterns from both historical and online data. The correct detection of such types of unusual behaviours allows system experts to take actions in order to avoid, correct and react to the situations associated with them.

The temporal aspect plays an important role in the analysis of control data; in this domain time series data represents the main object of analysis in order to detect regular patterns against the sensors’ measurements as described in [3]. In recent years a growing attention has been paid to online knowledge discovery and data mining (KDD) techniques [4] for multivariate time series data. In the systems analysed, the change point or anomaly detection from data streams was an unsupervised learning task, which aimed at deciding whether the new generated sensors’ measurements showed a different trend from the historical reference.

In this paper, we address the problem of change point detection for streams of multivariate time-series data. Specifically, this paper describes three different algorithms for online detection of faulty measurements that have been developed and integrated into the CERN control system as a continuous monitoring task of the machine operation. Once these analyses have been deployed, the system experts are notified on specific issues or possible anomalous conditions through the generation of alarms. To achieve the aforementioned task the proposed solutions are based on unsupervised techniques due to the lack of labelled training data.

The last sections of the paper present a comparison of the three developed algorithms and some anomalies detected through the analysis of the CERN cryogenics control system.

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LASER DAMAGE IMAGE PRE-PROCESSING BASED ON TOTAL VARIATION

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Abstract

The inspection and tracking of laser-induced damages of optics play a significant role in high-power laser systems. Laser-induced defects or flaws on the surfaces of optics are presented in images acquired by specific charge coupled devices (CCDs), hence the identification of defects from laser damage images is essential. Despite a great effort we have made to improve the imaging results, the defect identification is a challenging task. The proposed research focuses on the pre-processing of laser damage images, which assists identifying optic defects. We formulate the image preprocessing as a total variation (TV) based image reconstruction problem, and further develop an alternating direction method of multipliers (ADMM) algorithm to solve it. The use of TV regularization makes the pre-processed image sharper by preserving the edges or boundaries more accurately. Experimental results demonstrate the effectiveness of this method.

INTRODUCTON

In high-power laser systems, because of reasons such as self-focusing, the laser-induced damage threshold of the optics that are irradiated by long periods of a high-power laser is lowered. The damage should be detected and tracked at the early stage of formation [1-2].

Currently, the inspection and tracking of laser-induced damages of optics play a significant role in high-power laser systems, and is also widely applied. NIF is the world's most energetic laser, delivering up to 2.0 MJ at 351 nm with its 192 beamlines. The Final Optics Damage Inspection (FODI) camera system is inserted in the centre of the NIF target chamber after a laser shot to acquire images of any or all of the final optics for all 192 beamlines [3]. The acquired images are processed using custom image processing and analysis software [4-5], referred to as the Optics Inspection (OI) package, to detect anomalies on the surface of the optics, with the intention of identifying and tracking laser-induced damage. The online inspection system technology for final optics damage was studied in order to build a final optics damage online inspection system for SG-III prototype device [6].

However, damage analysis has been surprisingly difficult over the years. And many efforts have been made in this research area, which can be divided into two main categories, one is to develop the optic illumination techniques, and the other is to improve the damage image analysis and defect identification technology. Proper illumination of the optics to be imaged is critical for the successful performance of the final optics damage inspection. In [7], based on total internal reflection of flat optics, the light emitting from array LED was coupled into the large aperture optics, the edge illumination methods were employed to illuminate the optics. Further the method of timesharing illumination of large aperture optics was developed for damage imaging, and the model of signal noise ratio was developed for dark-field imaging mode. A technology of detecting laser-induced damage on optics, using line-scan imaging and dark-field imaging principle, is proposed in [8]. Defect inspection relies heavily on image processing. Optics inspection analysis is an essential component of the FODI system, whose main aim is to conduct automated image analysis, processing each image quickly and identifying candidate sites on each optic that may correspond to laser-induced damage [3]. During each inspection cycle up to 1000 images acquired by FODI are examined by OI to identify and track damage sites on the optics. The process of tracking growing damage sites on the surface of an optic can be made more effective by identifying and removing signals associated with debris or reflections. Considering the manual process to filter these false sites is daunting and time consuming. In [9], G. Abdulla etc. discuss the use of machine learning tools and data mining techniques to help with this task. To improve the inspection resolution of the FODI device in the ICF, an inspection method based on image mosaic was proposed [10]. Because of the tiny size of defects compared to the image, detection of the defects is a challenge. Moreover, the grey value of different image areas is different because of the uneven distribution of illumination. Considering these two factors, a robust defects detecting method based on Local Area Signal Strength (LASS) and 2-D histogram is theoretically and experimentally proposed in [11].

Laser-induced optics damage and image analysis process are described in the next section. Issues about the image preprocessing is further discussed in section Ⅲ, including the problem description, total variation (TV) based model, and the ADMM-based algorithm development. On this basis, section Ⅳ provides the results of preliminary experiments. Finally, we conclude this paper in section Ⅴ.

OPTICS DAMAGE AND IMAGE ANALYSIS

Currently, the laser flux in high-power laser systems is increasing more and more fast. Because of reasons such as self-focusing, laser-induced damages are likely to happen to the optics, and the laser-induced damage threshold of the optics that are irradiated by long periods of a high-power laser is lowered. Usually, laser-induced defects or flaws on the surfaces of optics are presented in images acquired by specific charge coupled devices (CCDs). Fig. 1 is an example

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SwissFEL - BEAM SYNCHRONOUS DATA ACQUISITION – THE FIRST YEAR

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Abstract

The SwissFEL beam-synchronous data-acquisition system is based on several novel concepts and technologies. It is targeted on immediate data availability and online processing and is capable of assembling an overall data view of the whole machine, thanks to its distributed and scalable back-end. Load on data sources is reduced by immediately streaming data as soon as it becomes available. The streaming technology used provides load balancing and fail-over by design. Data channels from various sources can be efficiently aggregated and combined into new data streams for immediate online monitoring, data analysis and processing. The system is dynamically configurable, various acquisition frequencies can be enabled, and data can be kept for a defined time window. All data is available and accessible enabling advanced pattern detection and correlation during acquisition time. Accessing the data in a code-agnostic way is also possible through the same REST API that is used by the web-frontend. We will give an overview of the design and specialities of the system as well as talk about the findings and problems we faced during machine commissioning.

OVERVIEW

As described in the general SwissFEL paper [1], there are two categories of data to be dealt with at SwissFEL, namely synchronous and asynchronous data. This paper will only focus on the synchronous part of the system although both are using same/similar infrastructure and software.

Figure 1: Basic building blocks.

As shown in Figure 1 the beam synchronous data acquisition system consists of simple basic building blocks. Each block will be described in detail in the following sections.

The beam synchronous data acquisition system consists of two independent subsystems dealing with **small** (scalars and waveforms) and **large** data (cameras, detectors). Both subsystems consist of the same building blocks although different software components are used. The differences we will be outlined in the respective sections below.

Sources

All beam synchronous sources are connected to the central SwissFEL timing system [2]. The realtime timing system distributes the readout triggers as well as the unique pulse-id for each FEL pulse. After reading out the data upon receiving a readout trigger, the sources immediately attach the corresponding pulse-id to the data and send out an atomic message including all readout data and pulse-id.

Each readout value of a source is called channel and a source can have various channels.

Each source can be dynamically configured via a REST API, i.e. what channels to read out and in what frequency, without the need of reboot or restart.

A source can be implemented in various ways. At the moment, there are sources implemented as Epics IOCs and real-time applications running on a real-time Linux at SwissFEL.

Synchronization / Dispatching

Data send out by the sources is received by the Dispatching layer. For small data, this layer consists of currently twelve machines that form a cluster with the ability to synchronize data on the fly.

Clients can transparently request synchronized streams of channels coming from different sources via a REST API from this layer. Upon a client request, the Dispatching layer creates a customized data stream for the client as if it would originate from a single source. This technique frees the client from synchronizing data on its own.

Once the client disconnects from the custom stream, the Dispatching layer takes care that the stream gets closed and all required resources are cleaned up.

The Synchronization and Dispatching layer decouple the sources from the clients. Therefore, sources are protected from being overwhelmed by client requests.

Beside the ability to synchronize data and provide custom streams this layer also forwards all data to the buffering layer that is hosted on the same machines.

For large data this layer currently consists of currently one machine taking care of the receiving of camera data, compressing the images, doing (optional) standard analysis on the data and passing the data on to the large data buffering system.

Buffering

The Buffering layer temporarily stores all beam synchronous data for later retrieval. At the time of writing, the retention period of data inside the buffer is two days for scalar values, two hours for waveforms and two hours for images.

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REPRODUCE ANYTHING, ANYWHERE: A GENERIC SIMULATION SUITE FOR TANGO CONTROL SYSTEMS*

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Abstract

Synchrotron Light Sources are required to operate on 24/7 schedules, while at the same time must be continuously upgraded to cover scientists needs of improving its efficiency and performance. These operation conditions impose rigid calendars to control system engineers, reducing to few hours per month the maintenance and testing time available. The *SimulatorDS* project has been developed to cope with these restrictions and enable test-driven development, replicating in a virtual environment the conditions in which a piece of software has to be developed or debugged. This software provides devices and scripts to easily duplicate or prototype the structure and behaviour of any *Tango Control System*, using the *fandango* python library to export the control system status and create simulated devices dynamically. This paper will also present first tests using multiple SimulatorDS instances running on a commercial cloud.

INTRODUCTION

The classical paradigm for building a simulation infrastructure is the development and prototyping of a new control system, a period in which a software team is already committed to the development of a complex system but doesn't have yet access to the real hardware nor infrastructural resources[1].

Software Testing Techniques

Continuous Delivery and other widespread methodologies emphasize the importance of delivering well-tested systems to operators, as it will build confidence over the delivered system[2]. The two most common techniques for software testing are *Unit Testing* and *Functional Testing.*

Unit testing is a well established technique in the software field for validating libraries and API's; based on breaking up library components in basic software procedures that can be validated against well specified interfaces. It's widespread and well-established, but costly to apply in already existing or inherited projects where documentation may be scarce or outdated.

Functional testing instead proceeds to test the different parts of the application behaviour, validating that each of the functionalities of the program behaves according to the expected results. Depending of the scope and objective of the tests it can be known as integration testing, regression testing, usability testing, smoke testing, sanity testing amongst others.

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PySignalSimulator

In the case of most control systems, it is not possible to do a functional test without a certain capability to simulate the hardware system to be controlled.

The *PySignalSimulator* Tango Device Server was developed to cover these needs during ALBA Synchrotron construction phase. It provided an easy-to-configure[3] generic simulation tool for testing graphical applications. Based on single-line formula definitions stored in the Tango database (Table 1), it allowed to simulate hardware and to test the control system infrastructural services, like archiving[4] or alarms[5]. The success of this approach enabled other Tango Collaboration[6] members like MAX IV to reuse our developments during its design and development phases.

Table 1: Dynamic Attributes as Declared in Tango DB

`Square=0.5+square(t) #(t = seconds since the device started)`
`NoisySinus=2+1.5*sin(3*t)-0.5*random()`
`SomeNumbers=DevVarLongArray([1000.*i for i in range(1,10)])`

But, once ALBA Synchrotron entered in operation, new necessities appeared for simulators that a simple approach like PySignalSimulator was not able to cover. For a facility in a growing phase like ours, upgrades of the control system are required monthly, in systems as critical like Linac injection modes, Radiofrequency upgrades, orbit feedback improvements, … Upgrades that must be applied without interrupting the current operation schedule of 5912 yearly hours of beam for users, a constrain that limits the availability of hardware for testing to a few hours per month.

This lack of testing time availability created the need of an automated way of validating updates by replicating a running Tango Control System in a test environment.

SIMULATORDS

Several studies [7] has been done on the advantages of using simulation environments for software development. These works have pointed out that the effort of building a fully detailed model is often hardly justifiable if the work needed to implement a simulation environment must doesn't tend towards 0.

This lack of profitability of simulation environments is often caused by the impossibility to replicate the real hardware infrastructure or the obsolescence of the simulation design, as real systems tend to change a lot during building phases.

The SimulatorDS [8] package has been developed to overcome these certain limitations of the model-based

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AUTOMATIC FORMAL VERIFICATION FOR EPICS

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Abstract

We built an EPICS-based radiation therapy machine control program and are using it to treat patients at our hospital. To help ensure safety, the control program uses a restricted subset of EPICS constructs and programming techniques, and we developed several new automated formal verification tools for this subset.

To check our control program, we built a *Symbolic Interpeter* that finds errors in EPICS database programs, using symbolic execution and satisfiability checking. It found serious errors in our control program that were missed by reviews and testing.

To check the EPICS runtime (EPICS Core) itself, we first developed a *Formal Semantics* for EPICS database programs, based on the EPICS Record Reference Manual (RRM) and expressed in the specification language of an automated theorem prover. We built a formally-verified *Trace Validator* and used it to check the EPICS runtime against our semantics by differential testing with millions of randomly generated programs. The testing process generally corroborated that the EPICS runtime conforms to its specification in the RRM, but it did find several omissions and ambiguities in the RRM that might mislead users. Our formal semantics for EPICS enables valuable future developments: a full proof of correctness for our EPICS program, verified analyses for arbitrary EPICS programs, and a *Verified Compiler* that could compile an EPICS database to a verified standalone program, while dispensing with much of the unverified EPICS toolchain and runtime.

INTRODUCTION

The Clinical Neutron Therapy System (CNTS) at the University of Washington Medical Center (UWMC) has been treating cancer patients with radiation therapy and making isotopes since 1984 [1]. The system includes a cyclotron and a treatment room with an isocentric gantry and leaf collimator operated under computer control. The system was built and installed by a vendor, but since then has been maintained and upgraded by UWMC staff. In 1999 we replaced the therapy portion of the vendor's original control system (a PDP11 programmed in FORTRAN) with new hardware and our own software (a 68040 in a VME crate running VxWorks programmed in C) [2]. In 2015 we replaced the therapy control hardware and software again, this time using the Experimental Physics and Industrial Control System (EPICS) running under Linux on an x86 processor [3].

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EPICS has been used for over twenty-five years in many demanding applications [4–6]. Nevertheless, some experienced EPICS developers caution against using it for safety-critical controls:

> (EPICS) code is not rigorously audited to the standards ... that would be needed (for medical applications). [7]

> EPICS should never be relied on for safety-critical operations [8]

Despite these warnings, we use EPICS at CNTS on some safety-critical signal paths essential for therapy. Our therapy control system uses relays, PLCs, and other non-EPICS components for safety-critical functions nearest the hardware, but we do use EPICS to process some of the data that is input to these components, and to process output that is collected for record keeping. In particular, we use EPICS to retrieve stored prescriptions from a database (comprising about 50 parameters per treatment field), load them into the control hardware, check conformance between the hardware and the prescription, store treatment records, and to restore and finish interrupted treatment sessions. Programs written in high-level languages running on general-purpose computers are best suited to handle these processing steps. For this, EPICS is no worse than the alternatives and offers some advantages. This judgment is based on many years of experience at our installation with EPICS and several alternatives.

We have always had a safe system design and a careful development process [2,3,9]. However, in view of warnings from experienced EPICS developers, the greater complexity of EPICS compared to our previous platforms, and the lack of any close precedents for our project, we felt an obligation to focus exceptional care and scrutiny on the EPICS components in our system.

We chose two complementary approaches. First, we limited ourselves to a restricted subset of EPICS components and programming styles that we expect to be feasible to understand, review, and analyze. Second, we developed specialized software tools for analyzing both our own code (an EPICS database, or program, written in our restricted style) and the EPICS runtime (the EPICS implementation, also known as EPICS Core). These remedies are complementary, since our restricted programming style limits the amount of EPICS our tools must model. For the latter, CNTS staff are collaborating with faculty and graduate students from the University of Washington School of Computer Science and Engineering (UW CSE) who are experts in the formal verification of software.

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CONTROL SYSTEM SIMULATION USING DSEE HIGH LEVEL INSTRUMENT INTERFACE AND BEHAVIOURAL DESCRIPTION*

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Abstract

Development of Karoo Array Telescope Control Protocol (KATCP) based control systems for the KAT-7 and MeerKAT radio telescopes proved the value of a fully simulated telescope system. Control interface simulators of all telescope subsystems were developed or sourced from the subsystems. SKA SA created libraries to ease creation of simulated KATCP devices. The planned SKA radio telescope chose the TANGO controls framework. To benefit from simulation-driven development tango-simlib, an OSS Python library for data-driven development of TANGO device simulators, is presented. Interface simulation with attributes only requires a POGO XMI file; more complex behaviour requires a simple JSON SIMDD (Simulator Description Datafile). Arbitrary behaviour is implemented selectively using Python code. A simulation-control interface for back-channel manipulation of the simulator for e.g. failure conditions is also generated. For the SKA Telescope Manager system an Eclipse DSEE (Domain Specific Engineering Environment) capturing the behaviour and interfaces of all telescope subsystems is being developed. The DSEE produces tango-simlib SIMDD files, ensuring that the generated simulators match their formal specification.

INTRODUCTION

The current MeerKAT Control And Monitoring (CAM) system is developed against a fully simulated telescope system. In development environments, all the subsystems that would make up the real telescope are simulated at the level of their KATCP interfaces. KATCP is a communications protocol based on top of the TCP/IP (Transfer Control Protocol/Internet Protocol) layer. It is a syntax specification for controlling devices over a TCP link. The full, actual, MeerKAT CAM is run against the simulated devices, thus CAM functionality to be tested without the need of real telescope hardware. This is exploited by CAM developers in their own development environments and also allows automated functional integration tests to be run daily.

The testing of SKA Telescope Manager (TM) will be started in the absence of other Elements since not all of them will be available when TM is ready to be tested, it would be beneficial to have a mechanism that allows TM testing without depending on other element's Local Monitoring and Controls (LMCs). A useful tool for developing an evolutionary TM prototype is a data-driven TANGO simulation framework that is used to develop Element LMC simulators that can be used in the TM test environment. The goal is to develop a simulation framework for Element LMC Simulators that can be used in the TM test environment. Furthermore, the TM interface to LMCs can itself can be simulated using this framework. The simulation framework was presented to Element Consortia to keep them abreast of developments in this respect. Element Consortia are being encouraged to make use of the Simulation Framework to develop LMC Simulators where required. The following risk reductions have been identified:

- Risk reduction for early Assembly Integration and Verification (AIV) support;
- Risk reduction for TM product development, by providing early LMC simulators;
- Risk reduction for Element development by producing LMC Simulator Framework to aid them in the development of element simulators;
- Risk reduction by producing an early scriptable TM Simulator that can aid Element LMC development and integration efforts.

The early AIV integration would demand complete development of some components. Unavailability of hardware or incomplete development of element can be a hurdle for such AIV integration. The simulation framework reduces such risk by generating simulators that could be used in place of LMC's which are not fully developed or unavailable due to hardware dependencies. The test framework provides an approach to create test cases and points out areas where it can reduce manual effort in writing test cases through some amount of automation. It was shown that a basic LMC simulator can be produced using the information provided by the Element LMC Interface Control Document (ICD) through the simulation data-description file. The approach also enhanced our understanding of how domain specific simulators can be integrated into the testing and simulation framework as and when they become available. The simulation framework demonstrates how this risk can be mitigated for the TM product development by auto generating the simulators for the LMC's to a great extent based on the Self Description-Data (SDD) data that captures the information typically captured using ICD's in a structured and machine processable manner. Initially this was an exploratory prototype with the aim to develop it further into an evolutionary prototype during 2017 in the period towards Critical Design Review [1].

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STREAMLINING SUPPORT AND DEVELOPMENT ACTIVITIES ACROSS THE DISTINCT SUPPORT GROUPS OF THE ALBA SYNCHROTRON WITH THE IMPLEMENTATION OF A NEW SERVICE MANAGEMENT SYSTEM

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Abstract

The MIS section in the Computing & Controls division at ALBA Synchrotron designs and supports management information systems. This paper describes the streamlining of the support and development work of twelve support teams into a single customer portal and issue management system.

Prior to the change, ALBA was using five different ticket systems. To improve coordination, MIS researched tools able to support ITIL Service Management, as well as PRINCE2 and Agile Project Management. Within market solutions, JIRA, with its agile boards, calendars, SLAs and service desks, was the only solution with a seamless integration of both.

Support teams took the opportunity to redesign their service portfolio and management processes. Through the UX design, JIRA has proved to be a flexible solution to customize forms, workflows, permissions and notifications on the fly, creating a virtuous cycle of rapid improvements, a rewarding co-design experience which results in highly fitting solutions and fast adoption.

Team, project and service managers now use a single system to track support and development in a timely manner, view trends, and get a consolidated view of efforts invested in the different beamlines and accelerators.

PROBLEM: SILO MANAGEMENT SYSTEMS FOR SERVICE SUPPORT AND DEVELOPMENT

Prior to the change, ALBA was using five different ticketing systems:

- **Request Tracker**: an open source ticket system customized to handle **Service Desk** requests (service requests, changes, incidents, problems) as well as maintenances and small projects; first used by **Control Systems, Electronics, IT Systems and MIS**, then **Infrastructure**, **Vacuum**, **Alignment**, **Floor Coordinators** and **Beamline Technicians**.
- **Redmine**: an open source **software project** management system used by **Control Systems** and **MIS**, used with an agile project management plugin for backlog prioritization, sprint planning and tracking.
- **Safety Ticket**: a home-made web application used by **Health & Safety** for the prevention of occupational hazards and radiation protection.
- **Internal Order**: a home-made web application used by **Engineering Workshop** to manage **production orders**.
- **Manipulation Order**: another home-made web application used by **Engineering Workshop** to manage **transport and installation** orders.

In ALBA Computing division, Control Systems and MIS were using two distinct management systems, Request Tracker and Redmine, for service requests and for software projects, which resulted in a **lack of integration between support and development**. For instance, problems or new needs reported via the Service Desk in Request Tracker would be duplicated in Redmine for them to be addressed in the right Agile development team, generating cumbersome double tracking.

Similarly, having different service management systems for different teams did not facilitate **cross functional collaboration**. For example, every shielding movement would be handled both in Safety Ticket by the Radiation Protection team and in Manipulation Order by the Engineering division, without communication between the two systems.

In addition, the five systems from before 2007 were becoming **difficult to maintain** with outdated technologies and business processes. In particular, Health & Safety had revamped their management processes and Safety Ticket was no longer fit for purpose.

SOLUTION: USE JIRA AND CONFLUENCE AS A UNIQUE TOOLSET FOR SERVICE SUPPORT AND DEVELOPMENT

Based on a pressing need to coordinate service support and development tasks better, MIS investigated tools able to handle management processes based on **ITIL** service management best practices [1] and **PRINCE2** [2] and **Agile** [3] project management methodologies. Within available market solutions, JIRA was the only solution supporting both.

JIRA Software and JIRA Service Desk [4] have proved to be extremely versatile and flexible solutions to manage different **Service Desk teams** accessed through a **unique Customer Portal**, configure highly customized Request Forms using dynamic Custom Fields [6], and design complex Workflows, without any programming involved.

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NEW EPICS/RTEMS IOC BASED ON ALTERA SOC AT JEFFERSON LAB

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Abstract

A new EPICS/RTEMS IOC based on the Altera System-on-Chip (SoC) FPGA is being designed at Jefferson Lab. The Altera SoC FPGA integrates a dual ARM Cortex-A9 Hard Processor System (HPS) consisting of processor, peripherals and memory interfaces tied seamlessly with the FPGA fabric using a high-bandwidth interconnect backbone. The embedded Altera SoC IOC has features of remote network boot via U-Boot from SD card or QSPI Flash, 1Gig Ethernet, 1GB DDR3 SDRAM on HPS, UART serial ports, and ISA bus interface. RTEMS for the ARM processor BSP were built with CEXP shell, which will dynamically load the EPICS applications at runtime. U-Boot is the primary bootloader to remotely load the kernel image into local memory from a DHCP/TFTP server over Ethernet, and automatically run RTEMS and EPICS. The first design of the SoC IOC will be compatible with Jefferson Lab's current PC104 IOCs, which have been running in CEBAF 10 years. The next design would be mounting in a chassis and connected to a daughter card via standard HSMC connectors. This standard SoC IOC will become the next generation of low-level IOC for the accelerator controls at Jefferson Lab.

INTRODUCTION

The accelerator control system at Jefferson Lab is based on the Experimental Physics and Industrial Control System (EPICS) which uses a client/server model. Currently, the servers, or IOCs consist of VME IOCs, PC104 IOCs and Soft IOCs. PC104 IOCs running Real Time Executive for Multiprocessor Systems (RTEMS) and EPICS have been successfully used in the accelerator control system for the past 10 years with more than 280 in service [1]. However, the PC104 manufacturer, Kontron, has discontinued the PC104 board, so we have to decide whether to source another vendor to continue using the PC104 or seek a new embedded IOC platform that meets our long term goals. The PC104 is a stackable Single Board Computer (SBC) with an ISA bus connecting a carrier board. The data transfer baud rate between the processor and the carrier board is limited by the ISA bus. This limitation pushes us to seek a new IOC which has high bandwidth, especially for those applications which require fast data transfer. Since most of our designs are using a Field-Programmable Gate Array (FPGA) and a separate microprocessor, a System-on-Chip (SoC) FPGA should definitely be considered. The SoC FPGA is likely to provide comparable, if not superior functionality and performance, but at a lower board space, lower power, and lower system cost. The integration of thousands of internal connections between the processor and the FPGA leads to substantially higher bandwidth and lower latency compared to a two-chip solution. Some SoC FPGAs have been designed as EPICS IOCs for other accelerator control systems [2,3]. The Intel (formally Altera) Cyclone V SoC [4] was chosen as our standard IOC platform. In this paper, we will describe the design of the SoC IOC board, the booting of the SoC, and the real-time operating system development.

HARDWARE DESIGN

The Terasic SoCKit and DE0-Nano-SoC Development Kit were chosen as our hardware design reference platforms [4,5]. Both of the kits were built around the Intel/Altera Cyclone V SoC FPGA, which integrates an ARM-based HPS consisting of a ARM Cortex-A9 processor, peripherals and memory interfaces tied seamlessly with FPGA fabric using a high-bandwidth interconnect backbone. On our first design of the SoC motherboard, we keep most features of the SoC kits and add an ISA bus to be compatible with the PC104 IOC. Figure 1 shows the block diagram of the new SoC motherboard. It has the following feature devices:

- Altera Cyclone® V 5CSEBA2U19C8N device.
- Serial configuration device – EPCS.
- USB-Blaster II onboard for programming; JTAG Mode.
- 25MHz clock sources from the clock generator.
- One ISA Bus header.
- 600MHz Dual-core ARM Cortex-A9 processor.
- 1GB DDR3 SDRAM (32-bit data bus).
- One EEPROM for MAC address.
- 1 Gigabit Ethernet PHY with RJ45 connector.
- Micro SD card socket.
- Two UART to RS-232 10-pin connectors.
- One 64 MB QSPI Flash.
- One header for Reset, Led and Speaker.
- One user button and one user LED.
- Switches for boot selection.

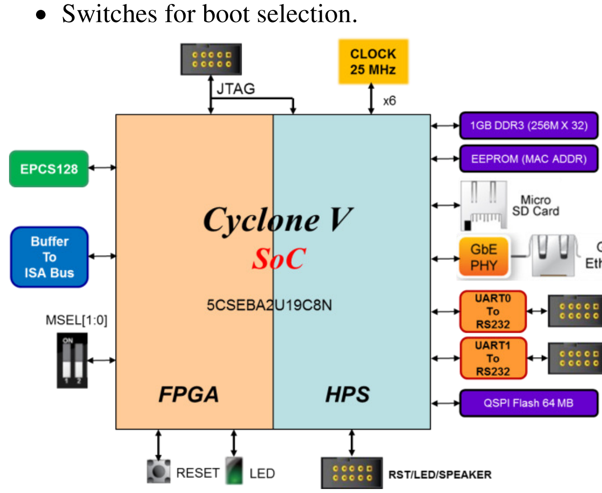

Figure 1: Block Diagram of the SoC IOC.

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LCLS-II TIMING PATTERN GENERATOR CONFIGURATION GUIs*

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Abstract

The LINAC Coherent Light Source II (LCLS-II) is an upgrade of the SLAC National Accelerator Laboratory LCLS facility to a superconducting LINAC with multiple destinations at different power levels. The challenge in delivering timing to a superconducting LINAC is dictated by the stability requirements for the beam power and beam rate up to 1MHz (Table 1). A timing generator will produce patterns instead of events because of the large number of event codes required. This paper explains how the stability requirements are addressed by the design of two Graphical User Interfaces (GUI). The Allow Table GUI filters the timing pattern requests respecting the Machine Protection System (MPS) defined Power Class and the electron beam dump capacities. The Timing Pattern Generator (TPG) programs Sequence Engines to deliver the beam rate configuration requested by the user. The TPG generates the patterns, which contain the timing information propagated to the Timing Pattern Receiver (TPR). TPG and TPR are implemented in FPGA solution and configured at the EPICS level. This paper will explain the requirements and show an overall design of the high-level software solutions that meet the physics requirements for LCLS-II timing.

INTRODUCTION

LCLS-II timing system does a variety of tasks for the triggering and synchronizing of the beam bunches and data acquisition. The configuration of the timing system can be accomplished on a low-level programming or by a user-friendly interface. The timing GUIs will be generating beam rate patterns including all the intermediate rates between 0 and CW operation at 1MHz. The GUIs will also allow the generation of single shot and burst mode. The timing team, together with the physicists and the MPS team, identified three GUIs to meet specifications; the identified interfaces are listed in Figure 1.

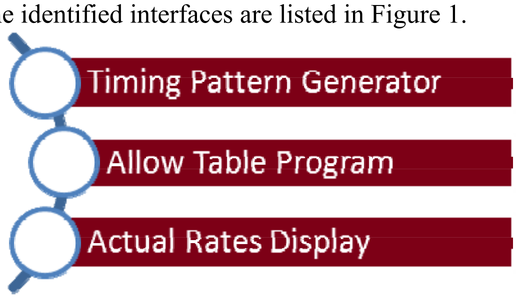

Figure 1: TPG GUIs list.

This paper will describe the features offered by each one of the listed GUIs.

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BEAM RATE PATTERN

The LCLS-II Timing System prescribes the actions to be performed on a sequence of bunches as they are injected into the accelerator using the timing pattern. The timing pattern will dictate the rate, temporal separation of bunches and the bunch destination (to the HXR, SXR, dumps etc.) as well as other parameters that can be altered on a bunch-by-bunch basis (energy, peak current etc.). The pattern that is applied to the sequence of bunches will repeat itself continuously until the timing generator makes a change in the pattern [1].

There are two classes of beam rate pattern: Standard beam rate and the AC synchronous beam rates.

Standard Beam Rate Pattern

The standard patterns are defined as a fixed integer number of RF phase reference cycle.

The LCLS-II standard patterns are listed in Table 1.

Table 1: LCLS-II Standard Pattern Rates

Nominal Rate	Exact Rate
Zero rate	0
Single shot	Once, on request
Burst mode	Specify number of shots Specify number of spacing
1 Hz	0.928 Hz
10 Hz	9.28 Hz
50 Hz	46.4 Hz
100 Hz	92.8 Hz
1 kHz	0.928 kHz
10 kHz	9.28 kHz
100 kHz	92.8 kHz
Half rate	262.285 kHz
Full rate	928,571,428.571 Hz

The described patterns are absolute and not locked to the variable AC frequency [1].

AC Synchronous Beam Rates

The beam rates included in this class are locked to the AC power line. In spite of the standard pattern rates, the AC synchronous beam rates do not guarantee the same number of RF cycle at full rate.

The following list contains the beam event triggers synchronized to the power line:

- Time slot assignment for AC synchronous beam rate;
- Bunch trains;
- Bunch trains to compensate beam-loading transients.

The format of the timing pattern frame is enumerated in Table 2. (Figure 2)

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STRATEGIES FOR MIGRATING TO A NEW EXPERIMENT SETUP TOOL AT THE NATIONAL IGNITION FACILITY

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Abstract

For the last 10 years, the National Ignition Facility (NIF) has provided scientists with an application, the Campaign Management Tool (CMT), to define the parameters needed to achieve their experimental goals. Conceived to support the commissioning of the NIF, CMT allows users to define over 18,000 settings. As NIF has transitioned to an operational facility, the low-level focus of CMT is no longer required by most users and makes setting up experiments unnecessarily complicated. At the same time, requirements have evolved as operations has identified new functionality required to achieve higher shot execution rates. Technology has also changed since CMT was developed, with the availability of the internet and web-based tools being two of the biggest changes. To address these requirements while adding new laser and diagnostic capabilities, NIF has begun to replace CMT with the Shot Setup Tool (SST). This poses challenges in terms of software development and deployment as the introduction of the new tool must be done with minimal interruption to ongoing operations

INTRODUCTION

CMT has been under steady development for almost 15 years. Initially created to commission the NIF laser, it was designed to put many low-level experiment configuration details into the hands of expert users and architected primarily around the repeating patterns of the NIF laser hierarchy: 192 beams, 48 quads, 24 bundles, four clusters, two laser bays, and one NIF. However, since the start of NIF science campaigns in 2009, the overwhelming source of feature development pressure has come not from evolving the NIF laser but from ongoing development and evolution of the target chamber diagnostic systems employed to capture x-ray, neutron, and optical radiation generated during NIF experiments. These “target diagnostic” systems carry, individually, a tiny fraction of the complexity of the NIF laser, but they evolve at a much faster pace as physicists invent novel approaches for extracting evermore useful data from NIF experiments.

During the DOE-mandated 120 Day Study, completed in 2014 and conducted to identify changes in NIF operations necessary to significantly increase the shot rate, one of the findings was the need to make experiment configuration faster and simpler for experimentalists, i.e., simplify CMT. Even prior to that study, an increased rate of target diagnostic development coupled with staff changes in the Shot Configuration project that maintains CMT had brought into sharp focus the challenges in continuing with the existing architecture and development lifecycle.

DECIDING ON THE PATH FORWARD

In theory, the overall requirement of simplifying CMT was straightforward; just make the tool easier to use by the user community and make it quicker. But before the team could begin to make such a transition, they had to assess what other high-level requirements could be addressed as part of this change.

Interviewing the key stakeholders of the User Office, NIF operations, experimentalists and Control Systems software developers and by talking to the SST developers themselves added eight more high level requirements that the team was to develop to (see table 1).

Table 1: Shot Setup Tool High Level Requirements

Requirements
Ensure data is consistent with other User Tools.
Use rule sets to set up an experiment.
Integrate with the facility configuration management system.
Provide integrated access controls.
Employ a data group-centric setup.
Support non-contiguous experiment setup.
Maintain interfaces to external systems.
Be easier to maintain and evolve.
Do not interrupt current NIF operations

With the 120 Day Study providing a programmatic mandate, the door was open to update or replace CMT, and after an extensive requirements-gathering phase and internal architecture review, the Shot Configuration team determined that modifying CMT to meet current programmatic needs was not a viable solution.

At this point, the obvious issue confronting the team was how to go about re-implementing the one million lines of code currently used by CMT in an entirely new tool and adhere to the ninth high level requirement of not disrupting NIF operations. For many reasons, a single, big bang deployment of a replacement application would be extremely risky. It would be difficult to create an accurate plan that would estimate when the tool would be complete, user needs would likely change over the duration of the development and in reality, there would be a lot of new bugs that would need to be addressed as users found them.

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CONCEPTUAL DESIGN OF DEVELOPING A MOBILE APP FOR DISTRIBUTED INFORMATION SERVICES FOR CONTROL SYSTEMS (DISCS)*

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Abstract

Due to involvement of different engineering disciplines, tools and methodologies in design, construction and operation of an experimental physics facility (EPF), an integrated information system is needed to efficiently manage data. DISCS is a framework developed to address this need which includes multiple modules and services that provide web-based management tools and APIs to access EPF related information stored in various databases like Controls Configuration Database (CCDB) and Cables Database (CDB). In this paper we propose a conceptual design of a mobile application that can easily be used by technicians working at EPFs to access their required data. The proposed application would use QR code and Augmented Reality (AR) to enhance user experience. It can also be used as a means to create a collaborative environment by providing social networking features helping technicians to share their knowledge from different facilities worldwide.

INTRODUCTION

Mobile phones and other portable devices have become an integral part of our everyday life. People are getting used to various applications that help them with handling their personal and professional tasks. Technicians and other employees at an experimental physics facility may need to access multiple databases to gain the information required for their ongoing tasks, a mobile application can be used as a user-friendly tool to meet their needs.

An integrated information system is needed to manage the data and computation of an EPF. Distributed Information System for Control Systems (DISCS) is a framework for integrating, managing and accessing information base and other necessary computation [1].

European Spallation Source (ESS) is an under construction facility that will be the world's most powerful neutron source for research which is built in collaboration of 17 European countries. ESS has been cooperating in DISCS, one of the products of this collaboration is the development of CCDB which will be used to store data about control system components and some additional metadata [2].

DISCS is partitioned into smaller subsystems called modules based on user requirements, functionality, and cohesion among the data sources. Development of DISCS is kept decentralized and it consist of two main groups: the first is the Module Team that is responsible for development of a module and for its all deliverables like services, API, schema and applications. The second group named Collaboration Board is a group of stakeholders responsible for governance and architecture of the system, each module should be approved by the Collaboration Board before it is published as a part of DISCS [3].

Each module consists of one or more applications, services and databases. Applications and services within a module can access data directly or through some layers but user applications must access module's data only through its service API, the system is made up of a collection of collaborating modules as shown in figure 1 [1].

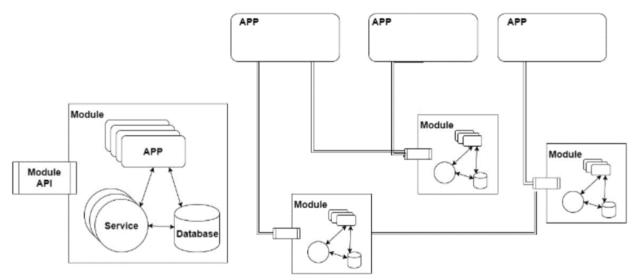

Figure 1: Collaborating modules.

CONCEPTUAL DESIGN

Comparing Different Approaches

There are three different approaches that can be used for the development of a mobile application for DISCS.

A naïve approach for providing access to the CDB via mobile application would be the developing of an app that runs the Cables module web application through an embedded web browser like android WebView [4].

Using this approach we can rapidly create a mobile application to access the cable information but in fact this would be just an alternative way of using the previously existing module's web application. The negative point of this approach is that the database is not accessed directly and new features cannot be added.

A major problem of this approach is that the application cannot be used if the web service is down or corrupted.

The other approach to design the application may use the API services provided by previously existing modules.

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MAX IV BioMAX BEAMLINE CONTROL SYSTEM: FROM COMMISSIONING INTO USER OPERATION

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Abstract

The BioMAX beamline at MAX IV is devoted to macromolecular crystallography and will achieve a high level of experimental automation when its full potential is reached due to the usage of high end instrumentation and comprehensive software environment. The control system is based on TANGO and Sardana for managing the main elements of the beamline. Data acquisition and experiment control is done through MXCuBE v3 web application, which interfaces with the control layer. Currently, the most critical elements such as the detector and diffractometer are integrated into the control system, whereas the integration of the sample changer has started. BioMAX has received its first users, who successfully collected diffraction data and provided feedback on the general performance of the control system and its usability. The present work describes the main features of the control system and its operation, as well as the next instrument integration plans.

BIOMAX BEAMLINE DESCRIPTION

BioMAX is the first X-ray macromolecular crystallography (MX) beamline of MAX IV Laboratory, which began its user operations in 2017. It is a state-of-the-art resource accommodating multiple cutting edge experimental possibilities. The design goal for BioMAX was to create a stable and reliable beamline that provides a user friendly environment. The beamline experiment set-up is highly automated, in terms of both sample handling hardware and data analysis, including feedback on the data collection. The X-ray beam focus is 20 x 5 μm^2 at the sample position and the operational energy range is 5-25 keV, [1]. Table 1 shows the main characteristics of BioMAX.

Optics

The main optical elements are a liquid-nitrogen cooled double crystal monochromator and two mirrors in Kirkpatrick-Baez geometry (named Vertical and Horizontal Focusing mirrors). The mirrors have three different stripes for different energy ranges, selectable by adjusting the position of several motors. Apart from in-air and in-vacuum motors, there are two piezo actuators for fine adjustment of the second crystal pitch and roll in the case of the monochromator, and additional two for the focusing mirrors' pitch. Before the focusing mirrors there is a slit module, consisting of two identical units, one with horizontal movements and one identical unit with vertical movements. In addition, there are measurements for temperature, flow, pressure, etc.

Several diagnostics modules are distributed along the beam path. The first module includes a fluorescent screen, a fixed Cu mask, a fixed bremsstrahlung mask and a filter unit. The screen switches between two positions by means of a pneumatic actuator and it also includes a CCD camera. The filter unit has two axes that are stepper motor driven. Each axis has five positions including four different filters and one position without filter. This diagnostic module also includes several temperature measurements. The second diagnostic module mainly contains a similar fluorescent screen setup as the previous one.

Table 1: Main Specifications of the BioMAX Beamline at MAX IV

Techniques	MX, MAD, SAD, S-SAD, atomic resolution data collection, large sample ensemble screening, in situ crystal diffraction
Beam Size	20 x 5 μm^2
Energy Range	5-25 keV
Samples	Single crystal (1 - 100 μm)

Experimental Station

This is the area where the most complex elements of the beamline are located. The main components of the experimental station are the beam conditioning unit, the MD3 diffractometer from Maatel/Arinax, the ISARA sample changer (Irelec), the EIGER 16M detector (Dectris) and all the associated motorised support tables (one for the beam conditioning unit and the diffractometer, and another one for the detector). The Figure 1 displays a recent picture of the experimental hutch. The MD3 diffractometer is an evolution from the previous MD2, which is an advantage since the communication API is the same and the MD2 was in use in the old MAX-lab MX beamline, therefore the development has been focused on the addition of the new functionality. Concerning the ISARA sample changer, it can hold up to 400 samples supporting both Unipack and Spine standards and a crystalization plate holder, and it provides a fast sample exchange due to a double gripper mechanism. Together with the state of the art detector, the goal is to provide a fast and highly automated environment for the users, aiming at a sample/crystal processing rate higher than 200 samples per eight hours shift.

In addition to those main components, further elements are the Beamline Conditioning Unit, which encloses several motorised devices such as two piezo actuator driven slits, an attenuator device consisting of three wheels, an

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CHALLENGES OF THE ALICE DETECTOR CONTROL SYSTEM FOR THE LHC RUN3

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Abstract

The ALICE Detector Control System (DCS) has provided its services to the experiment since 10 years. During this period it ensured uninterrupted operation of the experiment and guaranteed stable conditions for the data taking.

The DCS has been designed to cope with the detector requirements compatible with the LHC operation during its RUN1 and RUN2 phases. The decision to extend the lifetime of the experiment beyond this horizon requires the redesign of the DCS data flow and represents a major challenge. The major challenges of the system upgrade are presented in this paper.

THE ALICE DETECTOR CONTROL SYSTEM (DCS)

The ALICE Detector Control System is based on commercial SCADA system WINCC OA. Wherever possible it uses industrial components and tools to provide its functionality.

The DCS is using a five tier architecture (see Fig. 1). At the bottom, the hardware layer provides all devices and sensors required for the operation of the experiment. It consists of about 1200 network attached devices – mostly power supplies, PLCs and detector front-end electronic modules, and devices interfaced via industrial fieldbuses.

The hardware abstraction layer provides unification of the communication between a large variety of devices and the control system software. It consists of industrial OPC servers and of ALICE FED servers [1] providing OPC-like functionality on nonstandard devices. The communication interface of the FED servers is based on the on lightweight DIM protocol [2] developed at CERN.

The data acquired from the devices is processed in the DCS Controls layer. A farm of about 120 servers runs a distributed WINCC OA SCADA system configured to behave as one large system. Each received value is compared with the operational limits and if needed a corrective action is taken or the issue is brought to the attention of the ALICE shift crew. The control layer configures the control devices and sends commands to them. The configuration data as well as all acquired data is stored in the ORACLE database. The control layer is in charge of about 1 million parameters.

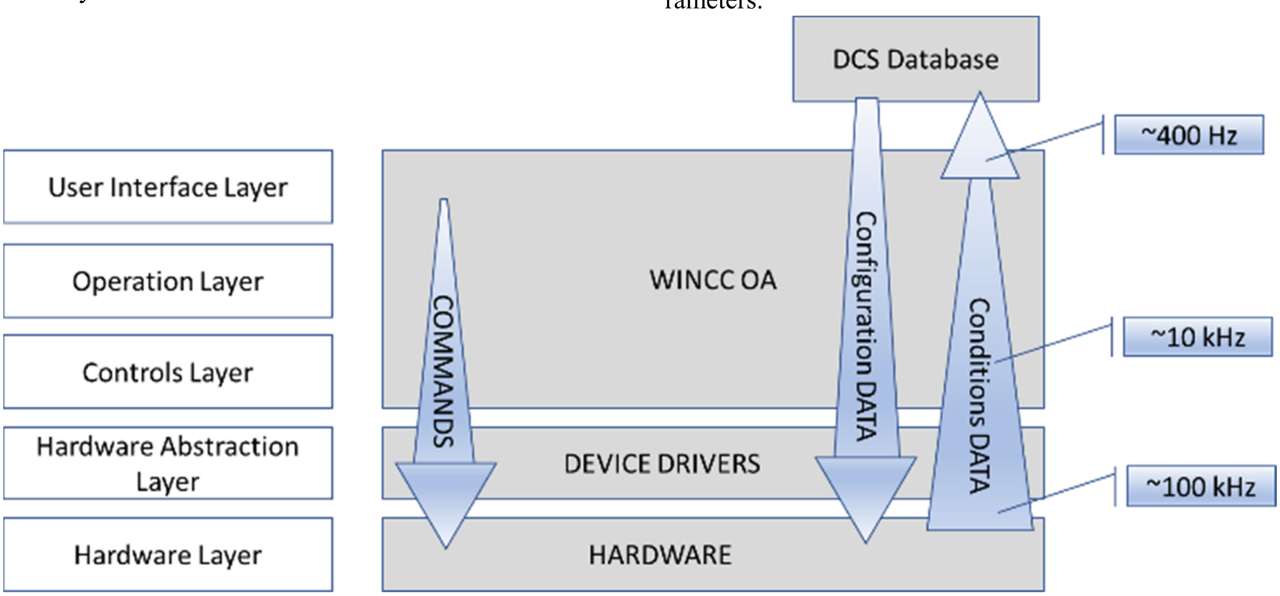

Figure 1: The mapping of the DCS layers to the hardware and software system components and the general data flow.

The operation of the experiment must follow a carefully tuned sequence of steps. For example a detector module cannot be turned on, unless sufficient cooling is provided, certain electronic modules may be powered only after the high voltage has been applied to the sensors, etc. This logic is implemented in the operations layer. Based on the

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NEW VISUAL ALIGNMENT SEQUENCER TOOL IMPROVES EFFICIENCY OF SHOT OPERATIONS AT THE NATIONAL IGNITION FACILITY (NIF)

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Abstract

Established control systems for scientific experimental facilities offer several levels of user interfaces to match domain-specific needs and preferences of scientists, technicians and engineers. At the National Ignition Facility (NIF), the low-level device panels address technicians' need for comprehensive hardware control, while Shot Automation software allows NIF shot directors to advance thousands of devices at once through a carefully orchestrated shot sequence. MATLAB scripting with the NIF Layering Toolbox has enabled formation of intricate deuterium-tritium ice layers for fusion experiments. The latest addition to this family of user interfaces is the Target Area Alignment Tool (TAAT), which guides NIF operators through hundreds of measurement and motion steps necessary to precisely align targets and diagnostics for each experiment inside NIF's 10-meter Target Chamber. In this paper, we discuss how this new tool has integrated familiar spreadsheet calculations with intuitive visual aids and checklist-like scripting to allow NIF process engineers to automate and streamline alignment sequences, contributing toward NIF shot rate enhancement goals [1].

INTRODUCTION

The National Ignition Facility at Lawrence Livermore National Laboratory (LLNL) is the world's most energetic laser system for experimental research in inertial confinement fusion (ICF) and high-energy-density (HED) physics. The NIF laser system consists of 192 laser beams which are focused inside the 10-meter Target Chamber (TC), delivering up to 1.8 MJ of ultraviolet light onto the target.

Eleven target and diagnostic positioners are used to precisely position NIF targets and diagnostic instruments inside the Target Chamber. NIF positioners are large electromechanical systems with several degrees of freedom. Positioners are 10-15 meters long and extend up to 5 meters reaching NIF's Target Chamber Center (TCC) (Fig. 1).

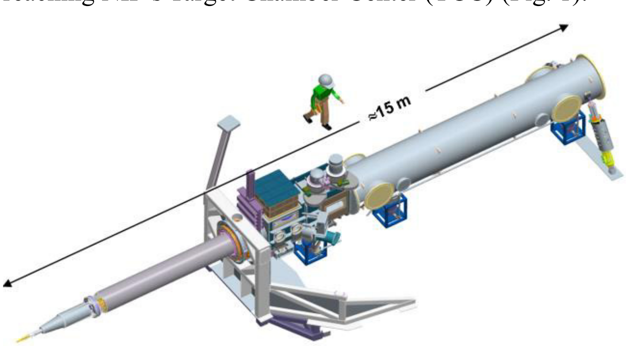

Figure 1: A NIF positioner.

NIF targets, diagnostics, and laser beams need to be precisely aligned for every NIF experiment (also called "shot") (Fig. 2). The alignment tolerances are determined by the type of diagnostic and the experimental requirements, and can be as demanding as tens of microns when aligning pinholes of the neutron imaging systems.

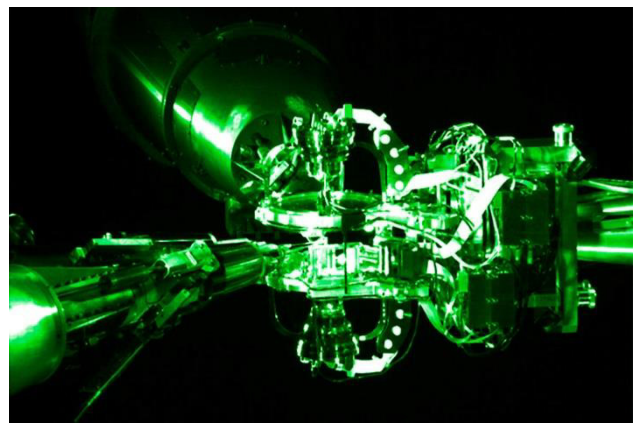

Figure 2: Multiple positioners at NIF TCC.

Most of the target and diagnostic alignments at NIF are performed by trained operators using visual features and alignment aids. Video cameras of various orientation and zoom levels support this process, such as the 50-megapixel Opposed Port Alignment System (OPAS).

With the addition of the Advanced Tracking Laser Alignment System (ATLAS), the exact positions of diagnostic instruments can be measured without relying on a human operator. This new NIF alignment capability opens the path toward precise, fully automated diagnostic alignment at NIF [2].

NEED FOR AN ALIGNMENT TOOL

Target and diagnostic alignment operations at NIF consist of hundreds of steps performed by skilled operators. Each experiment at NIF is unique due to variations in target designs and changing diagnostic configurations. The specifics of the experimental setup, target and diagnostics metrology all influence the alignment process. Based on these data, the expected positions of the alignment features are computed for each step. Once the equipment is coarsely aligned, the operator identifies the alignment features using one or more cameras and determines the feature location as projected on the camera image plane. NIF camera user interfaces (UI) are equipped with graphical alignment aids (GAA) which allow operators to draw lines, rectangular boxes, circles, etc. and then read out the positions of these aids. Using both the expected and actual positions of the

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DEVELOPMENT OF A MACHINE PROTECTION SYSTEM FOR KOMAC FACILTY

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Abstract

The Korea multi-purpose accelerator complex (KOMAC) 100 MeV proton linac has been developed and installed at the Gyeong-ju site [1]. The KOMAC consists of low-energy components, including a 50 keV ion source, a low-energy beam transport (LEBT), a 3 MeV radio-frequency quadrupole (RFQ), and a 20 MeV drift tube linac (DTL), as well as high-energy components, including seven DTL tanks for the 100 MeV proton beam. The KOMAC includes ten beam lines, five for 20 MeV beams and five for 100 MeV beams. The KOMAC utilizes a high power, heavy-ion linear accelerator to support diverse beam service, including a radio-isotope beam line and provides beams of 100 MeV with a beam power > 100 kW [2]. Therefore, in the event of operating failure, it is extremely important to shut off the beam to prevent damage to accelerator components such as the linac cavities and diagnostic equipment. The KOMAC machine protection system (MPS) is required to protect the high-performance accelerator components. The MPS developed previously with an analog circuit interlock box was upgraded to a digital interlock system [3]. We designed the new MPS to be flexible enough to accommodate both machine study and beam operations. In case of a beam abort, the KOMAC MPS inhibits all relevant devices to protect the accelerator components against beam losses, thereby avoiding damage leading to long maintenance times. In this paper, we present the KOMAC machine protection architecture, technical specification, and performance results of the new machine protection system.

MPS ARCHITECTURE

The KOMAC linac and multi-beam lines were designed to provide users with a proton beam under various beam conditions. Representative specifications of the KOMAC linac are maximum beam energy of 100 MeV, and peak beam current of 20 mA, and the adjustable repetition rate is up to 120 Hz, as described in Table 1.

Table 1: Specifications of the KOMAC Linac

Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 - 20	1~100
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1~4.8	0.1~1.6
Pulse Length (ms)	0.1~2	0.1~1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160

The maximum beam repetition rate is 120 Hz at 20 MeV, and 60 Hz at 100 MeV. The KOMAC has a plan for increasing the beam power to 160 kW. The accelerator components are protected from damage by a MPS that shuts off the beam within one beam pulse during normal 120 Hz operation. The damage to sensitivity components when operating an accelerator facility comes from beam loss. The machine interlock system uses KOMAC-built hardware with both commercial processor and field programmable gate array (FPGA) chips. The system comprises eleven local interlock nodes covering the 100m machine from the injector to the 100 MeV beam dump. The local interlock nodes are located each 30m in the component gallery of the KOMAC facility, as shown in Fig. 1.

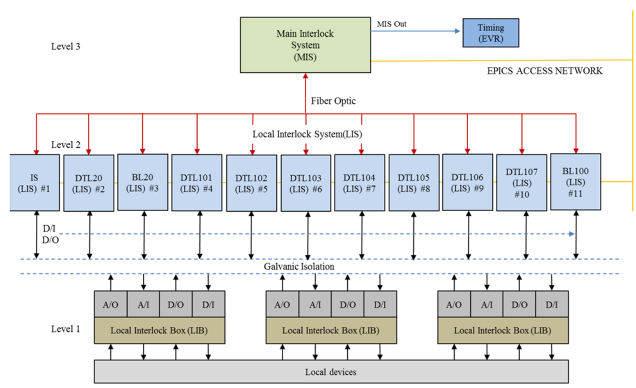

Figure 1: Network overview of the machine protection system.

The local interlock nodes are connected to the main interlock node in a star topology over a fiber connection. The MPS is intended to detect failures of the accelerator components. The components need to be controlled according to beam conditions. An unstable beam can lead to undesirable results such as damage to equipment and long maintenance times.

MPS IMPLEMENTATION

In order to protect the linac cavities and other accelerator components from beam loss, a fast response time by the interlock system is required. The required global response time of the KOMAC MPS is from 20 to 50 μs for the high power linac that runs at the maximum beam repetition rate of 120 Hz at 20 MeV and 60 Hz at 100 MeV with a pulse length of 0.1 to 2 ms. The KOMAC MPS has been designed in three layers: local interlock box (LIB), local interlock system (LIS), and

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THE IMPLEMENTATION OF KSTAR FAST INTERLOCK SYSTEM USING C-RIO*

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Abstract

In the tokamak using superconducting magnet that can operate in long pulse with high temperature and density plasma, the interlock system is becoming more and more important to protect the device itself. Korean Superconducting Tokamak Advanced Research (KSTAR) achieved high-confinement mode (H-mode) operation for 70 seconds in 2016. In this case, it is necessary to have precise and fast operation protection device to protect Plasma Facing Component (PFC) from high energy and long pulse plasma. The higher the energy of the plasma, the faster the protection is required, and the protection logic should be implemented to process the signals from the various devices as quickly as possible. To meet these requirements, KSTAR implemented the Fast Interlock System (FIS) using NI's Compact Reconfigurable Input Output (c-RIO). The c-RIO is a device using FPGA (Field Programmable Gate Array), its form is similar to PLC (Programmable Logic Controller) and is easy to expand I/O. The implemented protection logic is performed in the FPGA, so input and output can be processed quickly and much. The EPICS IOC performs communication with peripheral devices (PCS, CCS, SIS, heating devices) and operation of c-RIO. In this paper, we describe the detail implementation of the FIS in the actual KSTAR situation, as well as future plan.

INTRODUCTION

The fast interlock is an interlock that stops the heating device to prevent components in the vessel from being damaged during plasma discharge. Tokamak using superconducting magnets is capable of long pulse operation and high temperature and density plasma confinement, so that the function of the interlock system to protect the device is becoming more important than the conventional tokamak. KSTAR (High Superconducting Tokamak Advanced Research) achieved high-confinement mode (H-mode) operation for 70 seconds in 2016 [1]. In this case, KSTAR also has an accurate and fast-acting protection device for protecting in-vessel components from high energy and long pulse plasma. The higher the energy of the plasma, the faster the protection device is needed, and the protection logic must be realized using the signals from various related devices.

OVERVIEW OF KSTAR FAST INTERLOCK SYSTEM

The final target of the KSTAR device [2] is 2MA for plasma current and 300second for pulse length, and it is in the process of reaching the target value through continuous upgrade. The KSTAR team is constantly contemplating how to protect equipment from high-energy and long pulse plasma [3-5]. As results of these troubles, three versions of fast interlock system have been constructed, tested and supplemented. The core contents can be summarized as follows [6]:

- 1st Version, 2009

  Central Control System (CCS) activates heating stop from Plasma Control System (PCS) using RFM within 200 ms.
- 2nd Version, 2012

  Fast interlock interface activates heating stop from plasma current (Ip) signal using Timing Synchronization System (TSS).
- 3rd Version, 2014

  2nd Version plus

  Plasma Facing Component (PFC) fault, NB armor fault, CCS to PCS using RFM

Running the previous three versions of FIS, we needed to migrate to CCS functionality that works on the existing VME VxWorks. We also needed a new system that could easily extend I/O, easily implement control logic, and flexibly accommodate various types of information. First, the new system includes NI-Compact-RIO, which has an FPGA as a main controller and supports various I/Os. It also can be configured to process information with peripheral devices and communicate with compact-RIO in the EPICS IOC Server. The NI compact-RIO is chosen as the main processor with the following benefits.

- Fast response time, fast processing time.
- Proven device, platform, high reliability.
- Easily implement and modify logic using FPGA and labview.
- Fast system development.
- Communication with EPICS using IRIO is possible.

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OPERATION STATUS OF J-PARC MR MACHINE PROTECTION SYSTEM AND FUTURE PLAN

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Abstract

The J-PARC MR's Machine Protection System (MR-MPS) was introduced from the start of beam operation in 2008. Since then, MR-MPS has contributed to the improvement of safety including stable operation of the accelerator and the experiment facilities [1]. The present MR-MPS needs to be reviewed from the aspects such as increase of connected equipment, addition of power distribution building, flexible beam abort processing, module uniqueness, service life etc. In this paper, we show the performance of MR-MPS and show future consideration of upgrade.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator facility. It consists of three accelerators: 400-MeV linear accelerator (LINAC), 3-GeV Rapid Cycling Synchrotron (RCS), and 30-GeV Main Ring synchrotron (MR), and three experimental facilities: Material and Life Science Experimental Facility (MLF), Neutrino Experimental Facility (NU), and Hadron Experimental Facility (HD) [2-4].

The MR has two beam operation modes: a fast extraction (FX) mode for beam delivery to the NU, a slow extraction (SX) mode for beam delivery to the HD. The MR operation cycle based a main magnet current pattern shown in Figure 1. The MR-MPS ensures the safety of accelerator and experimental facilities by stopping beam operation and abandoning beam to abort dump when accelerator components or experimental facilities components interlock signal occur.

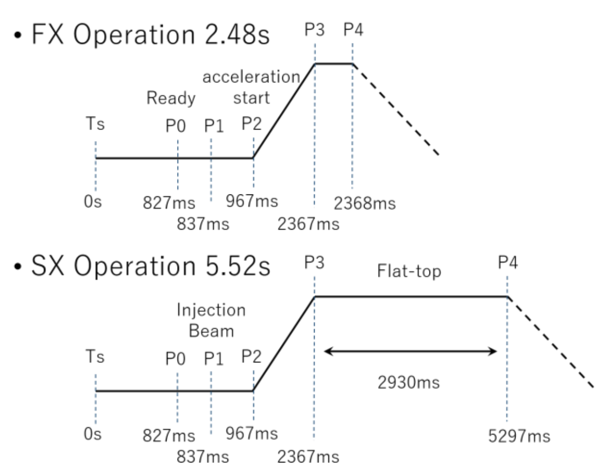

Figure 1: MR operation cycle of the two modes.

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Figure 2: Photo of MR-MPS unit.

PRESENT MR-MPS

The MR-MPS consists of 6 BLM-MPS units, 8 MR-MPS units and 5 MR-MPS units in experimental facilities. The BLM-MPS unit monitors 254 channels Beam Loss Monitor (BLM) signal of 3-50 Beam Transport line (3-50BT) and MR. The MR-MPS unit monitors 134 kinds of interlock signals of 3-50BT and MR components including BLM-MPS units in three power distribution buildings (D1-D3). A photograph of the MR-MPS unit is shown in Figure 2. The MR-MPS unit consist of 1 CPU module, 10 input modules, 4 input/output modules and 1power supply module. The input module is 3 types: an optical signal input module using ST connecter for main bending and quadrupole magnets power supply's interlock signal, a contact signal input module for interlock signal of various MR component and TTL signal input module for timing signal. The input/output module is an optical transceiver module using SC connecter for communicating between MPS units. 2 MR-MPS units and 2 BLM-MPS units are installed in the Local Control Room (LCR) of each power distribution building, 3 MR-MPS units in NU and 2 MR-MPS units in HD. The MR-MPS layout is shown in Figure 3. All MR-MPS signals are consolidated in the dedicated MR-MPS units of the D3 power distribution building. They do a beam abort by sending a signal to the kicker power supply and also stop

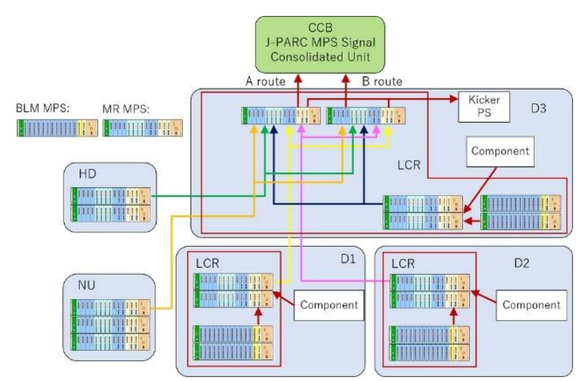

Figure 3: Layout of MR-MPS in J-PARC.

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OPC UA TO DOOCS BRIDGE: A TOOL FOR AUTOMATED INTEGRATION OF INDUSTRIAL DEVICES INTO THE ACCELERATOR CONTROL SYSTEMS AT FLASH AND EUROPEAN XFEL

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Abstract

Integrating off-the-shelf industrial devices into an accelerator control system often requires resource-consuming and error-prone software development to implement device-specific communication protocols. With recent progress in standards for industrial controls, more and more devices leverage the OPC UA machine-to-machine communication protocol to publish their functionality via an embedded information model.

Here we present a generic DOOCS server, which uses a device's published OPC UA information model for automatic integration into the accelerator control systems of the FLASH and European XFEL free-electron laser facilities, thus reducing software development time and errors.

We demonstrate that the server's and protocol's latency allows DOOCS-based burst-to-burst feedback in the 10Hz operation modes of FLASH and European XFEL and is capable of handling more than 10^4 data update events per second, without degrading performance. We also report on the successful integration of a commercial laser amplifier, as well as our own PLC-based laser protection system into DOOCS.

MOTIVATION

The DOOCS control system [1] of the FLASH and European XFEL free-electron laser facilities extends to thousands of individual sensor and actuator devices, connected to hundreds of distributed computer nodes. Many of these devices are off-the-shelf industrial products and the majority of them feature a device-specific communication protocol. Integrating them into the control system requires implementing the custom protocols and mapping the devices' functionality to the DOOCS data model. This software development process is both resource-consuming and error-prone.

The development of a general OPC UA to DOOCS bridge software enables the immediate integration of OPC UA devices into the control system, based on the device's published OPC UA information model. Thus integration effort and costs are minimized.

INTRODUCTION TO OPC UA

A result of recent progress in industrial controls is the standardization of the OPC UA (Open Platform Communications, Unified Architecture) protocol [2]. It differs significantly from it's predecessors by it's ability to not only transport machine data (such as control variables, measurements and parameters) but also describe them semantically in a machine-readable information model.

In the simplest case, the device-specific part of the OPC UA information model consists of named Variables, Objects and Methods, called *nodes*. The device-specific root node is a defined object, fittingly named *Objects*.

- ***Objects*** contain any number of variables, methods and/or other objects.
- ***Variables*** are either scalars or fixed-size arrays of a fixed type (e.g. 32-bit integer, float, string)
- ***Methods*** have zero or more input arguments as well as zero or more output arguments. The arguments are named and typed, similar to variables.

The OPC UA protocol follows a server-client communication model over TCP/IP. Clients can perform synchronous requests to read and write node values, i.e. get or set the value of a variable and call a method. Additionally, clients can subscribe to nodes to be asynchronously notified when a variable's value changes.

INTRODUCTION TO DOOCS

The DOOCS (Distributed Object-Oriented Control System) data model constists of named and typed *properties*. The type of a property can range from simple scalar values such as bits or floating point numbers, over arrays, up to arbitrarily complex data types, such as camera images with metadata.

Properties are organized into l*ocations*, where one location typically corresponds to one physical device. Each location and it's properties can be identified by their DOOCS addresses. Several locations can run alongside each other in a server process on a specific computer node.

The DOOCS protocol also follows the server-client model over TCP/IP. Clients can read or write the values of properties synchronously via “get” and “put” requests. Alternatively, clients can subscribe to properties, to receive asynchronous updates of the properties value via a “server push” messaging mechanism.

MAPPING OPC UA TO DOOCS

Although there are considerable similarities between the data and communication models of OPC UA and DOOCS, some aspects are incompatible and impose limitations to the bridging between the two protocols.

First, one DOOCS location connects to a single OPC UA server and exports the objects, variables and methods in a subset of it's data model as DOOCS properties. At the same time it is possible that several DOOCS locations connect to the same OPC UA server, mapping separate,

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RF HEAT LOAD COMPENSATION FOR THE EUROPEAN XFEL

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Abstract

The European XFEL is a 3.4km long X-ray Free Electron Laser. The accelerating structure consists of 96 cryo modules running at 1.3 GHz with 10 Hz repetition rate. The injector adds two modules running at 1.3 and 3.9 GHz respectively. The cryo modules are operated at 2 Kelvin. Cold compressors (CCs) pump down the Helium vapour to 30 mbar which corresponds to 2 Kelvin. Stable conditions in the cryogenic system are mandatory for successful accelerator operations. Pressure fluctuations at 2 K may cause detuning of cavities and could result in unstable CC operations. The RF losses in the cavities may be compensated by reducing the heater power in the liquid Helium baths of the nine cryogenic strings. This requires a stable readout of the current RF settings. The detailed signals are read out from several severs in the accelerator control system and then computed in the cryogenic control system for heater compensation. This paper will describe the commissioning on the cryogenic control system, the communication between the control systems involved and first results of machine operations with the heat loss compensation in place.

THE XFEL CRYOGENIC SYSTEM

The cryogenic system for the European XFEL [1] consists of two cold-boxes with the associated warm compressors. One cold cox is enough for cryogenic operations up to the desired operation point of 17.5 GeV in the linac. The cold-boxes were refurbished from the former hadron electron ring HERA. Both cold-boxes are connected by a distribution box which feeds a transfer line into the XFEL shaft. The four stage cold compressors are located in the shaft followed by a valve box from where the Helium is fed into the XFEL tunnel and the injector section.

COLD COMPRESSOR OPERATIONS

The cold compressor box is housing four cold compressors which are running in sequence. The pressure in the 2 Kelvin areas of the injector and the XFEL tunnel is pumped down to 30 mbar which corresponds to 2 Kelvin. The pressure rise from 28 mbar at the entry of the cold compressor box (CB44) to 1 bar at its outlet is necessary to feed the helium back into the cold-boxes of the cryo plant. Cold compressors are necessary to improve the total efficiency of the cryogenic process. There is one limiting factor in cold compressor operations which is the small operation range for the individual compressor stages. Small fluctuations on mass flow or temperature may move the operation point closer to the surge line. This could cause the compressors to trip and the whole system to stop.

To avoid such a dramatic consequence the cold compressors have been equipped with a sophisticated bypass line. This bypass together with the speed control of the cold compressors helps to keep the mass flow changes within certain margins.

RF OPERATIONS

The XFEL RF systems may be operated independently of the cryogenic system as long as the impact on the cryogenic system is limited to minimal values. This approach was used for commissioning the RF components at very low load.

As soon as the heat dissipated due to the dynamic load reached certain limits it will cause liquid helium in the helium bath of the cryo modules to evaporate at higher rates. This will cause the level to drop and the level control valve to open for more mass flow. These changes will result in changes in both the forward direction (~3K @ 1.5bar) and in the return flow (2K @ 30mbar)

In the end the total mass flow in the whole system will be increased. This change must be compensated by the control loops implemented in the cold compressor box. As described this compensation may only occur within certain limits before the cold compressors will trip. This is the first reason why a compensation of the dissipated heat into the cryo system should be implemented.

The second reason to compensate the heat load is the resulting pressure fluctuation in the 2 Kelvin regime of the cryo modules. These fluctuations may cause a detuning of the superconducting cavities in the modules. This would disturb RF and thus machine operations and must be avoided. So there are two good reasons to compensate the dynamic heat load into the cryogenic system.

HEAT LOAD COMPENSATION

Implementation

There are several ways to calculate the dissipated heat load into the cryo system:

1. Calculating the dissipated heat from the initial measurements of the individual cavities before theses got installed into the cryo modules.
2. Calculating the dissipated heat from the measurements of the individual modules (with eight cavities) before they got installed into the XFEL tunnel.
3. Calculating the dissipated heat from the measured RF and the boundary parameters of the cryogenic string.

The basic implementation in the XFEL case is version three (3) where version two (2) is used to cross check the results of three.

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ADVANCES IN AUTOMATIC PERFORMANCE OPTIMIZATION AT FERMI

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Abstract

Despite the large number of feedback loops running simultaneously at the FERMI Free Electron Laser (FEL), they are not sufficient to maintain the optimal working point in the long term, in particular when the machine is tuned in such a way to be more sensitive to drifts of the critical parameters. In order to guarantee the best machine performance, a novel software application which minimizes the shot-to-shot correlation between these critical parameters and the FEL radiation has been implemented. This application, which keeps transversally and longitudinally aligned the seed laser and the electron beam, contrary to many algorithms that inject noise in the system to be optimized, run transparently during the experiment beam times. In this paper we describe the status of the FERMI optimizers and present a newly developed method to calculate a FEL quality factor starting from the images provided by a photon energy spectrometer which tries to mimic the evaluation of machine physicists, as well as the first results obtained using two model-less algorithms to optimize the FEL performance through maximization of the quality factor.

INTRODUCTION

In a seeded FEL [1], the transverse (horizontal and vertical) and longitudinal (temporal) alignment between the electron bunches and the UV seed laser pulses is fundamental for the quality of the produced FEL photon beam in terms of intensity, pulse energy stability and spectral purity. In order to guarantee the alignment stability, a number of beam-based feedback loops [2] have been deployed over the years and very good results have been obtained in stabilizing the transverse coincidence between electrons and seed laser, which is now in the order of 10 uμ$_{rms}$. Moreover, continuous advances in the LLRF system of the linac RF plants and in the locking systems of the photo injector and seed lasers, have reduced the average fluctuations of the arrival time between electrons and the seed laser down to 150 fs in a time period of a few hours.

However, the FEL performance in the long term is still affected by a slow decay of the FEL intensity and a consequent increase of the shot-to-shot jitter (e.g., Fig. 1). This is mainly due to a loss of longitudinal and transverse superposition between the electron bunch and the seed laser pulse.

The main cause of the transverse drift is the seed laser pointing which is not completely controllable due to the technical difficulty to place diagnostics inside the undulators.

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The origin of longitudinal drifts is more difficult to ascribe to a particular system. The extreme sensitivity of the laser systems to temperature variations, which can affect the timing of the systems, small changes in the distribution of electron charge and energy in the bunches or drifts of the time of flight from the gun to the first bunch compressor are probably the main causes.

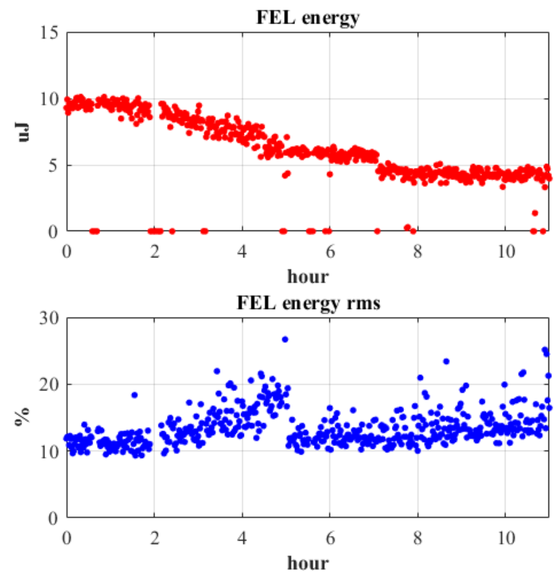

Figure 1: Typical decay of the FEL intensity and increase of the jitter in a time span of 11 hours. The jitter was reduced at the 5th hour by a manual re-optimization of the delay between the seed laser pulses and the electron bunches. The intensity could not be fully recovered because of an ongoing transverse misalignment of the two beams.

A more predictable case in which both the transverse and longitudinal alignment could be perturbed is when the seed laser wavelength (and consequently the FEL wavelength) is intentionally changed by the operators on request by the beamlines. The delay introduced by the Optical Parametric Amplifier (OPA) changes with the laser wavelength and a feed-forward loop implemented to compensate for this variation is not able to completely suppress the residual error. Moreover, by changing the wavelength, the pointing of the seed laser can be disturbed by a variation of shape and intensity of the laser spot measured on the CCD cameras, which affects the calculation of the centroids and induces the pointing feedback to an improper correction.

Before the deployment of correlation-based optimizers, no preventive actions were taken during the experiments to recover the machine performance and a re-optimization

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THE AUTOMATIC QUENCH ANALYSIS SOFTWARE FOR THE HIGH LUMINOSITY LHC MAGNETS EVALUATION AT CERN

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Abstract

The superconducting magnet test facility at CERN, (SM18), has been using the Automatic Quench Analysis (AQA) software to analyse the quench data during the Large Hadron Collider (LHC) magnet test campaign. This application was developed using LabVIEW™ in the early 2000's by the Measurement Test and Analysis section (MTA) at CERN. During the last few years, the SM18 has been upgraded for the High Luminosity LHC (HL-LHC) magnet prototypes. These HL-LHC magnets demand a high flexibility of the software. The new requirements were that the analysis algorithms should be open, allowing contributions from engineers and physicists with basic programming knowledge, execute automatically a large number of tests, generate reports and be maintainable by the MTA team. The paper contains the description, present status and future evolutions of the new AQA software that replaces the LabVIEW™ application.

INTRODUCTION

The superconducting magnet test facility at CERN, known as SM18, has been using the Automatic Quench Analysis (AQA) software to analyse the quench during the Large Hadron Collider (LHC) magnet test campaign [1]. Nowadays, the magnet test facility is being upgraded to test the High Luminosity LHC (HL-LHC) [2] magnet prototypes and AQA is not anymore compatible and not flexible enough for the multitude of future HL-LHC magnets.

This paper will describe the requirements, design and special features for the new AQA.

SOFTWARE REQUIREMENTS

The superconducting magnets of the LHC have been tested at the SM18 facility [3], and the results of the tests were analysed with the AQA tool. AQA is in turn integrated in another program known as Viewer, both developed in LabVIEW™ and available in the SM18 control system. The Viewer was specially designed to interpret and display the measurements from the collection of tailored binary files (for data) and ASCII files (for metadata) generated during the tests by the acquisition systems. Both tools were adapted specifically for the series of LHC magnet measurements, which now dates back to the early 2000's.

For the HL-LHC magnet prototypes tests [4] an upgrade of the SM18 analysis framework was required to ensure the flexibility in the analysis algorithms [5].

In the actual SM18 test facility, the upgraded data acquisition (DAQ) systems now produce TDMS (Technical Data Management Streaming) files, which are not compatible with the previous generation analysis tools.

A new tool has been developed, which also satisfies the main requirements covered by the previous tool:

- Automatic detection of the quench location and energy released by the quench.
- Analysis of quench heater signals.
- Computation of the electric current derivative and identification of the functions that fit the electric current profile.
- Analysis of the magnet superconducting coil voltage signals.

The additional requirements that provides the new software are:

- Flexibility to accept different magnet types
- Compatibility with the new TDMS file format adopted in the SM18.
- Arrangement of the signals in the TDMS file to help the users to navigate through the data
- Concatenation of the magnet signals acquired by the DAQ system at high and medium frequencies before analysing.
- Ability to pre-select the coils, signals and parameters to analyse: inductive and resistive voltage, resistivity and its derivative, temperature, resistance and inductance, and energy.
- Automatic detection of the quench location and ability to allow the user to verify this location and manually modify it by his criteria.

The results must be saved as a TDMS file, but the tool should also be able to create a PDF report that summarizes and clearly displays the results of the analysis.

The new tool should give the possibility to the mechanical engineers, not expert programmers, to implement custom analysis algorithms in a user friendly language.

Implementation

National Instruments (NI) DIAdem® was introduced, in 2013, into the SM18 software framework to visualize and analyse existing data that had been previously converted to TDMS [6]. This first step of renovation was aiming to replace the legacy viewer, by using a commercial application and developing a converter for the binary files. A second step related to the new DAQ, gave the possibility to get directly the output files into TDMS [7].

As the NI DIAdem® environment offered the possibility of creating Visual Basic Script (VBScript) code, the new AQA tool could be developed in this language, which is also a standard language of the SM18 mechanical engineers.

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RESEARCH ON FAULT DIAGNOSIS OF POWER SUPPLY CONTROL SYSTEM ON BEPCII*

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Abstract

The reliable and stable operation of the accelerator is the premise and foundation of physics experiments. For example, in the BEPCII, the fault of the magnet power supply front-end electronics devices may cause accelerator energy instability and even lead to beam loss. Therefore, it is very necessary to diagnose and locate the device fault accurately and rapidly, that will induce the high cost of the accelerator operation. Faults diagnosis can not only improve the safety and reliability of the equipment, but also effectively reduce the equipment's cycle costing. The multi-signal flow model [1] proposed by Pattipati K.R is considered as the preferred method of industrial equipment faults detection. However, there are still some problems about fault probability conflict in the processing of correlation matrix diagnosis due to the hierarchical nature of multi-signal flow modelling. Thus we develop the fault diagnosis strategy based on the important prior knowledge of the fault. This method is applied to the front-end electronic devices of BEPCII magnet power supply control system and improves the fault diagnosis and analysis ability of magnet power supply control system.

MULTI - SIGNAL FLOW GRAPH METHOD

The basic principle of magnet power supply front-end electronics system modelling is based on the idea of multiple signal flow dependencies. Multi-signal flow graph model is a hierarchical model you can directly see the impact of a fault mode of transmission to other modules. The multi-signal flow graph model does not need to establish the exact quantitative relationship of the system. It only needs to determine the important functional attributes of the system. Since the multi-signal flow graph model covers multiple information flow models, the model is closer to the physical structure of the system. In addition, the signals in the model are independent and will not influence each other. These features make the modelling of multi-signal flow graphs simple, and the integration and verification of the models are relatively simple too.

Testing model analysis firstly performs FMECA(Failure Mode, Effects and Criticism Analysis) to determine all possible fault mode of various components of the system during the designing and manufacturing process through system analysis, and the causes and effects of each fault mode. According to this, the function and structure of the UUT (Unit under Test) are divided, and the correlation graph model is established by using the available test points. Then, the first-order correlation is established, furthermore the D-matrix model (also called the diagnosis matrix or dependency matrix) is acquired. After establishing the D-matrix model, the test points can be calculated, and the diagnosis tree and the fault dictionary can be established. Then the generated diagnosis strategy can be used to predict the system's fault detection rate and fault isolation rate [2].

APPLICATION OF MULTI - SIGNAL MODEL IN FAULT DIAGNOSIS

Supposing the correlation matrix of the simplified multi-signal model D = [d_{ij}] ($1 \le i \le m, 1 \le j \le n$, where m and n denotes the totality of the source of failure and the set of testing respectively), $y=\{y_1, y_2, ..., y_m\}$ is the possible set of fault sources for the system, $T=\{t_1, t_2, ..., t_n\}$ is the set of testing. The essence of fault diagnosis is to find the most likely candidate set of faults ($X \subseteq Y$) based on the structure of multi-signal model. And it is consistent with the test results, with the formula described as :

$$\max_{X \subseteq Y} \Pr ob(X \mid T_p, T_f) . \tag{1}$$

In the above formula, Prob() represents probability function and T_p represents success and T_f represents fault during tests.

For the sake of description, we define a vector, $x=\{x_1, x_2, \ldots, x_m\}$, if $x_i=1$,that means $y_i \in X$; if $x_i=0$, that means $y_i \notin X$. After deleting the constant term $\Pr ob(T_p, T_f)$ according to the Bayesian theory, the question turns to find the max value of the formula below:

$$\Pr ob(T_p \mid X) \Pr ob(T_f \mid X) \Pr ob(X) \tag{2}$$

Among them,

$$\Pr ob(X) = \prod_{i=1}^{m} p(y_i)^{x_i} (1 - p(y_i))^{(1-x_i)} \tag{3}$$

According to [3] ,after negating the left and taking natural logarithm and then deleting the constant term, this problem can be converted to an optimal set covering problem (SCP) :

$$\frac{\min}{X \subseteq Y^-} \left(\sum_{y_i \subseteq Y^-} c_i x_i \right) \tag{4}$$

Where Y^- is the set of the source of failure which excluded the normal components. The restriction is : $D_x \ge e$,

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BDN NSLS-II PROJECT STATUS: HOW TO RECYCLE A SYNCHROTRON?*

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Figure 1: Components of NSLS X15B being moved to NSLS-II 8-BM. From left to right: focusing mirror, monochromator, vertically collimating mirror, beam-defining slits.

Abstract

With many synchrotron facilities retiring or going through upgrades, what is the future of some of the state-of-the-art equipment and the beamlines built for a specific science at these older facilities? Can the past investments continue supporting the current scientific mission?

The Beamlines Developed by NSLS-II (BDN), former NxtGen project, are reusing scientifically valuable equipment recovered from the now shuttered NSLS. For example TES(8-BM) reported 2um x 3um beam size achieved with reclaimed KB mirrors [1].

This paper describes new, reused, adapted and modified instruments, which NSLS beamlines they came from, as well as their integration into the new NSLS-II control system.

Many popular NSLS programs and custom-built equipment developed for them are welcoming old and new users in NSLS-II.

INRODUCTION

Every facility puts efforts into minimize maintenance by standardizing common infrastructure and utilities. All BDN beamlines received the following new standardized equipment: photon shutters, vacuum gauges and controllers, Beam Intensity (BI) Monitoring equipment, CCDs and surveillance cameras, network and computing infrastructure, Personnel Protection System (PPS) and Equipment Protection System (EPS). Most of the beamlines received new optic for the mirrors, while reusing vacuum chambers and motorized positioning systems. Some mirrors were reused, as well as end station equipment. Fig. 1 shows X15B instruments being moved to NSLS2.

BDN is home for instruments developed by scientific non-commercial groups. CMS(11-BM), TES(8-BM), and XFM (4-BM) use KB-mirrors, designed by the Center for Advanced Radiation Sources (CARS) at the University of Chicago [1]. In-house developed electrometer by P. Siddons was used in many beam diagnostic solutions at all BDN beamlines. This design is now sold commercially [2].

All beamlines reused ion pumps and ion pump controllers, gate valves, bellows, viewports and more, wherever it was suitable, with some beamlines building mostly from recovered components.

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PROCEDURES OF SOFTWARE INTEGRATION TEST AND RELEASE FOR ASTRI SST-2M PROTOTYPE PROPOSED FOR THE CHERENKOV TELESCOPE ARRAY

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Abstract

The Cherenkov Telescope Array (CTA) project is an international initiative to build a next generation ground-based observatory for very high energy gamma-rays. Three classes of telescopes with different mirror size will be located in the northern and southern hemispheres. The ASTRI mini-array of CTA preproduction is one of the small sized telescopes mini-arrays proposed to be installed at the CTA southern site. The ASTRI mini-array will consist of nine units based on the end-to-end ASTRI SST-2M prototype already installed on Mt. Etna (Italy). The mini-array software system (MASS) supports the end to end ASTRI SST-2M prototype and mini-array operations. The ASTRI software integration team defined the procedures to perform effectively the integration test and release activities. The developer has to properly use the repository tree and branches according to the development status. We require that the software includes also specific sections for automated tests and that the software is well tested (in simulated and real system) before any release. Here we present the method adopted to release the first MASS version to support the ASTRI SST-2M prototype test and operation activities.

INTRODUCTION

The Italian National Institute for Astrophysics (INAF) is leading the ASTRI project [1] proposed for the ambitious Cherenkov Telescope Array (CTA) [2]. In the framework of the small size class of telescopes, a first step of the ASTRI project is the realization of an end-to-end prototype in a dual mirror configuration (SST-2M) [3] with the camera at the focal plane composed of a matrix of silicon photo sensors managed by innovative front-end and back-end electronics [4]. The ASTRI SST-2M prototype is installed in Italy at the INAF "M.G. Fracastoro" observing station located at Serra La Nave, 1753 m a.s.l. on Mount Etna, Sicily [5]. As a second step, as part of the early CTA southern site, the project includes the implementation of the ASTRI mini-array [6] composed of nine ASTRI telescopes. The ASTRI SST-2M prototype has been earlier verified and tested with the engineering software released in beta version. Later on we defined a software integration method to support the integration test and software release activities for the next software version [7]. We are adopting an iterative incremental approach for the development of the software, then we foresee many other software releases before to publish a stable software version which fulfils the whole ASTRI system requirements. In addition we plan to use this method also during the maintenance activities such as debugging and implementation of new functionalities. Figure 1 depicts the whole ASTRI software [8]. The Archive & Data Analysis System runs off site. It provides the management of permanent archive, the data analysis, the proposal management and the tools to access data and proposal [9]. The Observatory Control System (OCS) provides the graphic user interface (also for engineering purposes) for the management of the whole on site system. The resource manager is responsible to start up and monitor the resources in order to minimize any resource fault. The Logger stores continuously the system status; the OCS MASTER monitors and controls the operations. The Observatory Control System uses the on site repository through the TMCDB (the database for the software configurations and the monitor points), the Data Capturer (to support the on site analysis) and the DAQ (Data AcQuisition system) which archives the science data received from the camera server. The Device Control, used also by the Observatory Control System, has in charge the telescope and the ICT (Information and Communication Technologies). This software (written in high level programming such as C++, Java or Python) is built within the ACS (Alma Common Software) framework [10]. The Device Control components interact with the device firmware through OPC-UA [11] and with other ACS component through the ACS services. The camera server which deploys the DAQ software acquires the bulk data from the

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AUTOMATION OF THE SOFTWARE PRODUCTION PROCESS FOR MULTIPLE CRYOGENIC CONTROL APPLICATIONS

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Abstract

The development of process control systems for the cryogenic infrastructure at CERN is based on an automatic software generation approach. The overall complexity of the systems, their frequent evolution as well as the extensive use of databases, repositories, commercial engineering software and CERN frameworks have led to further efforts towards improving the existing automation based software production methodology.

A large number of process control system upgrades have been successfully performed for the Cryogenics in the LHC accelerator, applying the Continuous Integration practice integrating all software production tasks, tools and technologies. The production and maintenance of the control software for multiple cryogenic applications have become more reliable while significantly reducing the required time and effort. This concept has become a guideline for development of process control software for new cryogenic systems at CERN.

This publication presents the software production methodology, as well as the summary of several years of experience with the enhanced automated control software production, already implemented for the Cryogenics of the LHC accelerator and the CERN cryogenic test facilities.

INTRODUCTION

Cryogenic systems, an integral part of the infrastructure of the most important accelerators and experimental facilities at CERN, require complex industrial process control systems for operation. Their large scale and evolving requirements, functional (change requests) and environmental (updated control software components), are big challenges for developers, who have to produce error-free, robust and safe control system software.

From the very beginning the large scale of the control system for the Cryogenics of the LHC accelerator forced the use of automatic code production in the development process. The existing CERN code generation tools were adapted to cover the requirements of the control system for the Cryogenics of the LHC, which became fully operational for the first time in 2008. Experience after months of operation led to a review and optimization of the process functional analysis [1]. As a result the second major release was successfully deployed in 2010, ensuring the operability of the cryogenic infrastructure during the first run of the LHC accelerator.

The amount of changes to implement during the LHC's Long Shutdown 1 (LS1), a 2-year consolidation and maintenance work period (2013 - 2015), using the UNIfied COntrol System (UNICOS)-based complex and time-consuming software development process triggered work towards further improvements and more complete automation of some parts of the process, i.e. the software building and testing [2]. Introducing the Continuous Integration (CI) methodology to the development of the software for the LHC accelerator allowed to enter the second run of the LHC with a very reliable control system software, and with significantly improved and more efficient development process, allowing to address any modifications much safer and faster than before. Both have contributed to improving of the overall reliability and availability of the Cryogenics [3], what was especially important while facing new challenges with the beams of higher luminosity in the LHC accelerator [4].

The experiences in development and the use of the first version of the CI system along with new requirements and new projects led to further evolution of the CI system for control system software of the Cryogenics. These new developments and their applications are discussed below.

THE CONTINUOUS INTEGRATION SERVICE FOR THE CONTROL SYSTEM SOFTWARE FOR THE CRYOGENICS OF THE LHC TUNNEL

Building software for large-scale control system applications would be very difficult, if not impossible, without specialized tools facilitating the process. Automated code generation have been used in development of control system applications at CERN since many years [5]. The UNICOS framework with its Continuous Process Control package (UNICOS CPC, UCPC) is a standard for building programmable logic controller (PLC) based applications at CERN and other laboratories [6]. The framework, by providing a library of generic device types, a methodology and a toolset to design and implement industrial control applications [7], simplifies and unifies the way control system software is implemented. The architecture, the communication layer, the main data structures, the execution flow of the control applications and also development workflow is the same for all the projects and varies only in very project-specific areas.

Still, even using the framework, for very large scale control systems producing control system software is a complex and long process, requiring many time-consuming steps to be performed manually by the developer. During the LS1 it became clear that in the case of the control system for the Cryogenics of the LHC accelerator, the largest cryogenic system at CERN (and in the world), it would be very difficult to rebuild reliably the software implementing all required modifications without further automation of the pro-

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SOLEIL AND SYMETRIE COMPANY COLLABORATE TO BUILD TANGO READY IN-VACUUM DIFFRACTOMETER

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Abstract

Two years ago, SOLEIL (France) and MAXIV (Sweden) [1] synchrotron light sources started a joint project to partially fund two similar in-vacuum diffractometers to be installed at the tender X-ray beamlines SIRIUS and FemtoMAX. SOLEIL diffractometer, manufactured by the French company SYMETRIE and complementarily funded by an Ile-de-France region project (DIM Oxymore) [2] gathering SIRIUS beamline and other laboratories, features an in-vacuum 4-circle goniometer and two hexapods. The first hexapod (out of vacuum) is used for the alignment of the vacuum vessel and the second one (in vacuum) for the alignment of the sample stage which is mounted on the 4-circle diffractometer (Figure 1).

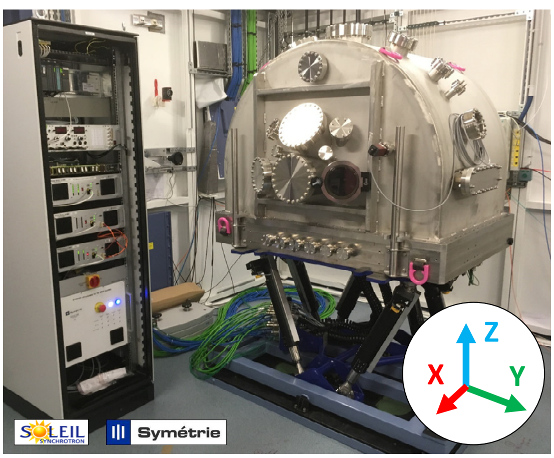

Figure 1: In vacuum diffractometer installed in the SIRIUS beamline experimental hutch with its electronics rack

In order to efficiently integrate this complex experimental station into SOLEIL control architecture (based on TANGO [3] and DELTA TAU [4] motion controller), SOLEIL and SYMETRIE [5] have worked in a close collaboration. SYMETRIE used SOLEIL developments and added to it its expertise in hexapods, motion control, and metrology. Multi-axial synchronization in the diffractometer subsystems is a key issue in this work and also opens up future possibilities in terms of improvement of the sphere of confusion thanks to corrections done by the sample stage alignment hexapod. This paper details the organization of this collaboration on the electronic and software control system.

A detailed description of the instrument mechanics, geometry and scientific applications will be the subject of a future work.

SIRIUS BEAMLINE DIFFRACTOMETER

SIRIUS takes advantage of the best energy range of the SOLEIL synchrotron ring between 1.2 and 13 keV in order to provide a tool for structural study to several communities of condensed matter.

The beamline, mounted on an HU36 undulator source and provided with two monochromators, is suitable of performing different x-ray characterization techniques such as: grazing incidence x-ray diffraction (GIXRD), small angle scattering (GISAXS) at fixed energy, and anomalous x-ray diffraction (AXD) and spectroscopies (XAFS, DAFS) in energy scans [6, 7].

Until 2015, the beamline has been equipped with two endstations (six-axis tower and kappa-head diffractometers) for hard x-ray studies of soft and hard condensed matter, respectively. However, no proper in vacuum instrumentation for fully exploiting the lower energy range of the undulator spectrum was available. The in-vacuum diffractometer project was thought to fill this lack. In fact, there is a great interest in performing resonant diffraction studies in the tender x-ray range, where the absorption edges of several chemical elements are located. These elements are common constituents of advanced materials used for technological applications such as functional oxides, III-V semiconductors and light metallic alloys.

The diffractometer is composed of three motion subsystems: The JORAN hexapod at the bottom (carries the system with the vacuum vessel), and a 4-circle in-vacuum diffractometer which is itself equipped on one of its circles of a with an in-vacuum BORA hexapod. The JORAN hexapod is used to align the center of the diffractometer according to the x-ray beam in the vertical (Z) and transverse (X) directions. It is also used as a 5th circle along the vertical (Rz-axis) which is synchronously moved with the 4-circles diffractometer. The BORA hexapod aligns the sample stage.

CONTROL REQUIREMENT

SOLEIL Motion Interface for TANGO Architecture

The diffractometer control is implemented with respect of the architecture defined in the so-called REVOLUTION project [8]. It is based on the DELTA

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SOFTWARE QUALITY ASSURANCE FOR THE DANIEL K. INOUYE SOLAR TELESCOPE CONTROL SOFTWARE

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Abstract

The Daniel K. Inouye Solar Telescope (DKIST) is currently under construction in Hawaii. The telescope control system comprises a significant number of subsystems to coordinate the operation of the telescope and its instruments. Integrating delivered subsystems into the control framework and managing existing subsystem versions requires careful management, including processes that provide confidence in the current operational state of the whole control system. Continuous software Quality Assurance provides test metrics on these systems using a Testing Automation Framework (TAF), which provides system and assembly test capabilities to ensure that software and control requirements are met. This paper discusses the requirements for a Quality Assurance program and the implementation of the TAF to execute it.

INTRODUCTION

During the software conceptual design phase DKIST elected to use a Common Services model as a basis for the standard distributed software infrastructure used to build the control subsystems. The Common Services Framework (CSF) was developed as a result of this decision, providing a standard framework supported in three programming languages (Java, C++ and Python) [1]. The framework offers many features including deployment support, communications support, persistence support, as well as application support and a broad library of additional tools. All of the DKIST control software subsystems are built using the CSF. Figure 1 shows a block-representation of the layout of the CSF. This infrastructure software, and the software required to control a large telescope such as DKIST presents developers and maintainers with a substantial level of testing needed to ensure the quality of the software remains at a satisfactory level throughout the lifetime of the project.

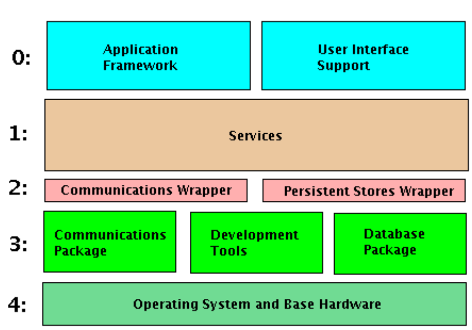

Figure 1: Layout of Common Services Framework.

DEVELOPMENT AND TEST SET-UP

The DKIST project offices in Tucson, Arizona and Boulder, Colorado have been equipped with the necessary control hardware to be capable of running the entire control software stack. This includes the required network infrastructure, Data Handling System (DHS) servers, CSF servers, an operator's station, 4k monitors and network hub [2]. The hub is provided for future expansion. This hardware installation is called the End To End (E2E) simulator. Every subsystem accepted by DKIST must be delivered with the ability to simulate all hardware at the interface level. This requirement allows the development team to run the simulated subsystem within the E2E environment. It is possible to run all of the subsystems together natively on the hardware, or spawn virtual machines to execute a subsystem in isolation. A network of virtual machines can be spawned to verify messaging and database logging across operating system and software versions. The virtual machines are created and executed using the VMWare commercial product VMWare Workstation [3]. VMWare has been developed for more than 15 years and aims to provide the most stable and secure local desktop virtualization platform in the industry. The E2E rack and operator's basic layout is shown in Figure 2. The rack shows the required network infrastructure, DHS, and CSF servers. The operator's station is shown with its two 4k monitors, desktop, and network hub. The instrument operator's position is shown with its Quality Assurance computer and 2 HD monitors. Figure 3 is a screen shot taken from the two 4k monitors with the subsystems and simulators running, and has a photo of the server rack overlaid in the top right hand corner.

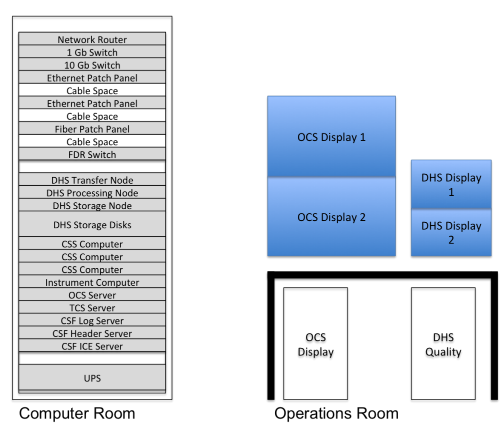

Figure 2: End to End hardware schematic.

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A NEW DISTRIBUTED CONTROL SYSTEM FOR THE CONSOLIDATION OF THE CERN TERTIARY INFRASTRUCTURES

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Abstract

The operation of the CERN tertiary infrastructures is carried out via a series of control systems distributed over the two main CERN sites (Meyrin and Prevessin). The scope comprises: ~260 buildings, *2 large heating plants (~50 MW overall capacity) with 27 km district heating network and 200 radiators circuits, ~500 air handling units, ~52 chillers, ~ 300 split systems, ~ 3000 electric distribution boards and ~ 100 000 light points.*

In the last five years and with the launch of major tertiary infrastructure consolidations, CERN is carrying out a migration and an extension of the old control systems dated back to the 70's, 80's and 90's to a new simplified, yet innovative, distributed control system aimed at minimizing the programming and implementation effort, standardizing equipment and methods and reducing lifecycle costs. This new methodology allows for a rapid development and simplified integration of the new controlled building/infrastructure processes.

The basic principle is based on open standards PLC technology that allows to easily interface to a large range of proprietary systems. The local and remote operation and monitoring is carried out seamlessly with Web HMIs that can be accessed via PC, touchpads or mobile devices.

This paper reports on the progress and future challenges of this new control system.

INTRODUCTION

CERN has a large infrastructure of buildings. Most of these are more than 40 years old (see Figure 1). In particular, a large set of buildings (260) are dedicated to tertiary functions. These functions are quite heterogeneous ranging from offices, workshops and warehouse, 2 large heating plants (~50 MW overall capacity) with 27 km district heating network and 200 radiators circuit to 3 restaurants, 3 hotels and a kindergarten.

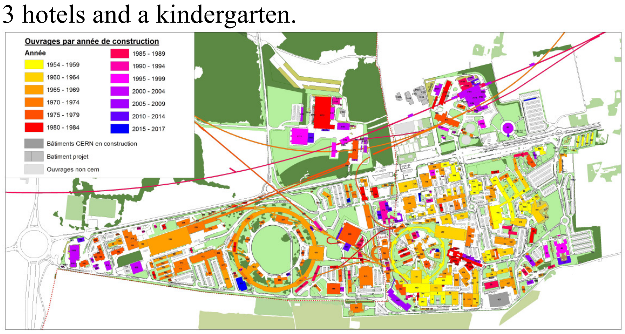

Figure 1: CERN buildings ages in Meyrin.

Throughout the years, different generations of building automation systems have been installed. These systems monitor and control building functions for the heating, cooling, ventilation, air conditioning, chillers, lighting, shading and, in general, functions aiming at optimizing energy usage and building operation and maintenance.

Given the age, some of these installations require substantial refurbishment: at CERN, this programme goes under the name of consolidation. The term "consolidation of infrastructure" identifies the main elements in the buildings and tertiary systems that needed to be refurbished, to be renovated or to undergo a large maintenance intervention. In addition, CERN has embraced the concept that a building doesn't have to be new to be smart and has taken the opportunity when renovating systems to incorporate smart building capabilities. This step-by-step process allows to develop the new smart capabilities along with the improvement of the building infrastructure.

Since early 2009 and as part of the consolidation of the infrastructure, a novel methodology has been applied for the development and the integration of the new controlled building/infrastructure processes. This paper is organised as follows: first, an overview of the methodology is described, second, the basic principles of the new distributed control system dedicated to the tertiary infrastructure is presented. Then, examples of installations deployed in the last five years are presented. Finally, the paper concludes with the most important ideas and future work

METHODOLOGY

In order to fully understand the reasons behind the methodology, it is important to provide some elements to contextualize the motivations:

1. the old systems were built over the years through international call for tenders leading to a large number of heterogeneous manufacturers and architectures;
2. the old systems were built without a remote control and were rarely upgraded with such functions;
3. the local control functions were not networked to improve energy building performances.

In addition to the context, the following facts should also be taken into account:

4. the replacement of the old control systems should allow interfacing with different system manufacturers;
5. new process equipment come with various standard interfaces (not always the same);
6. most of the work on the building control systems is typically subcontracted;
7. there was no interconnection between heating, cooling, lighting and, in general, among various building control functions;
8. the physical distribution of the building.

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NEW CONTROL SYSTEM FOR LAPECR2*

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Abstract

Lanzhou All Permanent magnet ECR ion source No.2 (LAPECR2) is the ion source for 320 kV multidiscipline research platform for highly charged ions. Its old control system has been used for nearly 12 years and some problems have been gradually exposed and affected its daily operation. A set of PLC from Beckhoff company is in charge of the control of magnet power supplies, diagnostics and motion control. EPICS and Control System Studio (CSS) as well other packages are used in this facility as the control software toolkit. Based on these state-of-the-art technologies on both hardware and software, this paper designed and implemented a new control system for LAPECR2. After about half a year of running, the new control reflects its validity and stability in this facility.

INTRODUCTION

Since built around the year of 2005, 320 kV multi-discipline research platform for highly charged ions has successfully produced and delivered ion beams with kinetic energy from several keV to MeV for many experiments such as ion-atoms/molecular collision, ion-surface interactions, low energy astrophysics [1], etc. Its operational time can amount up to 6500 hours per year. The 320 kV multi-discipline research platform for highly charged ions consists of the Lanzhou All Permanent magnet ECR ion source No.2 (LAPECR2) [2] located on 320 kV high voltage platform, an electrostatic accelerating tube, beamline and 6 experimental terminals.

After almost 12 years in operation, many problems of its old control system were gradually exposed such as the ever worse stability and reliability, high failure, poor maintainability and so on which affected heavily the daily operation of 320 kV research platform. Besides, the old control system is difficult to extend or change when the controlled devices are changed. Under this context, a plan to design and implement a new control system was proposed in 2016. The concrete goal of this plan is to design and implement a new control system for the ion source (LAPECR2) and beamline as well as experimental terminals.

In this paper, we report design and implementation of the new control system for Lanzhou All Permanent magnet ECR ion source No.2 (LAPECR2). Firstly, the structure of LAPECR2 is described briefly and control requirements are analyzed following. Secondly, design and implementation of the new control system are explained in detail. Finally, summary and future work are outlined.

LAPECR2 OVERVIEW AND CONTROL REQUIREMENTS

LAPECR2 was operated at 14.5GHz. By injecting microwave of proper power level and raw materials into vacuum chamber under appropriate magnetic field, the ions of plasma are generated. In order to extract ion beams from plasma, an electrical potential difference is needed. The max extraction high voltage is 15kV. The plasma chamber and some equipment needed to generate ion beams must be placed on high potential to enable effective extraction. After plasma is generated, a serial of measures are taken to achieve high quality ion beams. A solenoid located next to plasma chamber is used for ion beams focusing. LAPECR2 can produce multiple charge states for a given nuclide, whereas it only needs to provide a particular charge state according to a certain experiment. After strong focusing, ion beams are delivered to a 90° double focusing bending magnet, which is utilized to select the ion beam of specific charge state of the given nuclide according to the final application. Following the bending magnet are a pair of steering magnets. Following the steering magnets is a faraday cup. Next to the diagnostics is an einzel lens used to focus ion beams further. Downstream the einzel lens, there is an electric static accelerating tube. The accelerating voltage can reach up to 320kV. The mentioned equipment are all located on a high voltage platform as shown in Figure.1

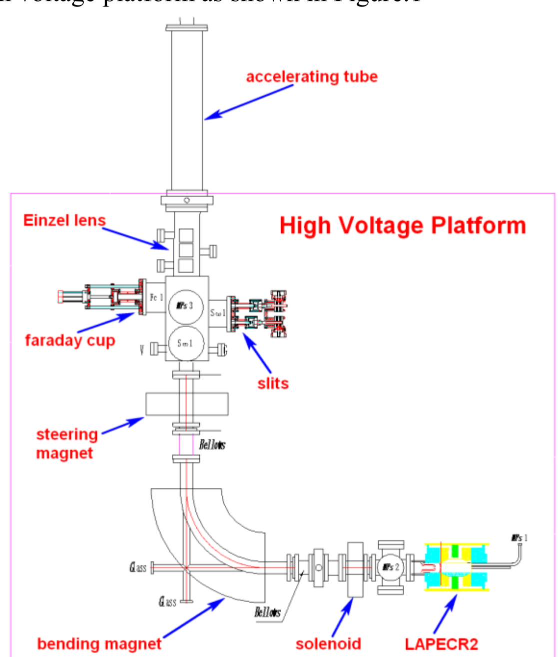

Figure 1: Layout of 320 kV high voltage platform.

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ACCELERATOR FAULT TRACKING AT CERN

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Abstract

CERN's Accelerator Fault Tracking (AFT) system aims to facilitate answering questions like: "Why are we not doing physics when we should be?" and "What can we do to increase machine availability?"

People have tracked faults for many years, using numerous, diverse, distributed and un-related systems. As a result, and despite a lot of effort, it has been difficult to get a clear and consistent overview of what is going on, where the problems are, how long they last for, and what is the impact. This is particularly true for the LHC, where faults may induce long recovery times after being fixed.

The AFT project was launched in February 2014 as a collaboration between the Controls and Operations groups with stakeholders from the LHC Availability Working Group (AWG).

The AFT system has been used successfully in operation for LHC since 2015, yielding a lot of interest and generating a growing user community. In 2017 the scope has been extended to cover the entire Injector Complex.

This paper will describe the AFT system and the way it is used in terms of architecture, features, user communities, workflows and added value for the organisation.

INTRODUCTION

People at CERN have tracked faults for many years, using numerous diverse, distributed and un-related systems. As a result, and despite a lot of effort, it was difficult to get a clear and consistent overview of what is going on, where the problems are, how long they last for, and what is the impact. This is particularly true for the LHC, where faults may induce long recovery times after being fixed.

In February 2014, CERN's Beams Department launched the Accelerator Fault Tracking (AFT) project as collaboration between the Controls and Operations groups with key stakeholders from the LHC Availability Working Group (AWG).

The project was initially divided into 3 phases, with the 1st phase completed ahead of the LHC restart (post Long Shutdown 1: 2013-2014) and delivering the means to achieve consistent and coherent data capture for LHC, from an operational perspective. Phase 2 of the project was in progress during 2015-16 working on detailed fault classification and facilitating analysis for equipment groups. Phase 3 (still pending) foresees extended integration with other systems e.g. asset management tracking to be able to make predictive failure analysis and plan preventive maintenance operations.

Due to the success of AFT for LHC during 2015, in 2016 CERN's Machine Advisory Committee proposed that AFT be used for CERN's Injector Complex. As such, work started in late 2016 to prepare AFT for use in the Injector Complex for the start of operation in April 2017. Since then, work has been on-going to further refine the system to cater for additional injector-specific needs and adapt to emerging requirements.

AFT SYSTEM

The AFT system aims to facilitate answering questions like: "Why are we not doing physics when we should be?" and "What can we do to increase machine availability?" To support this, AFT needs to provide the means to consistently and coherently capture details of faults and other events impacting machine availability (e.g. beam-related effects) together with the tools to visualize, analyze and extract the data.

Architecture

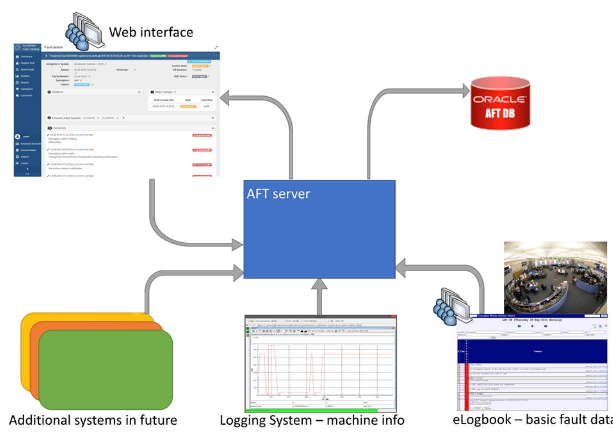

Figure 1: High-level AFT system architecture.

Figure 1 shows the distributed nature of the AFT system. At the core is a Java server, based on Spring Boot, which provides the necessary business logic and the means to both write and read back data. Certain functionality is exposed via RMI for use in CERN's Electronic Logbook, which has been adapted to allow operators to enter basic fault data that is sent directly to AFT where it is persisted in a relational database. This is the primary means of initial fault data capture. The AFT server also exposes methods to read and write data via REST. For the time being, the REST API is only used by the AFT Web application, which allows any authenticated user to consult the fault data, related statistics and graphical displays of historical data. The AFT Web application also allows authorized system experts to complete the details of faults assigned to their systems, while AWG members are able to define relations between faults (e.g. parent and child or blocking). The Web application is written in TypeScript and developed using the AngularJS framework. Authentication and row-level

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BOOSTER RF UPGRADE FOR SPEAR3*

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Abstract

SLAC's Stanford Positron Electron Asymmetric Ring (SPEAR3) Booster Radio Frequency (RF) system was recently upgraded where the existing klystron providing RF power to a 5-cell cavity was replaced with a Solid State Amplifier (SSA) [1]. The Low Level Radio Frequency (LLRF) Controls to drive the SSA was provided by a high performance Field-Programmable Gate Array (FPGA) based system built on SLAC's Advanced Telecommunications Computing Architecture (ATCA) modules. RF Cavity Tuner Controls were replaced with EtherCAT-based stepper motor controller. New hardware was designed and built for programmable logic controller *(*PLC*)* based Machine Protection System (MPS). Fast digitizers to sample and acquire LLRF signals were implemented in a LinuxRT Server. All of these required new controls software implementation. This paper describes the controls associated with each of the above hardware upgrades.

BOOSTER RF UPGRADE CONTROLS SYSTEM

The controls layout of the upgraded Booster RF system is shown in Figure 3. The main components are the Experimental Physics and Industrial Control System (EPICS) Input/Output Controller (IOC) controls for the SSA, ATCA, PLC MPS, Booster RF Cavity Tuner and the PCIe Digitizer. Each of these is described below.

EPICS IOCS

The software controls for all the new hardware described above are via EPICS Soft IOCs running either on a Linux or LinuxRT (Real Time Linux) Server. All IOCs provide the following generic functions:

- Alarm setup capabilities and alarm handling notifications.
- EPICS Process Variable (PV) archival for History plots.
- Save/restore values on IOC boot up.
- Monitoring of processor load, memory usage and IOC heartbeats.
- Extensible Display Manager (EDM) display panels for operator control.
- Message logging.

In addition, each IOC provides functions specific to the hardware to which it interfaces.

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SSA CONTROLS

The EPICS Soft IOC for SSA controls provides the following functions:

- Control of the SSA over the EPICS Channel Access (CA) network. This includes SSA ON/OFF, set operating mode to either Continuous Wave (CW) or Pulse mode, RF Operate or Standby mode, set DC Power Supply output voltage levels, enable/disable individual power supplies.
- 10 Hz Digital and Analog status updates of the SSA.
- SSA Internal and External Fault detection and Fault Reset capabilities.
- Read SSA Error Codes and provide appropriate alarms.

SSA IOC

The IOC interfaces with the SSA via the MODBUS protocol based network device. MODBUS is an application layer Messaging protocol in OSI model based on Client-Server communication. The Server in SSA's Main Controller Unit (MCU) supports MODBUS communications via on-board embedded Ethernet network device. The EPICS Soft IOC is the Modbus Client and runs on a Linux Server. The MODBUS communication protocol is over TCP/IP and uses the standard port 502. During development, "modpoll" application which is a MODBUS test utility was used for in-house SSA testing and Factory Acceptance tests. EPICS support MODBUS within the "Asyn" framework [2]. The application for the Soft IOC uses this Asyn based EPICS Module "modbus".

MODBUS supports several Data Types. The SSA uses only the 'Single bit' and '16-bit Register' Data Types. The communication between the Client (IOC) and the Server (SSA) consists of Request Messages sent from the IOC to the SSA and Response Messages received from the SSA by the IOC. The Request Message reads from or writes to 16-bit Modbus addresses defined by the SSA. The data transfer type is described as an 8-bit MODBUS function. EPICS MODBUS supports eight function codes of which the SSA uses only two function codes:

- Function Code 3: Read 16-bit SSA Registers
- Function Code 6: Write 16-bit SSA Registers

SSA Modbus I/O addresses are contiguous 16-bit Registers and begin from address 1. Spear3 Booster RF IOC currently has access to slightly over 400 SSA addresses. Each EPICS MODBUS Read operation is limited to transferring 125 16-bit words at a time. Write operations are limited to transferring 123 16-bit words. SSA responds to every Read or Write Request Messages from the IOC with a Response Message containing valid

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OVERVIEW OF THE GANIL CONTROL SYSTEMS FOR THE DIFFERENT PROJECTS AROUND THE FACILITY

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Abstract

The Ganil facility is drastically extending its possibilities with new projects, so increasing its capabilities in nuclear physics. The most significant one is the Spiral2 installation based on a linear accelerator, then to be associated with the S3, NFS and DESIR new experimental rooms. Beside of the legacy homemade control system handling the original installation, Epics was chosen as the basic framework for these projects. First, some control system components were used during preliminary beam tests. In parallel, the whole architecture was designed while the organization for future operation started to be considered; also, more structured and sophisticated tools were developed and the first high level applications for the whole machine tuning started to be tested, jointly with the current onsite beam commissioning.

Progression of the control system development is presented, from the first beam tests up to the whole Spiral2 commissioning. Then, according to the new projects to cope with, some highlights are given concerning the related organization as well as specific items and developments to be considered, taking benefit from the Spiral2 control system feedback experience.

OVERVIEW OF THE GANIL FACILITY...

The Ganil ("Grand Accélérateur National d'Ions Lourds") facility has quite yet a long history as the first beam was delivered to physicists in January 1983. It's a heavy ions accelerator complex devoted to nuclear and atomic physics, astrophysics, material science and radiobiology. The original installation consisted of several cyclotrons in cascade for accelerating the beam and, in 2001, was enhanced by the Spiral ("Système de production d'Ions Radioactifs Accélérés en Ligne") extension so that both stable and radioactive beams were able to be produced (see Figure 1).

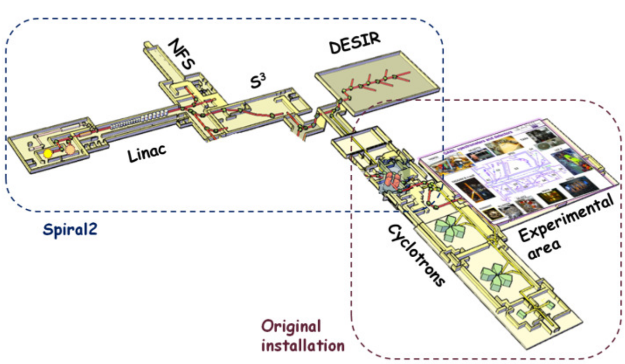

Figure 1: The Ganil facility.

In order to extend to increase the range and quality of exotic nuclei to be delivered, the Spiral2 project was approved in May 2005 [1] and is presently within the commissioning phase [2]. It is based on a superconducting linac delivering up to 5 mA proton or deuteron beams or 1 mA q/a>1/3 ions beams. The project also includes the experimental rooms named S3 ("Super Separator Spectrometer") and NFS ("Neutrons For Science") and, as a continuation, the low energy RIB experimental hall DESIR ("Desintegration, Excitation and Storage of Radioactive Ions").

... AND ITS CONTROL SYSTEMS

As well as the machine itself, control systems strongly evaluate according with time and emerging technologies but always having to take into account the existing solutions.

The initial control system was based on Camac serial loops and parallel branches handled by a minicomputer (specific language for programming) and local microprocessors (assembly language). In 1993, a major evolution replaced the Camac serial controllers by RTVAX/VaxELN CPUs linked through an Ethernet network integrating Vax/VMS machines. The Ada programming was used at every control system layer so all the software had to be rewritten while most of the hardware interfaces remained unchanged. In 1996, was introduced the VME standard with RTVAX/VaxELN CPUs then from 1998 by PowerPC/VxWorks CPUs, both still programmed in Ada. The last important evolution of the original Ganil installation control system was the migration from VMS servers to Linux ones in 2003. After two generations for the hardware servers organised as a cluster group, the last migration consisted this year of setting the servers into virtualized machines (Proxmox solution).

When the Spiral2 project started, many reflexions were carried out for the solution to be considered for the control system to be provided, so provoking many and strong debates. Even if the Ganil control system was functioning pretty well in a robust way, it was decided in 2006 to base the future control system upon a solution widely used among many laboratories, so allowing sharing developments and solutions and being within an opened environment. Epics was therefore chosen to be the basic framework for the control system. Is was decided nevertheless that the future Spiral2 control system would share the same central servers as the original installation control one; the VME standard was kept both for having the same hardware solution and minimizing human resources for implementation. At the same time, the aim was to ease the

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OPTIMIZED CALCULATION OF TIMING FOR PARALLEL BEAM OPERATION AT THE FAIR ACCELERATOR COMPLEX

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Abstract

For the new FAIR accelerator complex at GSI the settings management system LSA is used. It is developed in collaboration with CERN and until now it is executed strictly serial. Nowadays the performance gain of single core processors have nearly stagnated and multicore processors dominate the market. This evolution forces software projects to make use of the parallel hardware to increase their performance. In this thesis LSA is analyzed and parallelized using different parallelization patterns like task and loop parallelization. The most common case of user interaction is to change specific settings so that the accelerator performs at its best. For each changed setting, LSA needs to calculate all child settings of the parameter hierarchy. To maximize the speedup of the calculations, they are also optimized sequentially. The used data structures and algorithms are reviewed to ensure minimal resource usage and maximal compatibility with parallel execution. The overall goal of this thesis is to speed up the calculations so that the results can be shown in an user interface with nearly no noticeable latency.

MOTIVATION

To allow the commissioning and operation of the Facility for Antiproton and Ion Research (FAIR), the software used today has to be optimized. The CRYRING (YR), with its local injector, acts as a test facility for the new control system and in particular for the control systems' central component, the settings management system LHC Software Architecture (LSA) [1]. For the last YR commissioning beam time, about 3 700 manual trims (modifications of settings in LSA, that leads to a recalculation of all dependent parameter settings) were calculated per week with 80 working hours, which is about one trim every 77 seconds. Since the YR is a rather small accelerator ring, with a circumference of approximately 54 m [2], everything worked fine. The waiting time for these 3 700 trims summarizes to about 19 minutes distributed over the 80 working hours. The human reaction time is not much less, so the settings management system is pleasant to operate. But when it comes to calculate the Heavy Ion Synchrotron 18 (SIS18) or SIS100, the calculations get very slow. To calculate 3 700 trims for the SIS18, with its approximate 216 m [3], an operator would have to wait for over 13 hours distributed over the 80 working hours. The SIS100, with approximately 1100 m [4], calculation would even take over 91 hours which even doesn't fit into the 80 working hours. In 2025 not only single ring accelerators will be calculated separately, but the entire accelerator complex since the individual rings influence each other. Beams will start in the Universal Linear Accelerator (Unilac) and go their ways through the different rings and transfer lines to reach a target at the end, see also Figure 1. With the current calculation times it won't be possible to support an efficient beam operation for FAIR.

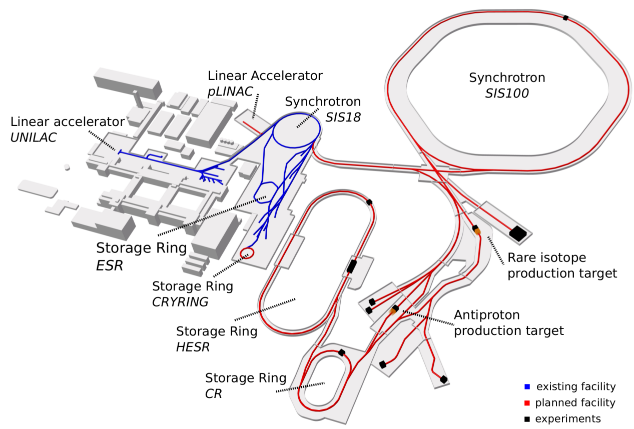

Figure 1: The layout of FAIR. The existing GSI Helmholtz Center for Heavy Ion Research (GSI) facility (blue) acts as injector for the new FAIR facility (red).

SPEEDUP

The speedup S represents a factor, that shows how two different algorithms perform on the same task. In the context of parallelization, the "speedup is a multiplier indicating how many times faster the parallel program is than its sequential counterpart. It is given by

$$S(P) = \frac{T(1)}{T(P)} \tag{1}$$

where $T(n)$ is the total execution time on a system with n processing units" [5]. $T(1)$ is also representable as

$$T(1) = T_{\text{setup}} + T_{\text{compute}} + T_{\text{finalize}} \tag{2}$$

Since the only part that can benefit from parallel optimization is T_{compute}, $T(n)$ can be written as

$$T(n) = T_{\text{setup}} + \frac{T_{\text{compute}}(1)}{n} + T_{\text{finalize}} \tag{3}$$

The efficiency can be expressed as

$$E(P) = \frac{S(P)}{P} \tag{4}$$

and gives an idea of how good a parallel code works. If the efficiency is close to 1, the parallelization is very good. The theoretically possible value for $E = 1$ is called a *perfect linear speedup* [5].

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MATLAB CONTROL APPLICATIONS EMBEDDED INTO EPICS PROCESS CONTROLLERS (IOC) AND THEIR IMPACT ON FACILITY OPERATIONS AT PAUL SCHERRER INSTITUTE

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Abstract

An automated tool for converting MATLAB based controls algorithms into C codes executable directly on EPICS process control computers (IOCs), was developed at the Paul Scherrer Institute (PSI). Based on this tool, several high level control applications were embedded into the IOCs, which are directly connected to the control system sensors and actuators. Such embedded applications have significantly reduced the network traffic and, as a result, the controls data handling latency. The paper concentrates on the most important components of the automated tool and some performance results of MATLAB algorithms converted by this tool.

INTRODUCTION

EPICS [1] Channel Access (CA) servers, which are also associated with Input-Output Controllers or IOCs, are well suited for interacting with sensors and actuators engaged in the control system. However, basic EPICS doesn't provide powerful standard options for dealing with sophisticated algorithms, which can be used on the IOC directly to process data obtained from sensors and to control actuators. Some simple available means include the calculation (calc) record with embedded elementary mathematical operations and the pid record for typical proportional-integral-derivative control functions. If more advanced mathematical calculations are required, then the dedicated procedures must be written. It can be either a C code to be implemented as a process function of a subroutine (sub) record or a state notation language (SNL) program.

The CA servers are developed and supported by control system specialists. This ensures that these servers are robust and their data are always available for users. At the same time, any efficient data analysis and data processing algorithms can only be developed by scientists who are experts in the fields of science associated with these data. This clear border of responsibilities between control system developers and users allows one to increase the research efficiency of any scientific organization.

Very powerful data processing and modeling features are provided by MATLAB [2], which is used in research organizations worldwide. In particular, PSI scientists and engineers have a long successful experience with MATLAB applications dealing with control system data. MATLAB is deployed at PSI as an integrated part of the well-established EPICS based data management environment [3]. The access to control system data, which are associated with EPICS records and referenced as channels, is provided by two in-house developed interface packages: Java based ca_matlab [4] and C/C++ based MOCHA/CAFE [5]. The latter, for instance, makes all basic CA functionalities available for MATLAB programs in terms of simple and transparent commands. For instance, to get the **value** from a channel with a specified name, one can use the following command:

value = **caget**('channel name').

Similarly, to set the control parameter represented by some channel name equal to the required value the next command can be used:

caput('channel name', **value**).

MATLAB codes are interpreted and executed line by line, which makes it an ideal tool for application prototyping and testing. The performance of the MATLAB programs versus their C program equivalents is, however, questionable. With all its great features, MATLAB is a good solution for "off-line" data analysis applications where a deterministic time response is not mandatory. However, to be useful for real "on-line" data processing applications, MATLAB, with its simplicity of the code development and maintenance, has to be combined with the C code performance and real-time data management mechanisms. The paper describes a way how to implement such a combination in the context of the EPICS CA server closed loop control.

MATLAB PROGRAM INTRACTION WITH EPICS BASED CONTROL SYSTEM

MATLAB programs at PSI are mostly used in closed loop control applications as illustrated in the Fig. 1.

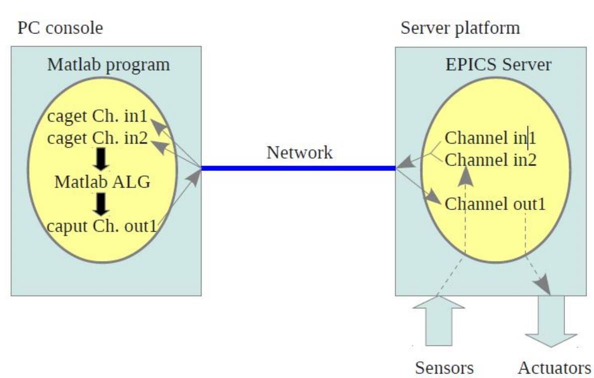

Figure 1: Closed loop controls with the use of an EPICS CA server and a MATLAB program.

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EXPERIENCES USING LINUX BASED VME CONTROLLER BOARDS

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Abstract

For many years, we have used a commercial real-time operating system to run EPICS on VME controller boards. However, with the availability of EPICS on Linux it became more and more charming to use Linux not only for PCs but for VME controller boards as well. With a true multi-process environment, open source software and all standard Linux tools available, development and debugging promised to become much easier. Also the cost factor looked attractive, given that Linux is for free.

However, we had to learn that there is no such thing as a free lunch. While developing EPICS support for the VME bus interface was quite straight forward, pitfalls waited at unexpected places.

We present challenges and solutions encountered while making Linux based real-time VME controllers the main control system component in SwissFEL.

SWISSFEL OVERVIEW

SwissFEL is a 720 m long Free Electron Laser facility at Paul Scherrer Instiut. It provides femtosecond X-ray laser pulses with 100 Hz repetition rate to currently one (later up to three) photon beam lines with up to three experimental stations each [1].

SwissFEL Control System

The control system is based on EPICS [2], currently version 3.14.12.4. An upgrade to 3.16 is planned. The over 300 control nodes, IOCs (Input/Output Controllers) in the EPICS nomenclature, fall into five categories:

1. So called “softIOCs” either not controlling any hardware directly or only controlling IP network accessible devices. These run Scientific Linux 6.8 on vmWare virtual hosts. An upgrade to Red Hat Enterprise Linux 7 is planned.
2. IOxOS IFC1210 VME single board computers [3] running ELDK 5.2 [4] as provided by the manufacturer.
3. Camera servers running Microsoft Windows Server 2008 R2. An upgrade to Windows Server 2016 is planned.
4. DeltaTau Power PMAC motion controllers running ELDK 4.2 as installed by the manufacturer.
5. Moxa DA-661, DA-662 and DA-662A serial servers for controlling devices with RS232 or RS485 serial interface. These run embedded Linux versions installed by the manufacturer.

Scientific Linux 6.8 is used as well on all Consoles and many central servers.

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IOXOS IFC1210

The IOxOS IFC1210 is a single board computer in VME 6U form factor. From controls point of view the main components are a Freescale P2020 PowerPC processor and a Xilinx Virtex-6 FPGA which are connected with PCI express. Other on-board components as well as some extension components are accessible though I²C.

The FPGA is used by various real-time applications, for example for low-level RF control. The “TOSCA II” FPGA framework [5] provides a PCIe bus bridge to three different hardware resources: User programmable FPGA functionality (“*USER*”) with access to two on-board FMC slots and to rear transition modules for I/O, the VME bus (“*VME*”) to access other boards in the same crate, and additional “shared” DRAM with dual access from the processor through PCIe and directly from the FPGA user logic (“*SHM*”).

Any of these TOSCA resources can map memory in 1 or 4 MB pages to PCIe and further to Linux user space. All can generate interrupts and all can be used in programmable DMA transfers.

EPICS INTEGRATION

Integrating devices into EPICS means accessing system hardware resources from a user space process using one or more of the following four methods:

1. Exchanging messages with the device. This is the typical access method for devices connected over network or a serial bus. In case of the IFC1210 this applies to the I²C devices.
2. Mapping device memory and registers for direct access by the CPU. Accessing device registers through memory maps is much faster than exchanging messages with the device. This is an important access mode for the VME, USER and SHM resources.
3. Transferring larger data blocks between the device and program memory efficiently. For large data blocks using specific DMA hardware is more efficient than keeping the CPU busy accessing mapped device memory. This is the second important access mode for VME, USER and SHM.
4. Handling device interrupts. Many devices signal when they need attention. This can be seen as a special type of message but deserves special attention because interrupts are asynchronous, they often do not contain all information why the device needs attention and thus require a handler which does additional register access. Interrupts are relevant for the VME and USER resources.

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MODBUS APPLICATION AT JEFFERSON LAB

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Abstract

Modbus-TCP is the Modbus Remote Terminal Unit (RTU) protocol with the TCP interface running on Ethernet. In our applications, an XPort device utilizing Modbus-TCP is used to control remote devices and communicates with the accelerator control system (EPICS). Modbus software provides a layer between the standard EPICS asyn support and EPICS asyn for TCP/IP or serial port driver. The EPICS application for each specific Modbus device is developed and it can be deployed on a soft IOC. The configuration of XPort and Modbus-TCP is easy to setup and suitable for applications that do not require high-speed communications. Additionally, the use of Ethernet makes it quicker to develop instrumentation for remote deployment. An eight-channel 24-bit Data Acquisition (DAQ) system is used to test the hardware and software capabilities.

MODBUS TCP/IP

Modbus is a serial communication protocol widely used by many manufacturers throughout industry since it was published by Modicon in 1979 for use with its programmable logic controllers (PLCs). It has become a standard communication protocol and is now a common available means of connecting electronic devices. Many applications in the field of accelerator control have implemented Modbus to communicate and control devices [1,2,3]. Modbus TCP is a Modbus variant used for communications over TCP/IP network. The Modbus TCP messaging service provides a Client/Server communication between devices connected on an Ethernet TCP/IP network[4]. Figure 1 shows a general Modbus TCP/IP communication architecture which includes different types of device, such as, Modbus TCP/IP Client and Server devices directly connected to the TCP/IP network, the interconnection devices like a bridge, router or gateway for interconnection between the TCP/IP network and a serial line sub-network, which permit connections of Modbus serial line client and server end devices. The messaging service of Modbus TCP/IP has four basic types of messages: Request, Confirmation, Indication, and Response. When a client initiates a Modbus Request message for a transaction, the server side will have a Modbus Indication and send back a Response message. Finally, the Client has the Confirmation message for the received Response message. By using these messages, the Modbus messaging services perform a real time information exchange between devices on the network.

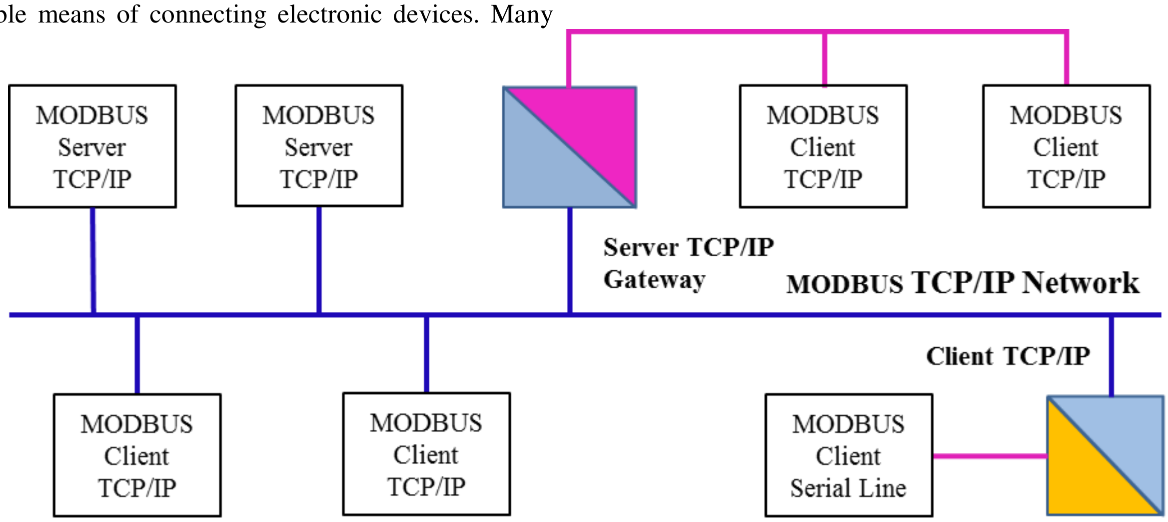

Figure 1: Modbus TCP/P Communication Architecture.

The Modbus protocol defines a basic Protocol Data Unit (PDU) independent of the underlying communication layers. The mapping of the Modbus protocol on a specific network will introduce some additional fields on the Application Data Unit (ADU). Figure 2 shows the Modbus TCP/IP ADU with a dedicated Modbus Application Protocol (MBAP) header which contains the fields of Transaction Identifier, Protocol Identifier, Length, and Unit Identifier. Modbus Function Code defines the various reading, writing and other operation of the Modbus data.

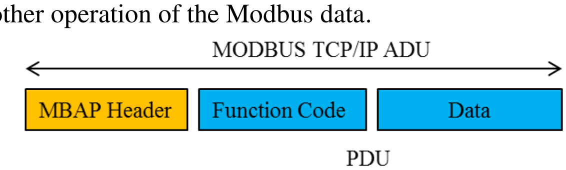

Figure 2: Modbus TCP/IP Request/Response Message.

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RECENT UPDATE OF THE RIKEN RI BEAM FACTORY CONTROL SYSTEM

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Abstract

The RIKEN Radioactive Isotope Beam Factory (RIBF) is a cyclotron-based heavy-ion accelerator facility. A major part of the components of the RIBF accelerator complex is controlled by the Experimental Physics and Industrial Control System (EPICS). A homemade beam interlock system (BIS) plays an essential role of safely delivering high-power heavy-ion beams. In this paper, we discuss the recent upgrade of the existing beam interlock system to a new beam interlock system (BIS2). Like BIS BIS2 is based on a programmable logic controller (PLC). It has a multi-CPU configuration with a Linux-based PLC-CPU on which EPICS programs can be executed in addition to a sequence CPU. The design of BIS2 and its offline tests in which its basic performance was verified are presented. We plan to expand BIS2 as a successor to the existing BIS that has been operating for over 10 years.

INTRODUCTION

The RIKEN Radioactive Isotope Beam Factory (RIBF) began operation in 2006 and has provided the world's most intense beams of unstable nuclei for nuclear physics studies. RIBF was constructed as an extension of our old facility (RARF) by adding three new cyclotrons, one of which is the world's first superconducting ring cyclotron (SRC). RIBF consists of two heavy-ion linear accelerator (LINAC) injectors and five heavy-ion cyclotrons. Various acceleration modes can be achieved by changing the combination of the accelerators used, and one of them is chosen according to beam energy and the ion species required by users. For example, a uranium beam, which is suited to produce very neutron-rich medium-mass ions, can be accelerated up to 345 MeV/nucleon by using a new LINAC injector and four ring cyclotrons. On the other hand, the K = 70 MeV Azimuthally Varying Field (AVF) cyclotron accelerates low-energy light-ion beams and provides them with its own experimental courses [1].

The components of the RIBF accelerator complex, such as magnet power supplies, beam diagnostic devices, and vacuum systems are controlled by the Experimental Physics and Industrial Control System (EPICS) [2] with a few exceptions, such as the control system dedicated to all the radio frequency systems of RIBF. However, all the essential operation datasets of EPICS and other control systems are integrated into the EPICS-based control system [3]. In addition, two types of interlock systems that are independent of the accelerator control systems are in operation in the RIBF facility: a radiation safety interlock system for human protection [4], and a beam interlock system (BIS) that protects the hardware of the RIBF accelerator complex from potential damage from the high-power heavy-ion beams [5]. In order to ensure safety, we implemented a dual interlock by inputting some signals to both systems. Figure 1 gives an overview of the RIBF control system.

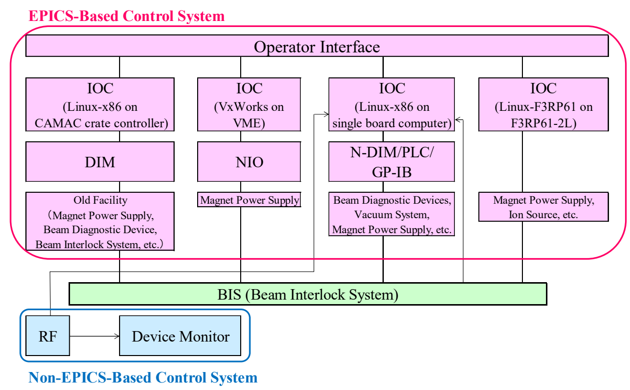

Figure 1: Overview of the RIBF control system.

EXISTING BEAM INTERLOCK SYSTEM

The existing BIS was designed to stop beams within 10 ms after receiving an alarm signal. On receiving an alarm signal, BIS outputs a signal to one of the beam choppers installed immediately below the ion source that deflects the beam immediately. Many accelerator and beam-transport-line components are registered to BIS and alarm signals sent to BIS are both digital and analog signals that show the abnormal behaviors of the components, such as an error in a magnet power supply or an overly high beam loss detected by baffle slits installed at various places on the RIBF accelerators and their beam transport lines.

One important function of the RIBF BIS is flexibility to impose appropriate interlock conditions according to each beam condition required by users. As mentioned previously, various beams (high power or low power) are accelerated by adopting various combinations of the accelerators. Hence, both the components relevant to the acceleration mode at that time and alarm levels have to be specified; for example, the allowable beam losses at baffle slits according to the actual beam power. To realize the flexibility required by daily RIBF operations, various interlock condition files in which the interlock signal pattern and alarm levels are specified are prepared in advance. BIS then downloads one of these interlock condition files appropriate to the experiment to be

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LIVE VISUALISATION OF EXPERIMENT DATA AT ISIS AND THE ESS

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Abstract

As part of the UK's in-kind contribution to the European Spallation Source [1], ISIS [2] is working alongside the ESS and other partners to develop a new data streaming system for managing and distributing neutron experiment data. The new data streaming system is based on the open-source distributed streaming platform *Apache Kafka* [3].

A central requirement of the system is to be able to supply live experiment data for processing and visualisation in near real-time via the Mantid data analysis framework [4]. There already exists a basic TCP socket-based data streaming system at ISIS, but it has limitations in terms of scalability, reliability and functionality. The intention is for the new Kafka-based system to replace the existing system at ISIS. This migration will not only provide enhanced functionality for ISIS but also an opportunity for developing and testing the system prior to use at the ESS.

INTRODUCTION

Currently under construction, the ESS is an accelerator-based spallation neutron source located in Lund, Sweden. After completion, it will be the World's most powerful neutron spallation source and as such will generate significantly more neutrons per pulse than existing neutron sources [5]. Initially the ESS will have a suite of 15 class-leading beamline instruments which will cover a range of different applications across many scientific and engineering disciplines.

For each neutron experiment, a range of different data need to be recorded to allow the scientist to analyse the results. Naturally, the core of these are the neutron detection events, but they also include vital complementary data such as sample environment measurements, details of the proton pulse from the accelerator, and experiment metadata. For the beamline instruments at the ESS, the intention is to capture each individual neutron detection event and every change in complementary data. Neutron data will typically form the largest contribution to produced data in terms of both frequency and volume, however the other data are equally as important for the scientist. The complete experimental information will be stored on disk using the NeXus data format [6].

As well as having the final data available after the experiment, it is becoming increasingly critical to be able visualise and process them during the experiment in near real-time. Being able to visualise and process data during the experiment allows the scientist to make more efficient use of their beamtime; for example: stopping an experiment early once the counting statistics are acceptable or aborting an experiment early because the sample is not aligned optimally.

To handle the predicted data rates of the ESS, whilst simultaneously enabling live visualisation and processing of data, requires a robust and scalable high-throughput data streaming system which is capable of handling both numerous sources of data and multiple consumers of data. It was decided that Apache Kafka would provide the backbone of the ESS data streaming system as it meets these requirements.

Collaboration of a team at ISIS with the ESS Data Management Group through an in-kind project provides an excellent opportunity to improve on current systems in use at ISIS and to prototype the system ahead of time for the ESS. Like ISIS, the ESS will use the Experimental Physics and Industrial Control System (EPICS) [7] for instrument control and the Mantid data analysis framework for live visualisation and processing. This overlap of technologies permits testing and gaining operational experience with the data streaming system at ISIS prior to it being used at the ESS.

THE SOCKET-BASED SYSTEM

Currently at ISIS, neutron event information from a beamline's detectors is collated in the *Data Acquisition Electronics* (DAE) which provides a time-stamp to each neutron event received. Depending on the requirements of the science the data is either stored as raw events or histogrammed in the DAE. Increasingly for analysis the preference is for the data to be available as events [8].

The operation of the DAE is controlled by the *Instrument Control Program* (ICP). The ICP's primary responsibility is to extract the event data from the DAE and combine them with sample environment measurements and experiment metadata to produce a NeXus file for data analysis. The sample environment data and experiment metadata are stored in a database independently of the ICP and are imported by the ICP when writing the NeXus file.

The ICP was previously extended to stream event data over TCP to visualisation clients, such as Mantid's Live Listener interface. Unfortunately, this simple streaming solution has a number of practical and functional limitations:

- Each new client connection requires its own TCP socket and data buffer, placing additional strain on the resources of the ICP which could cause data to be lost if the ICP cannot process neutron events in a timely manner.
- Clients are only able to view neutron events produced after they first connect; there is no way to "playback" previous data.
- Clients are unaware of any data that has been lost on-the-wire.

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USING AI IN THE FAULT MANAGEMENT PREDICTIVE MODEL OF THE SKA TM SERVICES: A PRELIMINARY STUDY

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Abstract

SKA (Square Kilometer Array) is a project aimed to build a very large radio-telescope, composed by thousands of antennae and related support systems. The overall orchestration is performed by the Telescope Manager (TM), a suite of software applications. In order to ensure the proper and uninterrupted operation of TM, a local monitoring and control system is developed, called TM Services. Fault Management (FM)[1] is one of these services, and is composed by processes and infrastructure associated with detecting, diagnosing and fixing faults, and finally returning to normal operations.

The aim of the study, introducing artificial intelligence algorithms during the detection phase, is to build a predictive model, based on the history and statistics of the system, in order to perform trend analysis and failure prediction. Based on monitoring data and health status detected by the software system monitor and on log files gathered by the ELK (Elasticsearch, Logstash, and Kibana) server, the predictive model ensures that the system is operating within its normal operating parameters and takes corrective actions in case of failure.

INTRODUCTION

The Square Kilometre Array (SKA) Project is aimed to build a radio telescope that will enable breakthrough science and discoveries, that would be impossible with current facilities over the next 50 years. In the overall SKA architecture, two telescopes (SKA MID and SKA LOW) are composed each one by several Elements covering all required functionalities, e.g. DISH and LFAA (the front-end Elements for direct radiation detection), CSP and SDP (data processing and delivery), SAT, SaDT and INFRA (support functionalities). The global orchestration of this huge system is performed by a central element called Telescope Manager (TM), which has three core responsibilities: management of astronomical observations (proposal and scheduling), management of telescope hardware and software subsystems (observation execution) and management of telescope engineering data.

TM is a complex (and distributed) system, mostly composed by software packages (TMC, OSO, Services), web applications and user interfaces running on a hardware & virtualization software platform. In order to ensure the proper and uninterrupted operation of TM, Software System Monitor and Fault Management of TM Services have the role to detect, isolate and recover faults.

TM failure situations are derived from accurate dependability analysis (like FMECA, FTA, ...) which are performed onto the system as it is being developed and built. The results are used by the Software System Monitor to immediately detect failures and by Fault Manager to easily isolate and correct the faults which caused them. This process, however, does not ensure the prediction of all possible failures, nor the tracement of every failure to a specific fault or set of faults, especially for complex systems like SKA TM.

In case of occurrence of an unexpected failure, its detection can be difficult and take some time: a much longer time, however, can be expected for the process of fault isolation (usually performed by manually drilling down monitoring data and inspecting log messages) and recovery. This could result in a significant and unacceptable outage period for the system.

On the other hand, the sudden (i.e. not preceded by abnormal, non-critical events) occurrence of a unpredicted failure is rather rare in a complex system: a deep post-event analysis of monitoring data usually reveals hidden correlations and structures which could not be taken into account in an a priori estimate and can be discovered only once the system is operating.

For all these reasons the use of Artificial Intelligence in discovering as many cause-effect relations as possible in TM, as well as speeding up the process of failure detection and fault isolation and recovery in TM, seems the most suitable to maximize its availability (defined as its ability to mask or repair faults such that the cumulative service outage period is within the required range).

In this paper a preliminary study of this approach is presented. The existing algorithms are reviewed and the selection of the most suitable ones for our application is discussed. Finally, the tools used for initial testing on a trial dataset are shown (Fig. 1).

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THE ALARM AND DOWNTIME ANALYSIS DEVELOPMENT IN THE TLS

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Abstract

TLS (Taiwan light Source) is a 1.5 GeV synchrotron light source at NSRRC which has been operating for users more than twenty year. There are many toolkits that are delivered to find out downtime responsibility and processing solution. New alarm system with EPICS interface is also applied in these toolkits to keep from machine fail of user time in advance. These toolkits are tested and modified in the TLS and enhance beam availability. The relative operation experiences will be migrated to TPS (Taiwan photon source) in the future after long term operation and big data statistic. These analysis and implement results of system will be reported in this conference.

INTRODUCTION

TLS is a small, state-of-the-art and compact synchrotron radiation facility featuring with adapted energy for users. This machine are still operated and supported with high reliability and stability beam quality. For this operation request, alarm in advance and analysis after event must be quick and true to keep from problem in the next time. Amount of signals analysis and calculation are heavy duty. The beam trip analysis expert system is developed to scan signal automatically and find sub-system problem after event. Big data in the achieve database is accessed and analysed by this toolkit in each event. Following subsystem from beam trip event and statistics are to classify signal that is effective to reduce searching time and CPU loading.

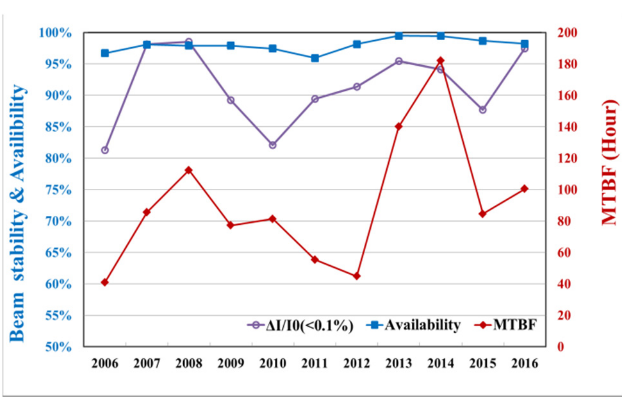

Figure 1: Annual operation statistic.

BEAM OPERATION STATISTIC

At a beginning of 200-mA top-up injection operations in October 2005 right after installation of the SRF module, TLS gradually raised the stored beam current to achieve 360 mA in 2010 and stayed there in the following years as limited by the available RF powers. Meanwhile it is always aimed to improve the performance of facility as indicated by availability, mean time between failures (MTBF) and beam stability index. Availability is defined as the ratio of delivered user time to the scheduled user time; MTBF as the ratio of scheduled user time to number of faults; and beam stability index as the shot-to-shot photon intensity variation of the diagnostic beamline with a ratio better than 0.1%. Together with the scheduled user time and the operation mode, these performance indicators for TLS operation from 2003 to 2016 is shown in Fig. 1, are the related performance indicators since 2006 as the accelerator operation was stable.

Table 1: Monthly Beam Stability Index of TLS in the 2016

Month	< 0.1%	< 0.2%	Month	< 0.1%	< 0.2%
1	95.3%	99.9%	7	97.0%	99.9%
2	98.0%	99.9%	8	95.9%	99.8%
3	99.0%	99.9%	9	NA	NA
4	99.5%	99.9%	10	98.1%	99.8%
5	97.1%	100%	11	97.5%	99.8%
6	97.0%	99.9%	12	97.7%	99.8%

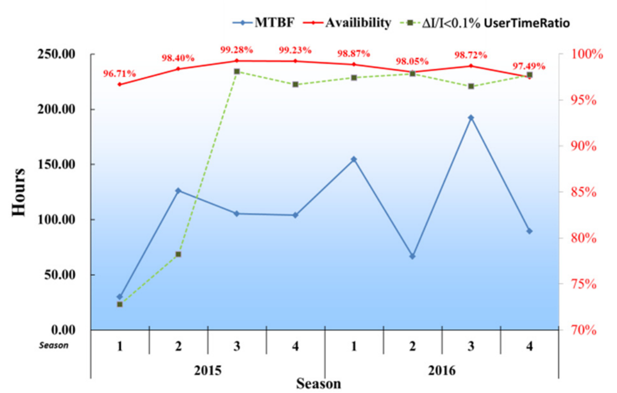

Figure 2: Season user time and beam performance indicators of TLS in 2016.

Mostly the operation performance of TLS in 2016 is better in comparison with 2015. On the basis of scheduled user time of 5526 hours, the delivered user beam time is 5427 hours to achieve an availability of 98.2%, while the MTBF and the beam stability index raises to 100.5 hours and 97.5%, respectively. Once an original component of old type aged to show bad performance, it was then upgraded to new model as possible. For example, the quadrupole power-supplies were all replacement with the new ones as the same

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PARALLEL PROCESSING FOR THE HIGH FRAME RATE UPGRADE OF THE LHC SYNCHROTRON RADIATION TELESCOPE

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Abstract

The Beam Synchrotron Radiation Telescope (BSRT) is routinely used for estimating the transverse beam size, profile and emittance in the LHC; quantities playing a crucial role in the optimisation of the luminosity levels required by the experiments. During the 2017 LHC run, the intensified analog cameras used by this system to image the beam have been replaced by GigE digital cameras coupled to image intensifiers. Preliminary tests revealed that the typically used sub-image rectangles of 128×128 pixels can be acquired at rates of up to 400 frames per second, more than 10 times faster than the previous acquisition rate. To address the increase in CPU workload for the image processing, new VME CPU cards (Intel 4 core/2.5GHz/8GB RAM) are envisaged to be installed (replacing the previous Intel Core 2 Duo/1.5GHz/1GB RAM). This paper focuses on the software changes proposed in order to take advantage of the multi-core capabilities of the new CPU for parallel computations. It will describe how beam profile calculations can be pipe-lined through a pool of threads while ensuring that the CPU keeps up with the increased data rate. To conclude, an analysis of the system performance will be presented.

THE BSRT INSTRUMENT IN THE LHC

The BSRT (Beam Synchrotron Radiation Telescope) is a very important instrument for the operation of the LHC and is currently the only system providing non-invasive measurements of the transverse beam size for calculation of emittance on a per-bunch basis. It does so by imaging the light intensity of visible and ultra-violet synchrotron radiation produced by the particles in each bunch.

Synchrotron radiation is generated whenever the trajectory of a moving, charged particle is bent due to a magnetic field. This radiation is emitted in the forward direction, in a narrow cone tangentially to the trajectory. The emitted radiation power is proportional to the fourth power of the beam energy and inversely proportional to the square of the bending radius.

In the particular case of the LHC, where the beam energy currently lies between $450GeV$ and $6.5TeV$, one can see that the BSRT system is required to handle a change of more than 4 orders of magnitude in terms of radiation power. For this reason, the BSRT setup comprises a set of optical filters placed between the light source and the image intensifier, to keep the light intensity in a range where it will not damage either the camera or the image intensifier. A simplified diagram of the instrument setup is shown in Fig. 1. In this diagram, most of the complexity of the overall setup including the details of the optical telescope path, light splitters, lenses etc have been omitted. For more details see [1].

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HARDWARE OVERVIEW

The hardware setup comprises various items. On the instrument side itself, a subset of the components requiring real-time control are:

- **Digital camera** - Basler Ace area scan CMOS-based 1936×1216 resolution camera
- **Relays** - controls camera on/off state
- **Image intensifier** - enhances/controls light intensity seen by the camera
- **Relays** - controls on/off state of image intensifier
- **Pneumatic device** - control of combinations of optical filters
- **3x step motors** - x,y,z position control of the camera
- **2x step motors** - x,y position control of the image steering mirror

The major change for the BSRT between the 2016 and 2017 LHC run was the replacement of the original analog cameras with digital cameras. The new cameras, Basler ACE acA1920-50gm [2], are CMOS-based cameras with 1936×1216 pixel resolution and a 1Gbit/s ethernet interface. Preliminary tests have shown that, when configured in free running mode and in steady state conditions, 128×128 pixels (typically used in LHC operations) can be streamed over ethernet at rates close to 400 frames/sec. Another crucial component of the overall system is the image intensifier which consists of a photo-cathode, a multi-channel-plate electron amplification stage and a fluorescent screen for enhancing the intensity of the light seen by the cameras. The connection between these components and their power supplies is controlled via relays using a serial interface. Such devices are also used to control the different optical filter combinations required to obtain the desired light attenuation. Finally, various stepping motors are used in real-time to control both the position of the camera and the image steering mirror to ensure the beam spot is always centred.

The VME-based [3] hardware used for the control, data acquisition and real-time processing of the BSRT instrument comprises the following modules:

- **CPU1** - runs the BSRT main controller as well as the controllers for the pneumatic actuators and relays
- **CPU2** - runs the stepping motor controllers

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AVAILABILITY ANALYSIS AND TUNING TOOLS AT THE LIGHT SOURCE BESSY II*

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Abstract

The 1.7 GeV light source BESSY II features about 50 beamlines overbooked by a factor of 2 on the average. Thus availability of high quality synchrotron radiation (SR) is a central asset. SR users at BESSY II can base their beam time expectations on numbers generated according to the common operation metrics [1]. Major failures of the facility are analyzed according to [1] and displayed in real time, analysis of minor detriments are provided regularly by offline tools. Many operational constituents are required for extraordinary availability figures: meaningful alarming and dissemination of notifications, complete logging of program, device, system and operator activities, post-mortem analysis and data mining tools. Preventive and corrective actions are enabled by consequent root cause analysis based on accurate eLog entries, trouble ticketing and consistent failure classifications with enhanced diagnostics. This paper describes the toolsets, developments, their implementation status and some showcase results at BESSY II.

OVERVIEW

Accelerator based light sources have become indispensable tools within the international scientific infrastructure. These instruments enable photon based cutting edge experiments for a huge variety of scientific disciplines. Even if the number of facilities is still growing, access to suited beamtime is a specific problem. The established "workhorses", the storage ring based light sources (SR), are serving many users at a time. Their detailed requirements on photon flux, energy, stability, coherence, polarization, time structure vary largely. Thus, within their technical limits, SR facilities try to accommodate users needs by offering adjusted operations modes for certain periods of time.

For the application for beamtime users have to decide first place on the best suited facility, the adequate available operation mode, appropriate beamline capabilities and experimental setups. Secondly the SR reliability, i.e. the ability to serve the promised function, over the assigned beamtime at the light source matters.

Independent of the level of sophistication the primary parameter for photon delivery of a light source is the stored beam current. Less obvious cases cover situations where degraded properties turn out to make stored beam not usable for most beamlines. Usually statistics on beam availability or “up-time” are published for most light sources. Conditions under which beam is considered “available” are frequently defined according to some common sense. Handling the rescheduling portions of the whole beamtime calendar due to disaster recovery or unforeseen technical necessities is very facility specific and typically very vague.

In order to improve comparability of light source availability some facilities made the attempt to define a simple, *common operation metric* [1]. Expectation is that application and refinement of such a common metric will improve understanding and comparison of light source performance. This will help to optimize the light source user experience and to assess the improvements of a specific facility over time.

Going through the different modes of operation of a single facility illustrates the difficulties to draw a conclusive picture. The challenge to maintain the desired beam properties is in addition complicated by tight radiation protection prescriptions that impose significant *top-up constraints*. At BESSY II these constraints are implemented in the top-up interlock, generating a number of enforced combinations of decay mode, closure of the beam shutters, restricted refilling modes. *Decay mode* is enforced by insufficient lifetime ($t < 5\,h$) or insufficient injection efficiency – a four hour average of injection efficiency $Eff_{\text{avg}} < 90\%$ enforces a $T = 4\,h * (90\% - Eff_{\text{avg}}\%)/(100\% - 90\%)$ compensation time of no injection. If a single shot with efficiency $Eff_{\text{shot}} < 60\%$, beam current drop $I_{\text{ring}} < I_{\text{min}}$ or unclear/inconsistent status of the top-up interlock occurs, a *beam shutter closure* is requested to allow for restoration of all top-up conditions and to leave the enforced decay state.

OPERATIONAL MODES

The annual beamtime calendar at BESSY II is organized in weeks of user operation, machine development and beamline commissioning, shutdown and beam scrubbing. A standard week of scheduled user beam time starts Tuesday 07:00 and ends Sunday 23:00 providing 3 basic user operation modes. Every other Sunday two eight hour shifts are dedicated to a single user, the National Metrology Institute of Germany (PTB, 4$^{\text{th}}$ mode).

Multi bunch hybrid mode This mode comprises 298 mA total current, kept constant by permanent top-up injections. General bunch pattern is an even filling of 300–350 bunches and a gap of about 100–50 bunches (500 MHz, harmonic number 400). In addition to this 280 mA multi bunch current up to 5 specific bunches are serving dedicated timing experiments.

A long “dark” gap (200 ns) and a higher current (4 mA), purity controlled camshaft bunch in the middle supports pulse picking with mechanical choppers and electronic gating. Three higher current (4 mA) bunches opposite

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SCADA STATISTICS MONITORING USING THE Elastic Stack (Elasticsearch, Logstash, Kibana)

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Abstract

The Industrial Controls and Safety systems group at CERN, in collaboration with other groups, has developed and currently maintains around 200 controls applications that include domains such as LHC magnet protection, cryogenics and electrical network supervision systems. Millions of value changes and alarms from many devices are archived to a centralised Oracle database but it is not easy to obtain high-level statistics from such an archive. A system based on Elasticsearch, Logstash and Kibana (the Elastic Stack [1]) has been implemented in order to provide easy access to these statistics. This system provides aggregated statistics based on the number of value changes and alarms, classified according to several criteria such as time, application domain, system and device. The system can be used, for example, to detect abnormal situations and alarm misconfiguration. In addition to these statistics each application generates text-based log files which are parsed, collected and displayed using the Elastic Stack to provide centralised access to all the application logs. Further work will explore the possibilities of combining the statistics and logs to better understand the behaviour of CERN's controls applications.

INTRODUCTION

There are around 200 controls applications maintained by the Industrial Controls and Safety systems group at CERN. Managing statistics, logs and detecting misconfigurations from these applications is difficult. This paper describes the service that we have implemented in order to more easily obtain statistics and error logs from all applications through a centralised web application.

Value Change and Alarms Statistics

Most of the controls applications archive value changes and alarms to a centralised Oracle database. The history of values changes and alarms for hundreds of thousands of devices are archived in a centralised Oracle High Performance Real Application Cluster (RAC), from around 200 controls applications. Mainly due to the structure of the database and the huge amount of data it is not easy to view, analyse or use this data to obtain high-level statistics.

It is not possible to easily obtain, for example, a list of devices that are archiving an excessive number of value changes. This is important to detect as it could indicate a faulty or misconfigured device.

The controls applications also generate alarms and it should also be possible to easily obtain information on the number of alarms from each application and device.

WinCC OA Logs

All the controls applications log errors, warnings and information messages to local log files on the servers on which they are running. It is difficult to examine these logs as they are distributed across many servers. For example, developers of the applications cannot easily or search these logs. It should be possible to collect and examine these logs centrally without putting an additional load on the production systems. In addition, since the log files on the servers are rolling, old log entries are lost when the log files are overwritten.

TECHNOLOGY

The implementation of the SCADA statistics monitoring service is built on the Elastic Stack [1] – Elasticsearch, Logstash, Kibana and Filebeat.

Elasticsearch is a distributed database that stores JSON documents designed specifically for search and analytics of semi-structured data. Unlike a relational database management system it is schema-free although it is not schema-less (like MongoDB for example) meaning that it is not required to define the types (string, number, etc) of the data before inserting it but it is possible to define types. The underlying technology is the Apache Lucene text search engine [2].

Logstash is a "data processing pipeline" that can ingest data from various sources, transform it and send it to various consumers; Elasticsearch is one of the many consumers that can be used with Logstash.

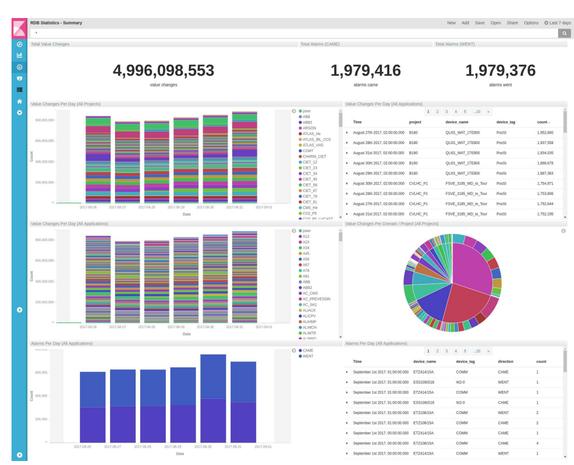

Figure 1: Value Change and Alarm Statistics Dashboard.

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DATA ANALYTICS REPORTING TOOL FOR CERN SCADA SYSTEMS*

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Abstract

This paper describes the concept of a generic data analytics reporting tool for SCADA (Supervisory Control and Data Acquisition) systems at CERN. The tool is a response to a growing demand for smart solutions in the supervision and analysis of control systems data. Large scale data analytics is a rapidly advancing field, but simply performing the analysis is not enough; the results must be made available to the appropriate users (for example operators and process engineers). The tool can report data analytics for objects such as valves and PID controllers directly into the SCADA systems used for operations. More complex analyses involving process interconnections (such as correlation analysis based on machine learning) can also be displayed. A pilot project is being developed for the WinCC Open Architecture (WinCC OA) SCADA system using Hadoop for storage. The reporting tool obtains the metadata and analysis results from Hadoop using Impala, but can easily be switched to any database system that supports SQL standards.

INTRODUCTION

In addition to the vast amount of physics data created at CERN, the control systems serving the accelerator complex and the supporting technical infrastructure generate very large amounts of data themselves. The analysis of this data is an important method for identifying and solving problems, which are not triggered by the alarms, in the underlying processes with the aim of maximizing the operational time of the CERN installations. A growing interest in smart solutions for the supervision and analysis of such data is resulting in the rapid development of many tools (e.g. Spark – a part of the Hadoop ecosystem) and advancements in machine learning. Often however, these analysis tools and techniques are applied by data analysis experts, and the results are not always easily available to process engineers and operators who might have use of this information in the daily running of the plants.

This article describes a tool that aims to 'close the loop' on the data analytics, allowing operators and process engineers easy access to the analytical data directly from the SCADA systems used at CERN. By making the results of data analytics available, operators and process engineers could gain useful and insightful information on how to maintain production systems in a scope of efficient and reliable work. The work presented in this paper is a pilot project and a proof of concept that was launched at the end of 2016, within the scope of the openlab collaboration at CERN.

* The project developed and supported through CERN openlab collaboration with Siemens, http://openlab.cern/

DATA ANALYTICS AND CERN CONTROL SYSTEMS

The Large Hadron Collider (LHC), its injector complex and its technical infrastructure represent one of the largest and most complex industrial control systems ever built by mankind. The volume of control data generated by these industrial facilities is growing year after year. The analysis of this data is crucial for evaluating and improving the performance, efficiency and predictability of the entire control system. Multiple innovative data-driven strategies have been designed and developed to deal with the ingestion, processing and storing of the huge amount of control data within a reasonable period of time.

Benefits of Analysing CERN Control Systems

The majority of raw control data does not provide a lot of value in its initial unprocessed state. Therefore multiple types of analysis have been developed aiming at distinctive, sometimes even divergent, control system aspects. As it has been already pointed out by other studies [1, 2] the detection of anomalies / disturbances in an industrial process represents a key factor in the quality of the overall control system. Several descriptive analyses have been deployed to condense long lists of control alarms into shorter, more useful system status summaries. One of the most recurrent problems was the classification of faults and their related root cause analysis. More sophisticated algorithms have been developed to detect anomalies or malfunctions in various CERN control systems [3]. These predictive analyses exploit statistical, data mining and machine learning techniques to extract a model from the historical data, which is then used for anomaly detection against the online streams of control data.

The analytics use cases have been divided into three different categories: online monitoring, fault diagnosis and engineering design. All of them focus on the control data to offer analytical services as added value on top of the traditional industrial control services.

Currently, the monitoring and operation of CERN industrial systems is mostly based on specific WinCC OA applications. Therefore, the online monitoring analytics studies aim at enhancing the services provided by the SCADA systems. For example the alarms analysis system, based on Complex Event Processing (CEP [4]) engines, has been designed to continuously collect events generated by each control device, and discover anomalous patterns [5, 6]. Specifically, the stream of historical events is analysed to calculate the number of events generated by individual devices under nominal conditions; then this information is used as a dynamic threshold to detect anomalies [7], with the assumption that a fault will generate a higher number of events. A similar approach has been adopted by the

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APPLYING SERVICE-ORIENTED ARCHITECTURE TO ARCHIVING DATA IN CONTROL AND MONITORING SYSTEMS*

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Abstract

Current trends in the architecture of software systems focus our attention on building systems using a set of loosely coupled components, each providing a specific functionality known as service. It is not much different in control and monitoring systems, where a functionally distinct sub-system can be identified and independently designed, implemented, deployed and maintained. One functionality that renders itself perfectly to becoming a service is archiving the history of the system state. The design of such a service and our experience of using it are the topic of this article. The service is built with responsibility segregation in mind, therefore, it provides for reducing data processing on the data viewer side and separation of data access and modification operations. The service architecture and the details concerning its data store design are discussed. An implementation of a service client capable of archiving EPICS process variables (PV) and LabVIEW shared variables is presented. Data access tools, including a browser-based data viewer and a mobile viewer, are also presented.

INTRODUCTION

As part of building Fermilab's Solenoid Test Facility (STF) [1][2], a unique magnet test facility designed for testing large aperture superconducting solenoid magnets, the authors designed and implemented a dedicated data archival service based on a microservice.

Monolithic software architectures have proven to be very difficult to develop and maintain efficiently. Service Oriented Architecture (SOA) allows for a modular approach to application design based on functional boundaries. Microservices offer a solution inside of SOA that focuses on the independence of the service as an entity, rather than as part of an application. Consequently, a service implemented as a microservice is developed and deployed independently from the applications that use it.

This design approach has been applied to the data management solution for the STF test facility. The developed management solution belongs to a class of systems known as a data historians.

Data historians are data management systems dedicated to recording and retrieving data organized by time, known as time-series data. Time-series data allow the user to view the data as a trend plot or as tabular data over a time range. Data historian applications are found in a large set of domains, including industrial process control and monitoring computing resources in data centres. Collected data can be analysed for performance monitoring, optimization, material consumption, plant availability, quality control, etc.

In control and monitoring systems, data historians (sometimes referred to as process historians) are used in systems that support management of the plant. Data from various sources, such as a PLC, embedded computers, instruments, and intelligent sensors, are collected in a set of uniquely named tags and, thus, provide a complete view of the controlled plant.

DATA ARCHIVING IN A TEST FACILITY

A typical process historian can be characterized by:

- High capacity storage and use of data compression.
- High insertion rates (thousands of points per second).
- Noise filtering and use of data interpolation for reducing data size.
- Interoperability with many heterogeneous data sources.
- Included analytic capabilities aiding in answering plant management relevant questions such as availability and utilization of plant equipment, production rates, and max/min values of gathered signals.
- Presentation of gathered data in the form of trends or calculated metrics.

Although data historians used in an R&D setting still need to save time-series data of many points, this niche application domain presents itself with a different and specific set of quality of service demands.

The data archival system for the STF R&D test facility can be characterized by:

- Relatively limited number of tags (measured in hundreds) and rather low insertion rate.
- Data organized as tests (uniquely identifiable time-boxed operations of the system).
- Storing all signal values, rather than only those values which have changed.
- Testing of different subjects (accelerator components such as superconducting magnets) leading to different sets of data to be archived for different tests.

The off-the-shelf data historians offer an abundance of features, but only a subset of them can be utilized in the R&D testing domain. They excel at handling time-series data, but are not designed to handle relational data. The limited ability to impose a structure on top of the time-series data, such as including metadata and relating the

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A GENERIC REST API SERVICE FOR CONTROL DATABASES*

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Abstract

Accessing database resources from accelerator controls servers or applications with JDBC/ODBC and other dedicated programming interfaces have been common for many years. However, availability and performance limitations of these technologies were obvious as rich web and mobile communication technologies became more mainstream. The HTTP Representational State Transfer (REST) services have become a more reliable and common way for easy accessibility for most types of data resources include databases. Commercial products to quickly setup database REST services have become available in recent years, each with their own pros and cons. This paper presents a simple way for setting up a generic HTTP REST database service with technology that combines the advantages of application servers (such as Glassfish/Payara), JDBC drivers, and REST API technology to make major RDBMS systems easy to access and handle data in a secure way. This allows database clients to retrieve data (user data or meta data) in standard formats such as XML or JSON.

INTRODUCTION

As a common resource of data, the usage of databases are essential for accelerator control systems. The way to access databases from all parts of the controls system, locally or remotely, can greatly affect the overall performance of the accelerator controls system. Traditional ways of accessing databases with JDBC or ODBC from different programming languages works fine in most cases. However, the rising and widespread use of mobile and web applications requires more sophisticated ways of accessing database resources for network-based programs. The Representational State Transfer (REST) API paves a universal way for this purpose. While several commercial products (such as RESTIFYDB[1], Drupal[2], Firebase[3] etc.) are available on the market, most of these REST API building products are based on JPA or Hibernate technology, and each product has its own advantages with rich functionality. However, there are also some disadvantages, requiring a constant and significant amount of maintenance work for dynamically changing control database systems such as the ones we are using.

In our controls system, we have several MySQL database servers and SAP Sybase ASE database servers, encompassing several hundred databases. Some databases are for storing the control system configuration data and others are for use to store real-time controls data. In addition, we have many controls application developers with different programming language backgrounds (C. Java, Matlab etc.), that work on different projects on different OS platforms, some locally and others remotely. This requires an easy and generic way to universally expose different kinds of database resource data to all kinds of clients.

Based on our database resource types and user environments, we developed a simple REST API service for our users to access controls databases. In the API design, we try to avoid the shortcomings of JPA/Hibernate technology on frequently changing database structures (such as dynamically mapping database objects into Java objects), while keeping the full syntax, flexibility and power of SQL language. This ensures that users and program developers can always get whatever database resource data they want, no matter how a database's structure changes overtime.

The API presents the resource data in either XML or JSON format along with the meta data, so users get everything they needed in a single API call. The data security issue of the REST APIs are also taken into the consideration in the API design.

APPLICATION SERVER SETUP

REST API services are normally delivered by an application server system. Our server system setup is shown in Figure 1 below. Here are some details:

- The main database servers and application servers are located inside our network firewall. The firewall is primarily responsible for basic system security and only allows authenticated users to access the REST API service.
- We make use of several MySQL (V5.1.73) and SAP Sybase ASE (V15.7) back end database servers. Since the core of this REST API is using the standard JDBC to make database server connections, and doing all CRUD database operations through JDBC underneath, this API can be extended to any JDBC supported database servers.
- The application server is running on a Red Hat Linux V6.5 OS. The application software is a version of the open source Payara application server form the Payara Foundation. The Payara server is derived from GlassFish, and provides developer support. [4]
- An internal reverse proxy server (NGINX) provides an HTTP gateway for all internal users behind a local firewall to access the REST API services available on the application server.
- An external reverse proxy (NGINX) server provides a secure HTTP gateway to allow authenticated users to access the REST API service inside the firewall.

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BUNCH ARRIVAL TIME MONITOR CONTROL SETUP FOR SwissFEL APPLICATIONS

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Abstract

Based on a Mach-Zehnder intensity modulator, Bunch Arrival time Monitor (BAM) is a single-shot non-destructive multi-bunch diagnostic instrument, which measures the arrival time with <10 fs precision in the range of 10-200 pC at 100 Hz repetition rate. Being directly coupled to a length stabilized fiber optical link, it has intrinsically low drift (<10 fs/day) and is thus a useful instrument for the machine feedback. The overall monitor complexity demands the development of an extremely reliable control system that handles basic BAM operations. Two BAM prototypes were successfully used in the SwissFEL Injector Test Facility and further two are being presently commissioned at the SwissFEL. The system is very flexible. It provides a set of tools allowing one to implement a number of advanced control features such as tagging experimental data with a SwissFEL machine pulse number or embedding high level control applications into the process controllers (IOC). The paper presents the structure of the BAM control setup. The operational experience with this setup is also discussed.

INTRODUCTION

SwissFEL is a compact X-ray Free Electron Laser (FEL) newly built at Paul Scherrer Institute (PSI). With total length of ~750 m, optimized to produce extremely bright and short X-rays in the range from 1 to 70 A and pulse duration in the order of 20 fs, it poses challenging demands on the diagnostic instruments regarding stability and sensitivity. The advanced SwissFEL characteristics open unique research opportunities in many disciplines such as medicine, biology, chemistry, electronics and nanotechnology.

SwissFEL is driven by a warm electron linac, which generates electron bunches with a repetition rate of 100 Hz and charges in the range of 10 pC to 200 pC. The longitudinal bunch stability of the machine is critical for user experiments. To monitor and control this stability, among other longitudinal and transverse beam diagnostics, the facility is equipped with several stations that provide non-destructive, shot-to-shot electron bunch arrival-time information relative to the extremely stable pulsed optical reference system [1]. Such Bunch Arrival time Monitor (BAM) stations [2] are valuable longitudinal diagnostics tools for SwissFEL operations.

BAM DATA ACQUISITION AND PROCESSING MODEL

The basic BAM detection principle is shown in Fig. 1. A pulse train from a mode locked laser at 1560 nm and 142.8 MHz repetition rate is sent to the BAM front end ("Box") via length stabilized single mode optical fiber links. In the BAM front end the amplitude of all reference laser pulses is modulated to the half with a Mach-Zehnder intensity modulator, biased at quadrature for maximum linearity. One reference laser pulse coincides with the zero-crossing of the S-shaped RF transient from the button pickup. With such an overlap there is no amplitude modulation, but any arrival-time change causes modulation by the non-zero voltage from the RF transient. Thus the arrival time information is encoded in the amplitude modulation with a fs precision. In view of the active fiber link stabilization, BAM has also a very low intrinsic drift.

To minimize any orbit offset influence, the signals from two opposite buttons (horizontal or vertical) are combined and fed in the RF port of the EOM.

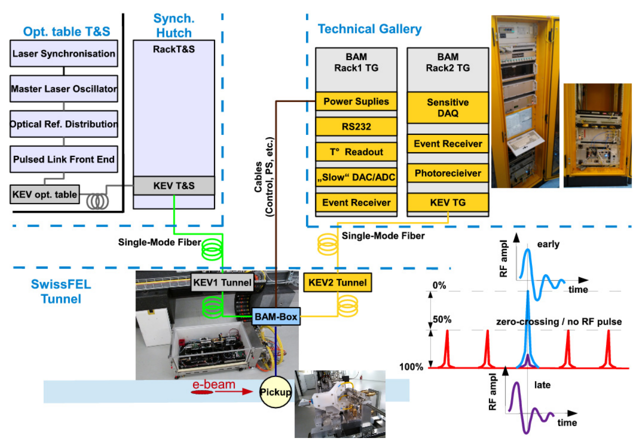

Figure 1: BAM topology and detection principle.

Each BAM station has the following components (see Fig. 2).

- An RF vacuum pickup consisting of four cone-shaped buttons, tapered to 50 Ohm vacuum feedthroughs with 40 GHz bandwidth. They are rotationally symmetrically mounted in the vacuum chamber with 16 mm diameter. Usually, two buttons are arranged horizontally and the other two vertically.
- Two Mach–Zehnder type electro-optic intensity modulators (EOM).
- Two erbium-doped fiber amplifiers (EDFA) with their controllers from Photop (II-VI).
- Reference laser pulse polarization control components (PCC), which include a Faraday rotating mirror, a polarization scanner, and a fiber polarizing beam cube.
- A high precision linear servo motor positioner MX80 from Parker with a controller from Copley Controls. The MX80 has a built-in incremental encoder with 10 nm

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DEVELOPMENT OF REAL-TIME DATA PUBLISH AND SUBSCRIBE SYSTEM BASED ON FAST RTPS FOR IMAGE DATA TRANSMISSION*

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Abstract

In fusion experiment, real-time network is essential to control plasma real-time network used to transfer the diagnostic data from diagnostic device and command data from PCS(Plasma Control System). Among the data, transmitting image data from diagnostic system to other system in real-time is difficult than other type of data. Because, image has larger data size than other type of data. To transmit the images, it need to have high throughput and best-effort property. And To transmit the data in real-time manner, the network need to has low-latency. RTPS(Real Time Publish Subscribe) is reliable and has Quality of Service properties to enable best effort protocol. In this paper, eProsima Fast RTPS was used to implement RTPS based real-time network. Fast RTPS has low latency, high throughput and enable to best-effort and reliable publish and subscribe communication for real-time application via standard Ethernet network. This paper evaluates Fast RTPS and Zstd about suitability to real-time image data transmission system. To evaluate performance of Fast RTPS and Zstd base system, Publisher system publish image data and multi subscriber system subscribe image data.

INTRODUCTION

KSTAR is a superconductive tokamak fusion reactor in Korea. KSTAR uses image data to analyse plasma status and protect device. Interlock system can use thermal imaging camera to monitor tokamak wall temperature status and to protect device. And TV Image Diagnostic system uses image data to analyse and understand status of plasma. In KSTAR, raw image data is required to transmit multiple remote server in real time. Because Image data acquired from image DAQ system cannot process in real time in DAQ system. and must be store to archiving server. And some diagnostic image data need to monitored in real time. In KSTAR, image DAQ system transfer image data to processing server. Because Processing image data take much computing cost. If image data processed in DAQ system, it can interfere the DAQ process. Therefore, we distribute system to image DAQ system and image processing system. most of the image are connected with Ethernet and image data transmitted by manual. we try to make automatic image processing routine by using the real-time image transmission system. by using these system, we can simplify image data sharing among servers which needs to image data in real time.

Transferring the image data in real time is challenging problem. Because, most of image data size is larger than other type of data.

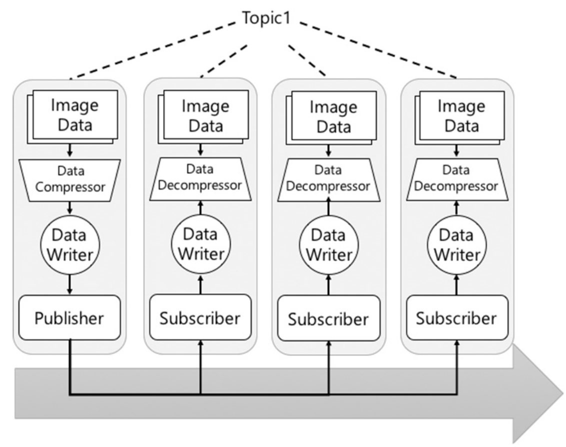

Figure 1: Configuration of image transmission system.

Sending/Receiving image data through network will takes most of network bandwidth and slow down the network performance. and publisher/subscriber node's network latency also will be degraded.

One image source required to transfer to multiple destination. For example, Image DAQ server acquires images from camera and simultaneously send this data to archiving server, image processing server and monitoring server. Increasing number of receiving server can create heavy load on data sending server. We use Real Time Publication Subscribe Protocol(RTPS) to reduce load to publish node and effectively share the image data. As figure 1 show us, real time image transmission system consists of compression/decompression module and RTPS module. Image data compress with lossless compress algorithm and publish to multiple subscriber. Each subscriber subscribe data and decompress data to get image data.

DESIGN AND IMPLEMENTATION OF THE IMAGE TRANSMISSION SYSTEM

Real Time Publication Subscribe Protocol(RTPS)

RTPS is a publish/subscribe protocol for Data Distribution Service(DDS) implementations. DDS is a network communication middleware Object Management Group(OMG) standard. RTPS facilitates scalable, real-time, reliable and high-performance system. RTPS provides best effort and reliable QoS reliability mode. By configuring the system to best effort QoS mode, we can implement high performance networking system. RTPS implements publisher/subscriber pattern to simplifies complex network programming.

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CONCEPTION AND REALIZATION OF THE VERSIONING OF DATABASES BETWEEN TWO RESEARCH INSTITUTES

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Abstract

This paper describes the version control of oracle databases across different environments. The basis of this paper is the collaboration between the GSI Helmholtz Centre for Heavy Ion Research (GSI) and the European Organization for Nuclear Research (CERN) on several aspects of the control system.
The goal is to provide a sufficient and practical concept to improve database synchronization and version control for the database landscape of the two research facilities.

First, the relevant requirements for both research facilities were identified and compared, leading to the creation of a shared catalog of requirements. In the process database tools, such as Liquibase and Flyway, were used and integrated as prototypes into the Oracle database landscape.

During the implementation of prototypes several issues were identified, which arose from the established situation of two collaborating departments of the research facilities. Requirements on the prototype were, to be flexible enough to adapt to the given conditions of the database landscape and an easy integration without too many changes into the existing development environment.

The creation of a flexible and adjustable versioning system enables the two research facilities to use, synchronize and update the shared database landscape.

INITIAL SITUATION

CERN and GSI collaborate since 2008 on the settings management framework LSA (LSA - LHC software architecture [1]) and the device controller software framework FESA (FESA - frontend software architecture [2]). During the collaboration so far, the main focus was on the software and software versioning and not on the database. The LSA and FESA frameworks have grown between the two institutes and the software is versioned in Subversion [3]. The databases grows without a system that allows to trace or track changes. Although, databases can be restored by backups, it is not possible to determine when which changes were applied and which database change belongs to which software feature. In addition, there is a lack of tools for the collaboration environments that allow the interactions on database level between the institutes, e.g. the easy exchange of features. In the past, both institutes saved the database schema changes in separate versioned text files and the order inside the file represented the execution ordering of the database schema changes.If the changes were executed on every database environment (development - testing - production), they were removed from the file. Therefore, the traceability of the changes was not provided and only existed if one compared two revisions of this file. This had, among other things, the disadvantage that software developers could not determine on which version of the database the software is currently running. This is a disadvantage, because the different database environments like development, production etc. may have different versions of the same schema.

METHODS

First, a requirements catalog of the two institutes was created and taken as basis for the choice of the best method to collaborate and later on for evaluation of a suitable tool. The second step was to make a model of each possible method and test these models in a simulation environment. This approach helped to discover possible issues, which, based on the concept only, could not be detected. To find out the institutes requirements, it was necessary to gain an impression of the actual environment and then ask the developers about the current state and functional requirements, which would be needed in the future.

Collecting of Requirements

To get an overview of each institutes requirements, it was helpful to figure out what the technical backgrounds were. CERN's LSA and FESA databases were built without any system of traceability, due to historical reasons. In the past, database versioning was uncommon. Because of this, many databases cannot be setup from scratch. They can be modified only by applying delta changes, while no global script for setup exists. Therefore, the versioning method of choice must be applicable on an existing, as well as on an empty database. In case of the empty one the scripts should setup the whole schemas from scratch, also for different environments like development and production.

Another important point was to analyze, how the existing traceability system for software versions works. One early requirement was, that the method for the database should be integrated into the existing software versioning system. For example, if the software is versioned in SVN, then the database scripts should also be stored in SVN. In this case the developer does not have to use two separate systems, but instead he can rely on a seamless workflow.

An issue, related specifically to the LSA-framework, was the availability of a lot of Java-code for interacting with the database, used to change the configuration of the LSA system. To prevent having to maintain the same SQLs in several locations, it was necessary for the tool to call Java-code for executing some of the tasks. Another point for importing data was, that it must be possible to run database imports scripts after a database migration step.This can be used, among other things, to repeatably update or import configuration data like calibration curves, granting database rights, or for compiling invalid objects. The tool for the database

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ADAPOS: AN ARCHITECTURE FOR PUBLISHING ALICE DCS CONDITIONS DATA

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Abstract

ALICE Data Point Service (ADAPOS) is a software architecture being developed for the RUN3 period of LHC, as a part of the effort to transmit conditions data from ALICE Detector Control System (DCS) to Event Processing Network (EPN), for distributed processing.

The key processes of ADAPOS, Engine and Terminal, run on separate machines, facing different networks. Devices connected to DCS publish their state as DIM services. Engine gets updates to the services, and converts them into a binary stream. Terminal receives it over 0MQ, and maintains an image of the DCS state. It sends copies of the image, at regular intervals, over another 0MQ connection, to a readout process of ALICE Data Acquisition.

INTRODUCTION

The purpose of this article is to present an overview of a new software architecture developed for an upcoming major upgrade to the ALICE experiment at CERN, along with simulation results demonstrating its performance and stability.

The O^2 project [1] involves extensive upgrades to the ALICE experiment [2,3] as the interaction rates will increase by a factor of 100 [4], during RUN3 period of LHC (scheduled to commence in 2021). *ALICE Data Point Service* (ADAPOS) is part of the pipeline for transmitting conditions data from ALICE *Detector Control System* (DCS) to O^2, where it will be used in the reconstruction of physics data from the experiment.

ADAPOS uses Distributed Information Management (DIM), 0MQ, and ALICE Data Point Processing Framework (ADAPRO). DIM and 0MQ are multi-purpose application-level network protocols. DIM and ADAPRO are being developed and maintained at CERN. ADAPRO is a multithreaded application framework, supporting remote control, and also real time features, such as thread affinities, records aligned with cache line boundaries, and memory locking. ADAPOS and ADAPRO are written in C++14 using OSS tools, Pthreads, and Linux API.

The basic unit of *conditions data* is called a data point. A data point can contain a temperature or voltage reading, typically from a single device or channel. When the state of a data point changes, an *update (event)* is generated, which ADAPOS needs to pass on to O^2.

ADAPOS is a soft real time architecture. It consists of three applications: *Engine*, *Terminal*, and *Load Generator* (LG). According to the specifications, ADAPOS Engine needs to:

1. not lose or corrupt data;
2. preserve the order of updates to a data point;
3. handle data with throughput rate and latency as predictable as possible;
4. be stable and responsive; and
5. allow redundant instances for maximising overall robustness and maintainability of ADAPOS while avoiding unnecessary downtime.

These requirements capture the essential aspects of the architecture that were considered. As the counterpart of Engine, Terminal needs to meet the same requirements. Load Generator, on the other hand, is only a tool created for testing the performance and reliability of the other two ADAPOS applications. A manager application was also built for controlling and monitoring Engine and Terminal.

The main use cases of ADAPOS architecture revolve around conditions data. These are service subscription (i.e. obtaining conditions data), transmitting updates to the readout application of *ALICE Data Acquisition* (DAQ) (via Terminal), and publishing statistics for service quality diagnostics. Figure 1 illustrates the use cases from the perspective of Engine.

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CONCEPT AND FIRST EVALUATION OF THE ARCHIVING SYSTEM FOR FAIR

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Abstract

Since the beginning of computer era the storing and analyzing the data was one of the main focuses of IT systems. Therefore, it is no wonder that the users and operators of the coming FAIR complex have expressed a strong requirement to collect the data coming from different accelerator components and store it for the future analysis of the accelerator performance and its proper function. This task will be performed by the Archiving System, a component, which will be developed by FAIRs Controls team in cooperation with XLAB d.o.o., Slovenia. With more than 2000 devices, over 50000 parameters and around 30 MB of data per second to store, the Archiving System will face serious challenges in terms of performance and scalability. Besides of the actual storage complexity, the system will also need to provide the mechanisms to access the data in an efficient matter. Fortunately, there are open source products available on the market, which may be utilized to perform the given tasks. This paper presents the first conceptual design of the coming system, the challenges and choices met, as well as the integration in the coming FAIR system landscape.

INTRODUCTION

Previous experience with the existing GSI facility showed the necessity of a centralized storage of historical data obtained and generated by individual accelerator components and their control system at a permanent location. The main focus of such data archive is to provide the possibility to correlate the actual and historic data in order to analyze the accelerator performance and its proper function. In the coming FAIR [1] facility this function will be offered by the Archiving System, which is currently developed by the Control Systems department, together with XLAB from Slovenia.

This system will allow storing the data on a configurable base of resolution in time, triggered by timing events or on-change. Collected data may be either values gathered from devices, higher level data like computed physics properties or generated abstract data. The Archiving System will include functionality to query, filter, correlate and display historical data. For data identification and synchronization purposes the system should be able to query, receive and store data from other control sub-systems, such as the accelerator's settings management system LSA [2], the Beam Transmission Monitor system or the Post-Mortem system.

The aim is to collect all the relevant data form the devices of the controls system. In numbers it means around 2000 devices, producing more than 30 MB of data per seconds. If stored plain, this amount of data will, in the long term, exceed the capacity possibilities of the controls systems infrastructure. Therefore the system must provide functionality to aggregate the historic data to reduce the required storage size.

SYSTEM OVERVIEW

In order to fulfill all requirements and manage the existing and future challenges in a fast changing environment, the archiving system is designed in a scalable and modular way. It consists of several components, which communicate with each other. Conceptually those components can be split in following functional parts:

- Downstream flow: collecting the data
- Storage component: storing the data
- Upstream flow: extracting the data from the storage

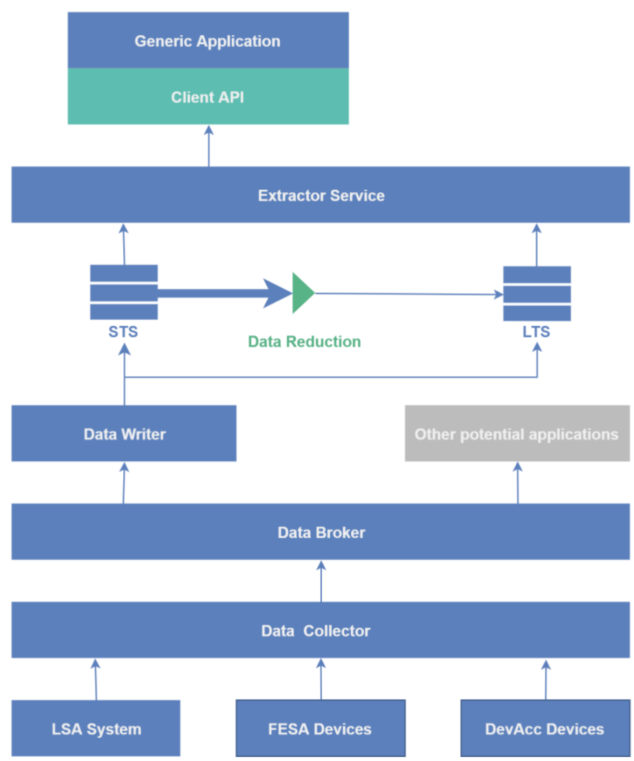

Figure 1: General system overview

In addition to those core parts, different supporting components will be a part of the Archiving System.

The basic idea of the whole systems architecture is to design and implement those components independent

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INTEGRATION OF THE VACUUM SCADA WITH CERN'S ENTERPRISE ASSET MANAGEMENT SYSTEM

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Abstract

With over 128Km of vacuum chambers, reaching pressures as low as in interstellar space, CERN is home to the largest vacuum system in the world. Its underlying architecture comprises approximately 15 000 pieces of control equipment, supervised and controlled by 7 Supervisory Control And Data Acquisition (SCADA) servers, and over 300 Programmable Logic Controllers (PLCs). Their configuration files are automatically generated from a set of ORACLE databases (vacDB) using a Java application (vacDB-Editor).

The maintenance management of such an amount of equipment requires the usage of an Enterprise Asset Management system (EAM), where the life cycle of every equipment is tracked from reception through decommissioning.

The equipment displayed in the vacuum SCADA is automatically integrated in its user interfaces (UIs) based on data available on vacDB. On the other hand, the equipment available in Infor-EAM for maintenance management activities (creation of work-orders, stock management, location tracking) resides in its own database. This leaves room for mismatches between what users see on the SCADA and in Infor-EAM. Although manual imports of equipment lists from vacDB to Infor-EAM are possible, the process is time consuming, error prone, and only guarantees the correctness of data while no equipment is added, deleted or modified in vacDB. Aiming to solve this issue, a web-based application called vacDM was developed to ensure continuous consistency between vacDB, Infor-EAM and CERN's dictionary database for equipment descriptions, the naming-DB.

Following the implementation of vacDM, the vacuum SCADA was updated to allow the generation of Infor-EAM work orders.

INTRODUCTION

Vacuum at CERN

Since the foundation of CERN in 1954 that its accelerator complex has been in constant growth. As new accelerators are designed and built to achieve higher energy beams, the requirements on the vacuum levels in the accelerator chambers become stricter. In order to achieve the specified beam lifetimes and also to reduce thermal conduction on cryogenic systems, the accelerator chambers at CERN operate at pressures between 10^{-6} and 10^{-12}mBar, achieved by a multitude of pumps, valves and gauges.

In order to meet the operational requirements, the vacuum control system has evolved over the years to what is now a multi-tier architecture as illustrated in Figure 1.

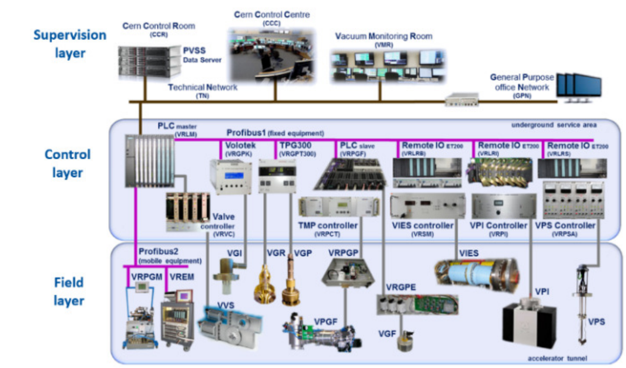

Figure 1: Vacuum controls architecture at CERN [1].

Data from field devices is acquired by the PLCs that are interconnected in CERN's technical network. The PLCs communicate with the SCADA server on the supervision layer, where the incoming data is archived, processed and displayed to the end user via dedicated consoles.

Data Engineering

The configuration of the SCADA and PLCs is performed through the vacDB-Editor, where equipment can be added, modified and deleted (Figure 2). The vacDB-editor stores persistent data in vacDB, a set of ORACLE databases that contains all of the required configuration parameters for every device. From the data in vacDB the export module of vacDB-Editor generates automatically the configuration for the SCADA and PLCs, mapping SCADA datapoints to memory locations in the PLC.

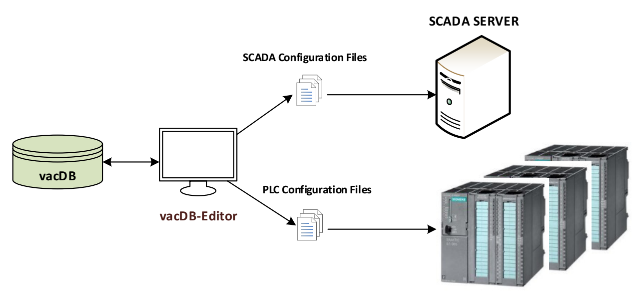

Figure 2: Control System Configuration Workflow.

The Need for an EAM System

With the increase over the last years on the number of equipment under the responsibility of the vacuum group, the task of tracking the location, stock levels and relationships between equipment became almost impossible using

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PLC FACTORY: AUTOMATING ROUTINE TASKS IN LARGE-SCALE PLC SOFTWARE DEVELOPMENT

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Abstract

At the European Spallation Source ERIC (ESS) in Lund, Sweden, the entire facility including all its instruments will be controlled by a large number of programmable logic controllers (PLCs). Programming PLCs, however, entails a significant amount of repetition. It is thus an error-prone and time-consuming task. Given that PLCs interface with hardware, this involves economic aspects as well, due to the fact that programming errors may cause damage to equipment. With PLC Factory, we managed to automate repetitive tasks associated with PLC programming and interfacing PLCs from EPICS. This tool is used in production at ESS and has led to a large increase in productivity compared to the previous status quo. We describe PLC Factory as well as its embedded domain-specific programming language PLCF$^\sharp$, which it is built upon.

INTRODUCTION

The European Spallation Source ERIC (ESS) in Lund is building large-scale infrastructure that is projected to include hundreds of programmable logic controllers (PLCs). Of particular concern is that PLCs directly control hardware, thus erroneous instructions may lead to damage to equipment. An additional problem is that programming PLCs is a rather repetitive affair. With a small number of PLCs, the tedium is certainly manageable. However, given the future large-scale deployment of PLCs at ESS, we were motivated to look into ways of automating some of the tedium associated with PLC programming with the dual goal of both saving time and increasing reliability as computers are better suited to repetitive tasks than humans.

The structure of this paper is as follows: After describing the problem we were facing at ESS in some detail, we present a high-level description of our solution, i.e. the application PLC Factory. That section covers how dependencies between devices are implicitly modeled by an in-house database, the role of template files and how they are processed, the detailed execution of PLC Factory via pseudocode, a description of the substitutions that are performed by a custom domain-specific language, a brief discussion of how we check for consistency in the data we produce, and an analysis of the computational cost of PLC Factory. This is followed by a short section on related work, and a section on future work.

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PROBLEM DESCRIPTION

ESS uses a database for configuration management, the Controls Configuration Database (CCDB). It is conceptually similar to a system at CERN with the very same name [1]. Yet, CCDB at ESS was developed from scratch. The Facility for Rare Isotope Beams (FRIB) at Michigan State University is another user of CCDB. CCDB contains static device information of the entire instrumentation hardware at ESS.

The problem we wanted to solve was to automatically generate both EPICS database records as well as code blocks in Structured Control Language (SCL) for the Siemens product TIA Portal. The former were intended to be complete records so that they could easily be imported into our local EPICS installation, the ESS EPICS Environment (EEE). The Experimental Physics and Industrial Control System (EPICS) is a distributed control system for scientific instruments [2]. The goal with regards to SCL code generation was to produce code blocks with relevant device information for a particular PLC. Furthermore, we wanted to explore approaches that allow the dynamic computation of values, such as memory addresses, which, for instance, may increase in fixed intervals.

CCDB stores information for each device instance and device type. Devices can be in two kinds of relations. First, a device is in a *controls* relationship with each device it controls. This is a finite number of controlled devices, which may be zero. Second, a device may also be in a *controlled-by* relationship that states which devices it is controlled by. In order to refer to these hierarchies of dependencies, we will use the term *dependency tree* in the following, or simply just *tree*. Those trees are only implicitly described by CCDB entries.

Before the advent of PLC Factory, a PLC programmer would use a number of templates according to device type, populate them *manually* with values taken from CCDB, hope to not have made a mistake, and use the resulting files for configuring EEE or as a starting point for continuing PLC programming in TIA Portal. This approach is repetitive, error-prone, and does not scale well with increasingly larger dependency trees. Thus, we were looking for a solution that handles the following cases of substitutions in template files:

1. direct substitution, i.e. for a given device d, use property p as specified in the corresponding CCDB entry for d
2. enabling shared properties between devices, in order to remove redundancies in CCDB

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VDI (VIRTUAL DESKTOP INFRASTRUCTURE) IMPLEMENTATION FOR CONTROL SYSTEM - OVERVIEW AND ANALYSIS

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WHAT IS VIRTUALIZATION?

Virtualization is a process that involves increasing the physical resources of a hardware through its virtualization.

There are different kinds of virtualization. We can divide virtualization into three groups:

- Hardware virtualization.
- Systemic virtualization.
- Network virtualization.

Because of virtualization implementation we are able to run multiple processes simultaneously on one physical machine. This process allows multiple operating systems(OS) to work at the same time on the same machine. We can also freely change the system configuration. On virtual machines we can increase or decrease:

- Processors and their cores.
- Hard drives:
  - RAM, Configure the network adapters.
  - USB devices.
  - USB controllers and many other devices.

Server virtualization is a great example of **hardware virtualization**.

If using the right software we can run 30 virtual servers based and operating on different operating systems (OS) on various subnets and performing different tasks at the same time.

Another type of virtualization widely used nowadays is **network virtualization**.

Creating VLAN (Virtual LAN) on switches allows to extend the capabilities of the device and increases its productivity. One port may have multiple VLANs or virtual subnets.

We can also use virtualized network adapters. There are only one physical network adapter and the right software needed to configure many virtual environments.

WHAT IS VDI?

I would like to discuss also an **VDI – Virtual Desktop Infrastructure**. It is the virtualization of desktops which are used in every office.

This method is called a *thin client* and it allows to implement an end-user application and its configured environment on the server. This involves creating a virtual machine resource (VM) for each user who is authorized and has access when logging into Vmware Horizion 7 with the installed agent on the terminal. The created virtual machines (MV) are on the server and work under control of hypervisior using the same process as in server virtualization.

Each VM desktop has appropriately configured RAM memory, disk space, and other resources. The entire installation takes place on a virtual disk created on the physical server. The user interacts with the VM using the remote graphical terminal protocol, for example: RDP (Remote Desktop Protocol). The VDI client is a simple terminal whose operation is solely connecting to the VDI infrastructure on the server. The protocols used for connection between terminal and VDI are:

- PCoIP
- VMWare Blast

This solution works very well in places where computers or laptops are used for multi-tasking and multi-shifts, or for different users who have access to a particular desktop where each of them have their own applications, directories and data. Also all data lives in the data center, not on the endpoint, so there are significant security benefits of VDI. There is no data on the machine itself. This is a big advantage and massive benefit of using VDI in the control system and therefore it was decided to test it in NCPS "Solaris".

VDI TEST IN NCPS "SOLARIS"

Tests were performed in the control room. Eleven desktop computers with Centos 64 v7.3 operating system and Tango system were virtualized. All computers had a special configuration, and were very sensitive to any change. Many packages and repositories have been installed for a long period of time to balance the quality of work and requirements imposed by operators (see Fig.1).

After moving these computers and creating the same number on virtual machines(VM), it occurred that there were no loses on the hardware performance. "Everything worked as well if not better" - this is a quote from the system users'. Also the assumption was made that the server must have efficient graphics card because each station has to be able to operate 4 monitors. The NVIDIA Tesla M60 GPU graphics card was used for testing. It was expected to be very efficient and meet our expectations After many tests a problem with the drivers was detected. The card could not handle 4 monitors at the same time. The

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ARES: AUTOMATIC RELEASE SERVICE

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Abstract

This paper presents the *Automatic RElease Service* (ARES) developed by the Industrial Controls and Safety systems group at CERN. ARES provides tools and techniques to fully automate the software release procedure. The service replaces release mechanisms, which in some cases were cumbersome and error prone, by an automated procedure where the software release and publication is completed with a few mouse clicks. ARES allows optimizing the time and the work to be performed by developers in order to carry out a new release. Consequently, this enables more frequent releases and therefore a quicker reaction to user requests. The service uses standard technologies (Jenkins, Nexus, Maven, Drupal, MongoDB) to checkout, build, package and deploy software components to different repositories (Nexus, EDMS), as well as the final publication to Drupal web sites.

INTRODUCTION

At CERN, the Industrial Controls and Safety group of the Beams Department (BE-ICS) provides solutions and support for industrial control systems and develops, installs and maintains safety systems. The software implemented by the group covers all layers of the control systems, i.e. ranging from front-end devices like PLCs (*Programmable Logic Controllers*), Front-End Computers executing real-time tasks up to the SCADA HMI and web visualization. Multiple languages and packages are employed to develop all this software, like:

- The Siemens/ETM WinCC Open Architecture (OA) SCADA(*Supervisory Control And Data Acquisition*) product for the supervisory software.
- Unity Pro and Simatic Step7 for Schneider and Siemens PLC programming respectively.
- C++ for real-time applications, industrial middleware like OPC Unified Architecture and extensions to the commercial WinCC OA package.
- Java and Python for controls applications automatic generation tools.
- Java, Javascript and Angular JS for web visualizations.

In addition, due to the different operating systems used for operation in different domains at CERN, most of the software needs to be built for both MS Windows and Linux.

Although all software is committed to a common repository, the build and release processes were traditionally left up to each developer. This led to a very heterogeneous set of release mechanisms that included standard automated tools like Apache Maven [1], custom scripts (Python or Perl) which were maintained by the developers, or manual procedures consisting of multiple steps. In some cases, the release procedure was cumbersome and error prone leading to various problems:

- Very specific procedures required an expert knowledge in order to make a release of a software component. This represented a major problem when an urgent hot-fix was required in operation but the release expert was not around.
- Software releases were infrequent since developers would tend to include multiple bug fixes in a new version of the component to avoid releasing multiple times. This resulted in a long time for users to wait for a bug-fix.
- Manual steps led to incorrect information during the distribution of the components, e.g. inconsistency between version number in the web pages used for distribution and the component itself, which created confusion among the users as well as it caused some published versions to be unnoticed since the version number in the distribution pages had not been updated.

To avoid these issues, the BE-ICS group decided to develop ARES, which is described in the next sections.

AUTOMATIC RELEASE SERVICE

ARES makes use of standard technologies (Jenkins [2], Nexus [3], Maven, Drupal [4], MongoDB [5]) to provide a unified and automated release procedure, thus reducing the complexity and time required for releasing new software and keeping in sync the repositories with the software published for the final users. The following sections will describe the service architecture and the software release and publication workflows.

ARCHITECTURE

Figure 1 shows the main architecture and workflow of the release service. The software responsible persons use Jenkins as the web interface to trigger and complete the release. The build and release steps run in the background and are implemented using Apache Maven. This approach hides the complexity of the different steps involved in the release and allows to trigger new releases by non-expert users.

ARES uses two different repositories:

- Sonatype Nexus is the main software repository. It contains the software binaries plus additional metadata used to qualify the release, like the description of the target system for the software package.
- EDMS (*Electronic Document Management System*) [6]. The repository is used to store the software documentation and additional information like the software release notes.

Once the software has been released, the publication procedure uses Nexus, EDMS and Jira [7] as data sources to obtain the list of released versions, the documentation and

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THE SKA DISH LOCAL MONITORING AND CONTROL SYSTEM

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Abstract

The Square Kilometre Array (SKA) will be the world's largest and most sensitive radio observatory ever built. SKA is currently completing the pre-construction phase before initiating mass construction phase 1, in which two arrays of radio antennas - SKA1-Mid and SKA1-Low - will be installed in the South Africa's Karoo region and Western Australia's Murchinson Shire, each covering a different range of radio frequencies. The SKA1-Mid array comprises 130 15-m diameter dish antennas observing in the 350 MHz-14 GHz range and will be remotely orchestrated by the SKA Telescope Manager (TM) system. To enable onsite and remote operations each dish will be equipped with a Local Monitoring and Control (LMC) system responsible to directly manage and coordinate antenna instrumentation and subsystems, providing a rolled-up monitoring view and high-level control to TM. This paper gives a status update of the antenna instrumentation and control software design and provides details on the LMC software prototype being developed.

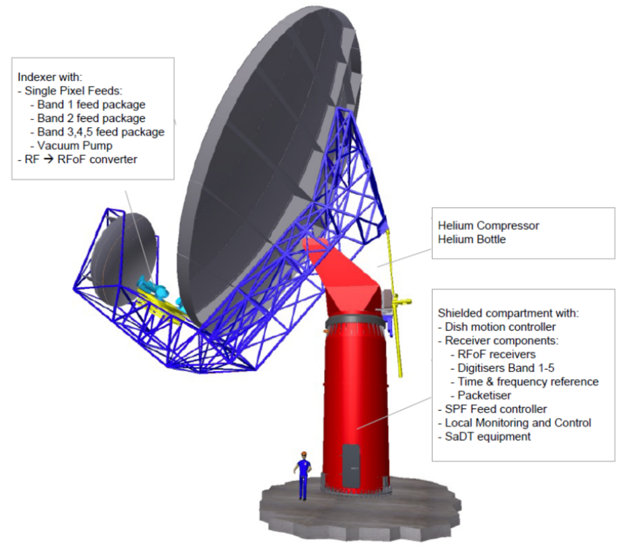

Figure 1: Schematic overview of SKA Dish design and instrumentation.

SKA DISH OVERVIEW

The SKA1-Mid Dish array will consist of 130 15-m Gregorian offset antennas with a feed-down configuration equipped with wide-band single pixel feeds (SPFs) for the SKA frequency bands 1 (0.35-1.05 GHz), 2 (0.95-1.76 GHz) and 5 (4.6-13.8 GHz) [1–3]. Band 5 will be installed in a subset (67 dishes) of the available antennas and splitted into two sub-bands - 5a (4.6-8.5 GHz) and 5b (8.3 to 15.3 GHz) - to improve the feed sensitivity and reduce the digitizer complexity and cost [4].
A sketch of the antenna is shown in Fig. 1 with the instrumentation distributed in three major locations: feed indexer, yoke and pedestal compartment.

Each feed package is mechanically mounted at the subreflector focus on the indexer which allows feed precision positioning and frequency band switching. The band 1 feed package is completely at ambient temperature. The band 2 feed package uses an ambient temperature horn, and cryogenic orthomode transducers (OMTs) and low noise amplifiers (LNAs). Bands 5 OMTs and feed horns will be cooled. All LNAs are followed by a second stage amplifier in the same package. The two cryogenic feed packages employ Gifford McMahon (GM) cryocoolers requiring high pressure helium. The helium compressor is mounted at the antenna yoke, with helium supply lines routed to the indexer. The cryogenic components inside the cryostat are thermally insulated by high vacuum. A vacuum pump is placed at the indexer with vacuum lines to all connected cryostats. Feed components can be monitored and controlled by low-speed serial lines.

The receiver sampler enclosure, located on the indexer, hosts the circuitry components and the ADC devices for feed signal amplification, filtering and sampling. ADC sampled and control data are trasmitted to/from the receiver FPGA components, located in the pedestal unit, by Optical Digital Links consisting of optical/digital transceivers connected with optical fibres. The digitiser packetizes and transmits the signal over a high-speed Ethernet link to the central signal processor. A master clock timer unit receives time and frequency reference inputs externally (provided by the SKA Signal and Data Transportation (SaDT) element) and generates timing and frequency references where needed, including the control of the calibration noise source that is transmitted over fibre to the feed packages.

A RFI-shielded cabinet is present in the antenna pedestal to house digital electronics and hardware for antenna movement and monitoring and control purposes. Among these the Antenna Control Unit (ACU), the single pixel feed and receiver controllers, the computing equipment hosting the Local Monitoring and Control (LMC) system and the networking equipment providing the Ethernet link among subelements. No active cooling is provided for equipments inside the cabinet, only a ventilation mechanism.

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THE CONTROL SYSTEM OF NOVOSIBIRSK FREE ELECTRON LASER

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Abstract

Novosibirsk Free electron Laser (FEL) based on multi-turn energy recovery linac is the source of coherent radiation with ability of wavelength tuning. It involves one single-turn and one 4-turn microtron-recuperator, which are have general injection channel and acceleration section. There are three different free electron lasers, mounted on different tracks of these accelerators, and operating on different electron beam energy and have different wavelength range and power of generated radiation.

Whole FEL facility is a complex physics installation, controlled by large amount of equipment of different types. Therefore, for effective control and monitor of FEL operation state and its parameters, the particularized control system was developed. In this paper the architecture, hardware, software compound parts of this control system are considered. In addition, main abilities, characteristics of this system and examples of its usage are presented.

INTRODUCTION

A Novosibirsk Free Electron Laser (FEL), on the base of microtron-recuperator [1] is operating now at Budker Institute of Nuclear Physics. This FEL involves three different configurations (operation modes), which are differ in electron beam energy, which is used for radiation generation and range of wavelengths of this radiation.

Certain number of accelerator turns and separated free electron laser is corresponds to each of these operation modes.

Moreover, the structure of whole facility is such, that some of its parts are used in all three operation modes, whereas other parts are used for operation of only one mode (see Fig.1)

All these three FEL configurations both separately and all together, are represents complex physical facility with large quantity of control and diagnostics parameters. Therefore, for full-functional operation of FEL, the specialized and distributed control system, containing specialized control equipment and corresponding software, was developed.

THE PRINCIPLES OF OPERATION AND FEATURES OF NOVOSIBIRSK FEL

The free electron laser is represents the source of coherent radiation, where the accelerated electron beam, moving through special magnetic structure – undulator, is act as working environment. The undulator is generates magnetic field, which is perpendicular to beam movement, constant in time, and harmonically changing along the beam propagation.

Accumulation and amplification of radiation is take place in optical resonator, which is installed on main axis of beam propagation (see Fig. 2). The wavelength of radiation is expressed by formula(1).

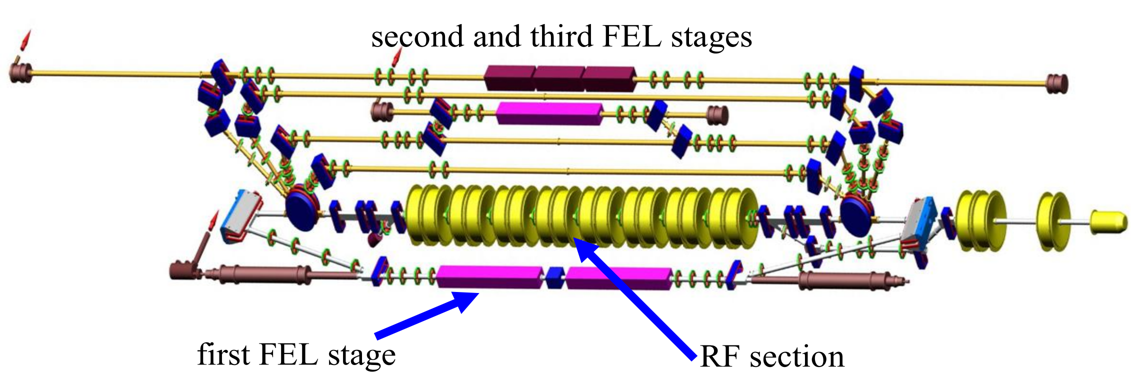

Figure 1: Multi-turn accelerator-recuperator of Novosibirsk FEL scheme.

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CONCEPTUAL DESIGN OF TREATMENT CONTROL SYSTEM FOR A PROTON THERAPY FACILITY AT HUST*

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Abstract

A proton therapy facility based on a superconducting cyclotron is to be built by Huagong Tech Company Limeted, Wuhan, China. This facility is aimed at providing proton beams with continuously tuneable energy from 70 MeV to 250 MeV, for kinds of cancer treatments. Our team is responsible for the development of the treatment control system, which consists a number of functional modules and connects to many subsystems. In this paper, we will report our conceptual design of the treatment control system.

INTRODUCTION

With the development of science and technology, proton therapy has made significant advances in the last ten years. While not yet considered as the main method of therapy, proton therapy is becoming widely available in cancer therapy centers, a number of proton therapy facilities are being built and planned all around the world [1].

Due to the great number of cancer patient in China, the demand for proton therapy is growing very fast. The development of proton therapy facility (PTF) directed by the Huagong Tech Company Limeted (HGTECH) is one of the projects supported by the Ministry of Science and Technology of China in the thirteenth five-year plan for science and technology.

The PTF mainly consists of a superconducting proton cyclotron, beamline system, gantries, scanning system, patient positioning system, Image Acquisition and Registration system (IAR), Safety Interlock System (SIS) and Treatment Control System (TCS). With degrader in the beamline, the proton beam with an energy ranging from 70 MeV to 250 MeV is delivered to the treatment room for cancer therapy. The TCS propagates the treatment information from the Oncology Information System (OIS) to other subsystems, coordinating the operation of all the subsystems based on the defined workflow. It provides the Graphical User Interface (GUI) to the clinical and other users for operation, and enables the users to execute the clinical and quality assurance workflow. In this paper, we will present the architecture design and functionalities of the TCS for this PTF.

TREATMENT CONTROL SYSTEM

The treatment control system is internally divided into a number of independent modules for specific functionalities, including the interface modules to subsystems. All the modules are designed to be standalone applications, each of them runs as a separate process, so that one will not affect another. The overview of the TCS is shown in Figure 1.

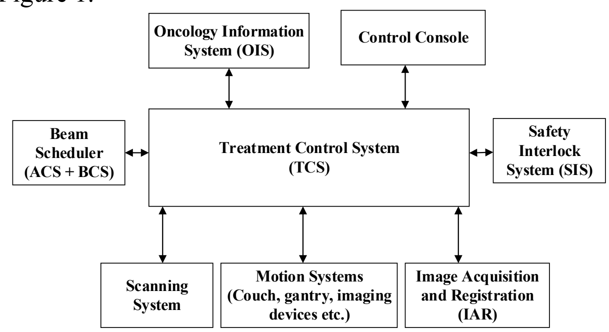

Figure 1: Overview of the treatment control system.

Data Distributed Service

The Data Distributed Service (DDS) is used for the internal communication among the TCS modules. It is an objective management group (OMG) machine-to-machine middleware standard [2]. It enables scalable, real-time, dependable, high-performance and interoperable data exchanges by using different strategies of QoS (quality of service) between the publisher and the subscriber, i.e. the modules of TCS. Thus, the TCS modules can exchange information in multiple modes: one-to-one, one-to-many and many-to-one. The nature of the DDS publish-subscribe pattern allows the individual modules to run over different hosts, which are connected through internet, thus the modules are transparent to each other. A central broker is not necessary for communication among modules in the TCS, therefore, this design prevents the effect of a single module failure to the whole systems, providing high reliability.

Functionalities

The TCS is basically a software used to guide and help the users to deliver the treatment according to the prescribed plan. Therefore, the TCS should have the following major functionalities from the users' point view:

- Allow the users to verify the patient information and prepare specific equipment;
- Allow the users to position the movable devices, e.g. couch;
- Allow image guidance, i.e. the image acquisition of X-ray or CBCT, thus allow automatic correction of the patient position using the registration information;
- Guide the users to perform required steps for a treatment session, inform the users about problems and safety issues when needed;
- Allow the users to execute the irradiation and moni-

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THE CONTROL SYSTEM FOR THE ELI-NP GAMMA BEAM DELIVERY AND DIAGNOSTICS*

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Abstract

The high brilliance Gamma Beam System (GBS) at ELI-NP is based on the Inverse Compton Scattering of laser light on relativistic electron bunches provided by a warm radio-frequency linear accelerator. The system will deliver quasi-monochromatic gamma-ray beams with a high spectral density and high degree of linear polarization. The Gamma Beam Delivery and Diagnostics (GBDD) of ELI-NP is implemented to deliver the gamma-ray beams to the experimental setups and to monitor the characteristics of the beams during the performance of the experiments. An EPICS control system is being developed for the GBDD to support the equipment for the delivery of the gamma beam and the devices for gamma beam diagnostics and monitoring. High-level software for the Gamma Beam diagnostics system is under development to complement the real-time measurements and monitoring. This paper describes the design and implementation status of the EPICS Control System for ELI-NP GBDD, including the device modular integration and the design of the high-level software.

INTRODUCTION

The High Brilliance Gamma Beam System (GBS) of Extreme Light Infrastructure - Nuclear Physics (ELI-NP) will produce intense gamma-ray beams with spectral densities of about 10^4 /s/eV, a narrow bandwidth (0.5%), high degree of polarization (>95%) and tuneable energy in the range from 200 keV to 19.5 MeV [1], based on the laser Compton backscattering technique on relativistic electrons provided by a linear accelerator.

The GBS system will be delivered by the EuroGammaS Association with its own EPICS based control system framework [2] to provide the data collection and constantly monitoring for the GBS.

The GBDD System is designed and under implementation to transport the gamma output to the Gamma Experimental areas and to monitor the gamma beam features. To optimize the operation of the ELI-NP GBS and its use for experiments, it is of utmost importance to have the proper means to accurately predict the spatial, spectral and temporal characteristics of the gamma beam. The ELI-NP GBDD work package is dealing with the equipment and techniques meant to transport and optimize the gamma beam in order to make it available for user experiments within required parameters [3]. Figure 1 shows the schematic layout of the ELI-NP GBS and GBDD.

The full ELI-NP GBS system providing the beam with the design parameters is expected to be ready soon. All diagnostics and monitor systems have to be already commissioned and ready to be used.

GENERAL SYSTEM REQUIREMENTS

The GBDD system consists of the low-energy and high-energy lines that cross the ELI-Building. The line starts after the low-energy interaction point, respectively after the high-energy interaction point, and goes until the experimental area [4].

Gamma Beam Delivery

The total length of the beam transport line is approximately 100 m. The vacuum pipe for the gamma beam transport has a modular design, allowing the removal of individual segments for the placement of experimental apparatus. The pumping stations will be distributed according to their pumping power, making vacuum connections between sections of pipe where that is necessary.

For the collimation of the Gamma beam, a collimator which is operated under vacuum and the aperture of the individual slits is controlled with stepper motors.

Five small beam dumps are going to be built at the exit from each of the experimental areas to ensure safety of work in the downstream rooms. These small beam dumps can be placed in different rooms, controlled with stepper motors to move in/out of beam.

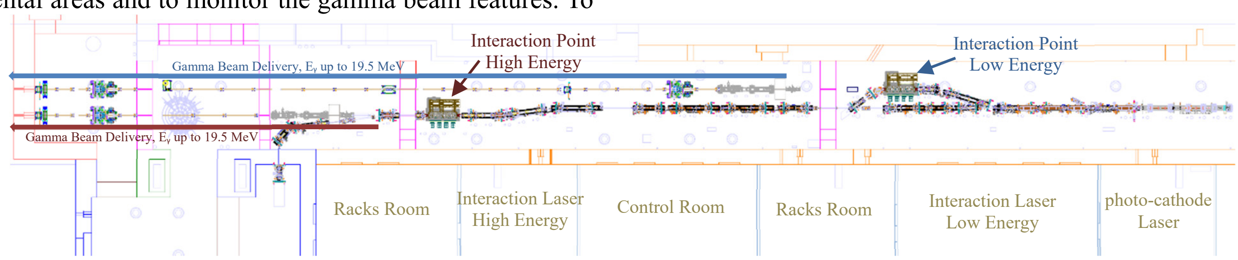

Figure 1: Schematic layout of ELI-NP GBS and GBDD.

Gamma Beam Diagnostics

The diagnostics modules of the GBDD system will provide five real-time beam monitoring systems including: energy and energy spread, flux measurement, spatial position

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GTHE CONTROL SYSTEMS OF SXFEL AND DCLS*

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Abstract

The high-gain free electron lasers have given scientists hopes for new scientific discoveries in many frontier research areas. The Shanghai X-Ray Free-Electron Laser (SXFEL) test facility is commissioning at the Shanghai Synchrotron Radiation Facility (SSRF) campus. The Dalian Coherent Light Source (DCLS) has successfully commissioned in the northeast of China, which is the brightest vacuum ultraviolet free electron laser facility. The control systems of the two facilities are based on EPICS. The embedded controllers, programmable logic controller (PLC) and field programmable gate array (FPGA) are adopted for the device control. The archiver is based on the PostgreSQL database. The high-level applications are developed using Python. The details of the control system design, construction and commissioning will be reported in this paper.

OVERVIEW

The Shanghai soft X-ray Free-Electron Laser facility (SXFEL) is being developed in two steps, the SXFEL test facility (SXFEL-TF) and the SXFEL user facility (SXFEL-UF). The SXFEL-TF is a critical development step towards the construction a soft X-ray FEL user facility in China, and is under commissioning at the Shanghai Synchrotron Radiation Facility (SSRF) campus. The test facility is going to generate 8.8 nm FEL radiation using an 840 MeV electron Linac passing through the two-stage cascaded HGHG-HGHG or EEHG-HGHG (echo-enabled harmonic generation, high-gain harmonic generation) scheme, as shown in Figure 1. The construction of the SXFEL-TF started at the end of 2014. Its accelerator tunnel and klystron gallery were ready for equipment installation in April 2016. The installation of the SXFEL-TF Linac and radiator undulators were completed by the end of 2016. In the meantime, the SXFEL-UF, with a designated wavelength in the water window region, began construction in November 2016. It was based on upgrading the Linac energy to 1.5 GeV, and the building of a second undulator line and five experimental end-stations. It is scheduled to be open to users in 2019[1].

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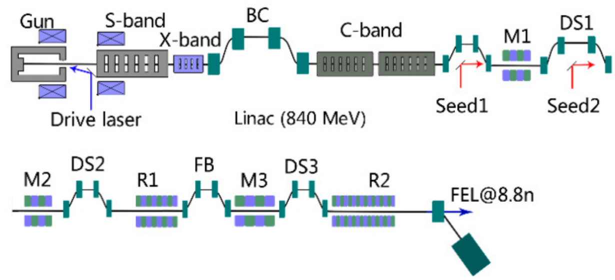

Figure 1: Schematic layout of the SXFEL-TF.

The Dalian coherent Light Source (DCLS) is a FEL user facility, which can deliver world's brightest FEL light in the energy range from 8 to 24 eV, making it unique of the same kind that only operates in the Vacuum Ultra Violet (VUV) region. It use a 300MeV Linac to produce fully coherent photon pulses in the wavelength range between 50-150nm by HGHG scheme. This project was launched at the beginning of 2012, and has successfully commissioned by the end of 2016. It was a close collaboration between the scientists and engineers from Dalian Institute of Chemical Physics and Shanghai Institute of Applied Physics, two Chinese Academy of Sciences institutes.

The control systems of SXFEL and DCLS are responsible for the facility-wide device control, data acquisition, machine protection, high level database or web applications, as well as network and computing platform. They provide operators, engineers and physicists with a comprehensive and easy-to-use tool to control the machine components to produce high quality electron beam and free electron laser.

ARCHITECTURE

The control systems are based on the open-source software, which are the combination of Linux, EPICS and Python. The CentOS (Community enterprise Operating System) is selected, which is a free operating system distribution based upon the Linux kernel. The EPICS (Experimental Physics and Industrial Control System) is adopted to reach the balance between the high performance and costs of maintenance. EPICS is a set of open source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as particle accelerators, telescopes and other large scientific experiments[2]. The high-level applications are developed using Python, which is a widely used object-oriented programming language.

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STATUS OF THE GBAR CONTROL PROJECT AT CERN

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Abstract

One yet unanswered questions in physics today concerns the action of gravity upon antimatter. The GBAR experiment [1] proposes to measure the free fall acceleration of neutral antihydrogen atoms. Installation of the project at CERN (ELENA) began in late 2016. This research project is facing new challenges and needs flexibility with hardware and software. EPICS modularity and distributed architecture has been tested for control system and for providing flexibility for future installation improvement. This paper describes the development of the software and the set of software tools that are being used on the project.

INTRODUCTION

The GBAR experiment [1] (see Fig. 1) is a collaboration of 14 institutes to build a precise measurement of the free fall acceleration of ultracold neutral anti hydrogen atoms in Earth's gravity field. This experiment is composed of several parts (source, trap, laser, beam line) provided by member institutes.

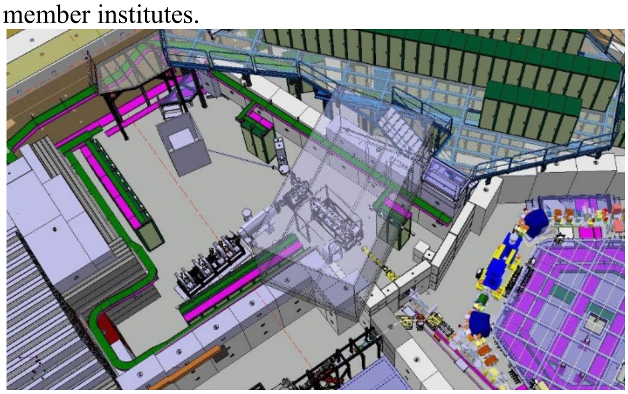

Figure 1: GBAR experiment CAO.

GBAR is currently in construction at CERN, Switzerland. More precisely, it is installed at the AD (Antiproton Decelerator) facility [2] connected to the new ELENA decelerator (Extra Low ENergie Antiproton) [3] which will provide a 100 keV antiproton beam.

To generate an antihydrogen atom, GBAR first needs two beam lines which transport a packet of positrons on one side and a packet of antiprotons on the other side.

To produce positrons, GBAR uses an electron LINAC (see Fig. 2) which will provide a 10 MeV beam at 300 Hz / 2µs. The electron beam hits a Tungsten target, many of the electrons pass through, but 0.5% of the electrons interact with the Tungsten by generating positrons.

Because we need a good amount of positrons for the reaction, the positrons will be trapped using two systems: a Buffer Gas and a Penning trap. The buffer gas is used as an injector to the high field Penning trap in order to increase the efficiency of positrons that will be able to enter the second trap by 25%. The purpose of the second Penning trap is to accumulate 10^{10} positrons with an expected efficiency of 50%.

On the other side of the experiment, ELENA will provide a slow antiproton beam with an energy of 100 keV, which is still too fast for GBAR. For this reason, this beam will go through the decelerator which will decelerate the beam at an expected energy of 1 keV.

By synchronizing trapped positrons and antiprotons packets, both beams will interact in the reaction chamber. Several reactions will occur with the help of precise energy boost provided by a laser to increase the chance of generating few antihydrogen ion with an energy of 1 keV.

Antihydrogen ion will be transported to one trap to decelerate it at 1 to 6 eV, and move in a second trap placed in the free fall chamber to decrease its energy at 10 microK.

Now, what we want is antihydrogen ion becomes an electric neutral antihydrogen that will fall on the detectors. For that, another LASER will provide the energy to take off the ion extra positron. As we will know the distance between the trap and de detectors, plus the time at which the LASER as kick off the positron, we will be able to evaluate the effect of the earth gravity on the antimatter.

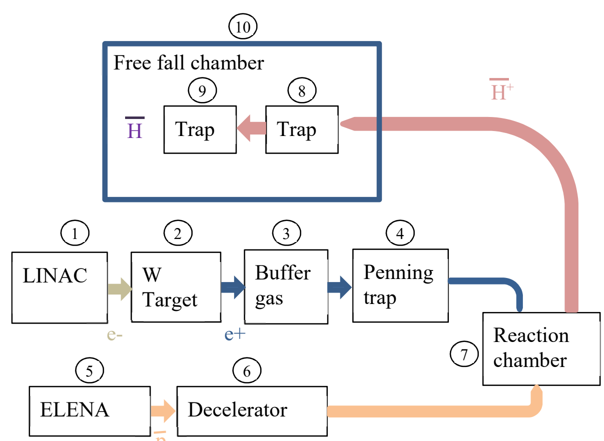

Figure 2: GBAR experiment principal.

CONTROL SYSTEM

Different part of GBAR is provided by a different institute with its own control system method and programming language like LabVIEW, Python, C++ and Siemens TIA Portal. EPICS is a good candidate for controlling all the different parts because we were able to find a communication driver for each of those languages.

IRFU is in charge of providing solutions for the main control system, and gives support to the front-end to integrate their software solutions to the EPICS [4] communication which is Channel Access.

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CONTROL SYSTEM OF THE LINEAR ACCELERATOR AS A PART OF NUCLEAR FACILITY NSC KIPT NEUTRON SOURCE

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Abstract

NSC KIPT Neutron Source on the base of subcritical assembly involves 100 MeV/100 kW electron linear accelerator as a driver [1,2,3,4]. Because the Neutron Source is nuclear facility, all technological systems of the facility are under regulation of State Inspection of Nuclear Regulation of Ukraine that is working in accordance with international nuclear regulation legislation. This regulation demands certain requirement to the design and realization of the facility control system in order to provide the conditions of the facility safe operation. In the paper, the features of control system of the linear accelerators as a part of nuclear facility NSC KIPT Neutron Source are described.

THE STRUCTURE OF CONTROL SYSTEM

Control System of the Linear Accelerator of "Nuclear Facility" is designed for monitoring and control the equipment of the accelerator and the accelerator transportation channel in all operation modes, ensuring the safety of the operation of the "Neutron source" and accelerator, the accelerator shut off for any violations of normal operation and accidents, control the power of a beam, the repetition rate and the charge of electron pulses.

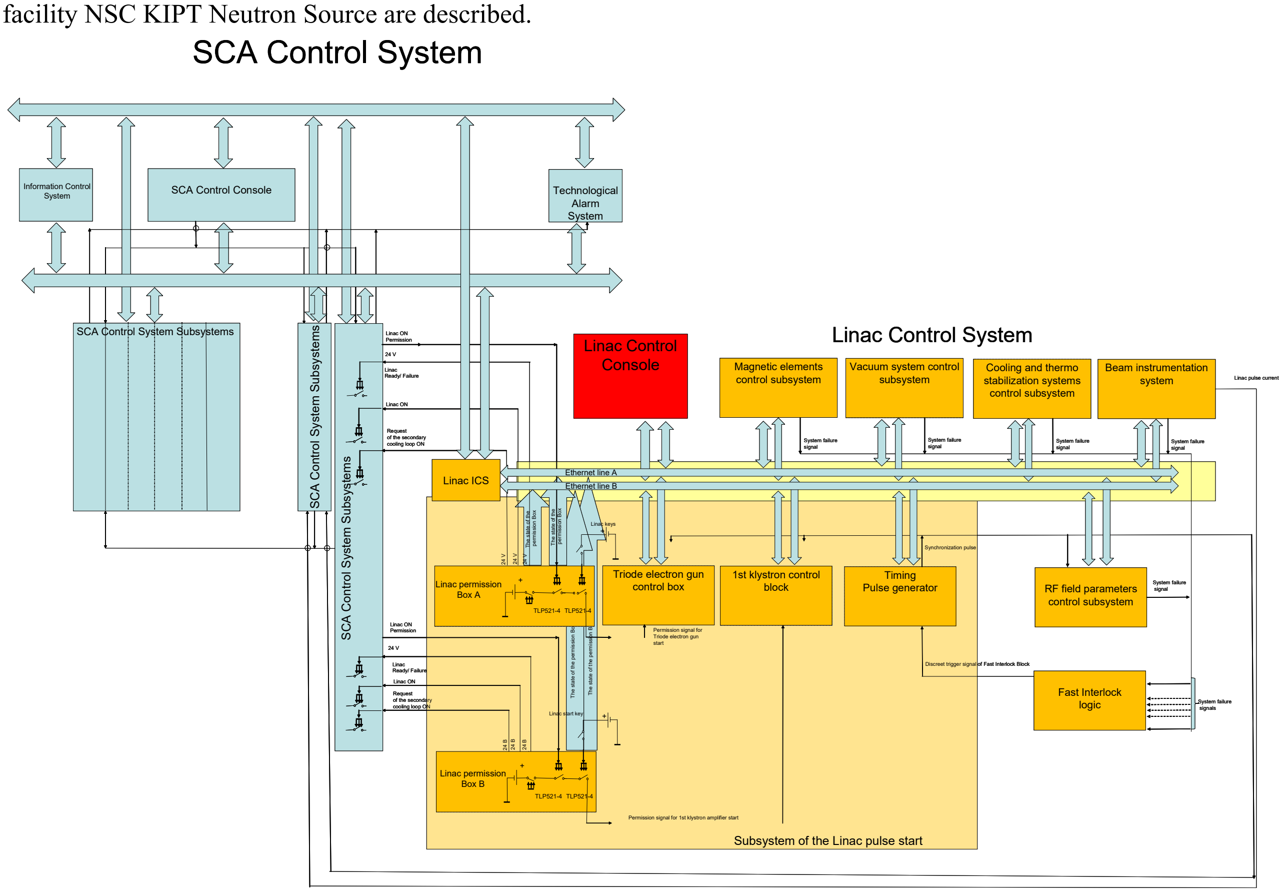

Figure 1: The control system structure diagram.

The Linac control system of nuclear subcritical assembling "Neutron source" consists of the following subsystems (Fig. 1):

Low level - sensors and control driven equipment and devices:

- driven equipment of the triode electron gun control block of the Linac pulse start subsystem;
- driven equipment of the RF parameters control subsystem;
- driven equipment of controlled power supplies of the subsystem for control the parameters of magnetic elements;

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STATUS OF THE NSC KIPT NEUTRON SOURCE

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Abstract

In NSC KIPT, Kharkov, Ukraine the state of art nuclear facility Neutron Source on the base of subcritical assembly driven with 100 MeV/100 kW electron linear accelerator has been build. The electron beam generates neutrons during bombarding the tungsten or uranium target. The subcritical assembly of low enrichment uranium is used to multiply the initial neutrons due to fission of the uranium nuclei. The facility is the first world facility of such kind. It is supposed that maximal value of multiplying neutron factor in the source will be equal to 0.95. So, the neutron flux will be increased as much as 50 times. Because of sub-criticality the facility eliminates the possibility to produce the self-sustained chain reaction. Now the Neutron source is under commissioning. In the report the facility and its control system current status is presented.

INTRODUCTION

Since February 2012 ADS Subcritical Assembly Neutron Source is under construction and assembling in NSC KIPT, Kharkov, Ukraine [1]. In 2016 the construction, assembling and installation of the main technological systems of the Neutron source were completed and commissioning of the systems were started. All buildings, technological constructions were completed in the end of 2014 year. The main facility specifications are shown in Table 1.

The electron linear accelerator, driver of the SA, was designed and manufactured in Institute of High Energy Physics (IHEP), Beijing, China [2]. Now the accelerator assembled in NSC KIPT and is under beam commissioning and tests. The electron beam commissioning for the whole accelerator was started in March 2017. As a result of the first experiments the electron beam was delivered to the middle of the transportation channel [3].

The SA core is a set of fuel elements of WWR-M2 type by the TVEL corporation production (Russia) of low enriched uranium (19,7% ^{235}U). The fuel is finely dispersed uranium dioxide UO_2 that is uniformly distributed in aluminium matrix. The main fissions of actinides are produced with thermal neutrons.

Neutron Source is nuclear facility all technological systems of the facility are under regulation of State Inspection of Nuclear Regulation of Ukraine that is working in accordance with international nuclear regulation legislation. This regulation demands certain requirement to the design and realization of the facility control system in order to provide the conditions of the facility safe operation [4].

Table 1: Main NSC KIPT Neutron Source Parameters

Parameter	Value
Neutron generating target	U, W
Target photo neutron output, n/s	$3{,}01\cdot10^{14}$ (U-target) $1{,}88\cdot10^{14}$ (W-target)
Neutron multiplication constant k_{eff}	Not more then 0,95
Fissionable material of the core	Low enriched uranium with 19,7% of ^{235}U isotope
Neutron reflector	Two zone: intrinsic zone is beryllium, outside zone is graphite
Moderator, coolant	Demineralised water (H_2O)
Neutron flux at the core, n/cm^2·s	$2\cdot10^{13}$
Energy release, kW	192 (U-target) 131 (W-target)

NSC KIPT NEUTRON SOURCE SUBSYSTEMS

NSC KIPT ADS Subcritical Assembly Neutron Source consists of the following main technological systems:

- Neutron Source building and technological constructions.
- Biological shielding.
- Linear accelerator and electron beam transportation channel.
- Neutron generating target.
- Facility core with fuel elements and moderator.
- Cooling systems of the facility core and neutron generating target.
- Fuel machine.
- Control system.
- Radiation monitoring system.
- Neutron flux and criticality measurement system.
- Waist fuel and target storage pools.
- Neutron channels.
- Special sewage system.
- Special ventilation system.
- Physical protection system

To provide the start up of the Nuclear facility that is NSC KIPT ADS Subcritical Neutron Source should provide and carry out the commissioning, State Accept and Licensing Procedure for technological systems, mentioned above.

Biological Shielding

Biological shielding consists of radial core biological shielding with shutters for the neutron channels and two

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AUSTRALIAN SQUARE KILOMETRE PATHFINDER - COMMISSIONING TO OPERATIONS

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Abstract

The Australian Square Kilometre Array Pathfinder (ASKAP) [1] is CSIRO's newest radio frequency interferometer located in Western Australia. It is currently operating in a mixed early science and commissioning phase. This paper gives an overview of the current instrument, highlighting updates and changes to software since the last status update. As previous papers, this overview centers on the monitoring and control software of ASKAP known as the Telescope Operating System (TOS).

OVERVIEW

Since the last status update [2] a lot of work by the monitoring and control software team has gone into supporting debugging of hardware and firmware of ASKAP. As engineers and scientist are progressing their understanding of this new, never used technology, requirements are continuously added or refined. We have also focused on the high level user interfaces as more time is allocated to routine observations and users gain experience with the instrument. The overall monitoring and control software architecture has been solid and has not changed since its inception about 10 years ago. Some minor modifications to this architecture have been driven by technology limitations or new requirements. The logical view of is presented in Fig. 1.

One of the features of the TOS is its configuration management. New deployment sites can be added mainly through configuration only additions. This is used to differentiate between different target deployments or even instruments now:

- ASKAP - the configuration of the main telescope containing the commissioned antennas and correlator
- MATES - the hardware test laboratory system
- COMMISSIONING - a independent subset of telescopes and hardware still to be commissioned
- EFFELSBERG - a self-contained TOS deployment for a PAF operating on Max Planck Institute for Radioastronomy Effelsberg telescope
- FASTRX - an engineering set-up to test the FAST multibeam receiver constructed by CSIRO for the FAST 500 meter telescope

For the EPICS systems sites are simply distinguished through different process variable prefix. This even allows co-location of systems in the same network deployment. The list above also shows non-ASKAP telescope deployments demonstrating the solid architectural choice. We are currently working on a TOS deployment for the next generation receiver system on our Parkes 64m telescope.

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PROJECT STATUS

Infrastructure

30 antennas have been with phased-array feed (PAF) technology. 24 antennas have the full compliment of digital signal processing backends installed in the central building and five out of seven correlator backends are available for use. The new hybrid diesel/solar power station, including battery storage has been connected to the telescope. 16 telescopes and the correlator form the ASKAP array for early science programs, the remaining eight are part of the COMMISSIONING array. The final six PAFs, 12 backend system and two correlator blocks are being installed in the upcoming months.

Science Data Processing

The ingest of data on the science data processing side is currently setting the limiting of antennas used for early science programs to 12. Processing is not yet done automatically after data ingest, but early science programs are processing their data suing the Pawsey supercomputing platform.

MONITIORING AND CONTROL SOFTWARE

Software Infrastructure

Software technologies have progressed since the inception of the TOS. In the early stages of the project numerous third party software systems were not available as part of the host operating system or were rapidly changing. For this purpose a from source recursive build system was developed in house. All software is deployed as a single version e.g. TOS-2.13 including all dependencies. We are in the process of moving towards OS provided packages and are changing as part of the upgraded to the latest version of debian - stretch. After this upgrade, software release will be per logical set of software as part of a continuous deployment platform. To facilitate this automation we are in the process of moving from subversion to git which integrates better with automated process and our issue tracking system JIRA. During this upgrade process all TOS software will move from bare server hosting to high-availability servers for better operational integrity and uptime.

EPICS

The `asyn` abstraction and composite IOC structure has been proven to work extremely well in hiding the complexity of the system. We are still based on EPICS version 3.12.x, however `pvaSrv` has now been added to all IOCs, so we can leverage v4 features. As described in the previous paper,

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THE LIGHT CONTROL AND INTERLOCK SYSTEMS

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Abstract

LIGHT (Linac Image Guided Hadron Technology) is a particle therapy system[1] developed by Advanced Oncotherapy plc. Accelerator, control and interlock systems are developed by its subsidiary A.D.A.M. SA, a CERN spin-off. The system is being designed to accelerate protons up to 230 MeV using a modular and compact 25-meter-long linear accelerator. It is being designed to operate in pulsed mode where beam properties (energy, pulse charge and spot size) can be changed at 200 Hz.

The LIGHT product will be installed in different facilities. As such, the installations will differ in accelerator and beam transfer line layouts, number of treatment rooms (with an optional gantry), facility services, equipment suppliers and equipment versions. Thus, the control and interlock systems need to be extensible through configuration and modularization. To achieve this, the control system relies on a multi-tier architecture with a clear separation between front-end devices and controllers. To minimize time-to-market, the systems rely mostly on COTS hardware and software, including a timing and triggering system and a light-weight software framework to standardize front-end controllers.

INTRODUCTION

ADAM S.A. is a CERN spin-off founded in 2007 in Geneva (Switzerland) developing applications of detectors and accelerators to medicine and is a subsidiary of London-based Advanced Oncotherapy PLC. ADAM S.A. is developing the linear accelerator to be used in the Linac for Image Guided Hadron Therapy (LIGHT) project of Advanced Oncotherapy PLC [1].

Current proton therapy solutions mostly rely on synchrotron and synchrocyclotron accelerators for accelerating protons. Driven by the recent advancements in linear accelerator technology, ADAM S.A. has designed a new linear proton accelerator as depicted in Figure 1. The main advantages are:

- **Precision:** the system has an active longitudinal modulation along the axis of beam propagation (beam energy and therefore the treatment depth can be electronically varied during therapy), rather than using a passive modulation system (where the cyclotrons' fixed initial energy is degraded by the interposition of variable thickness energy absorbers between the accelerator and the patient, causing a quality loss of the beam). Moreover, the LIGHT system has a dynamic transverse modulation that allows a precise 3D treatment of the tumours (spot scanning).
- **Compact:** the linear accelerator has compact dimensions compared to a cyclotron or synchrotron, therefore reducing size and costs of production and installation.
- **Modularity:** LIGHT is conceived as an assembly of modular units thereby facilitating installation and possible displacement to a different site. This specific feature offers radiation therapy centres complete freedom of customisation, allowing the choice of a wide range of maximum treatment energies.
- **High frequency:** the very short pulses (a few microseconds) typically for the linear accelerator and the high repetition frequency (up to 200 Hz) are extremely useful to perform a highly conformational therapy based on a fast 3D spot scanning of the tumour.

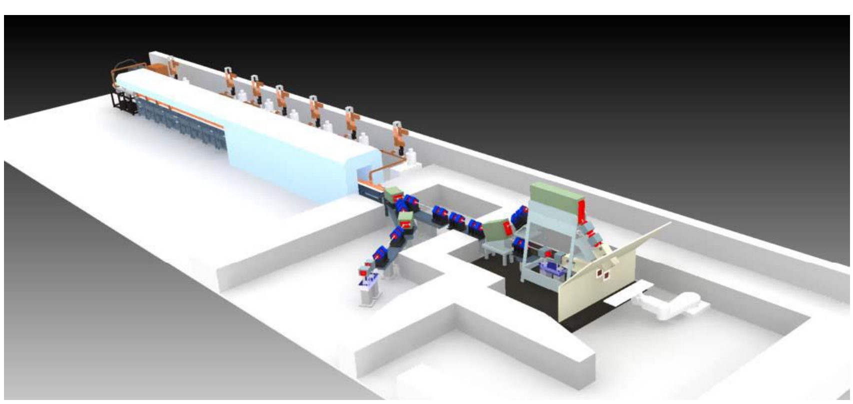

Figure 1: Example layout for LIGHT.

[1] The LIGHT Proton Therapy System is still subject to conformity assessment by AVO's Notified Body as well as clearance by the USA-FDA.

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RECENT ENHANCEMENTS TO THE LOS ALAMOS ISOTOPE PRODUCTION FACILITY*

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Abstract

Isotopes produced at Los Alamos National Laboratory (LANL) are saving lives, advancing cutting-edge research, and helping to address national security questions. For the past two years LANL's Accelerator Operations & Technology Division has executed a $6.4M improvement project for the Isotope Production Facility. The goals were to reduce the programmatic risk and enhance facility reliability while at the same time pursuing opportunities to increase general isotope production capacity. This has led to some exciting innovations. In this paper we will discuss the engineering designs for an upgraded beam raster system, a new beam diagnostics capabilities and our new collimator, which is both adjustable and 'active' (beam current and temperature measurements). We will also report on results obtained and lessons learned from the commissioning phase and initial production run.

INTRODUCTION

The Isotope Production Facility (IPF) is located on the northwest side of the Los Alamos Neutron Science Center (LANSCE) accelerator complex and consists of a dedicated beamline, target and hot cell as shown in Figure 1. Beam from the LANSCE 100 MeV drift tube linac (DTL) is directed through a shield wall in the main accelerator tunnel to a separate beamline in the IPF tunnel that connects to the IPF target.

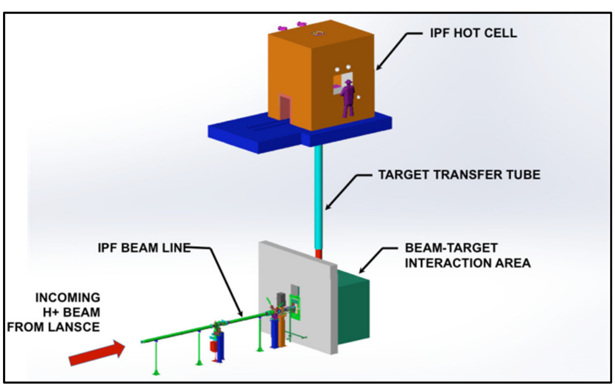

Figure 1: Layout of IPF Facility.

The overarching motivation for the IPF Accelerator Improvement Project (AIP) was

- To *reduce programmatic risk* with respect to beam window failure (which is a consumable)
- To *enhance IPF facility reliability* with improved diagnostic capabilities while at the same time pursuing opportunities
- To *enhance* general isotope *production capacity*.

PROJECT GOALS

Based on the overarching motivation four Focus Areas with associated goals were developed. The first is aimed at improving the beam window design to reduce programmatic risk associated with a target window failure. This is listed here for completeness but will not be discussed any further in this paper.

The second is aimed at improving the beam rastering system to ensure that the beam-power is distributed optimally across the surface of each target.

The third is aimed at developing and installing improved beam diagnostics in the IPF beamline to better predict the beam size and position at the target window and target therefore *enhancing the reliability* of IPF. This requires transverse emittance characterization of the beam, the measurement of rastered and unrastered beam profiles, accurate beam current measurement over a larger dynamic range and time-of-flight energy measurements at the nominal operational energies of 41, 72 and 100 MeV.

The last area was focused on the development of an active & adjustable collimator. The collimator is divided into four active-segments with a beam-spill current and temperature measurement for each segment. Furthermore, we will enable the use of larger diameter targets to *increase the production capacity* of various radioisotopes at IPF by replacing the fixed-diameter collimator with an adjustable aperture unit.

BEAM RASTER

The Beam Raster System is using an existing pair of Elgar SmartWave Switching amplifiers/power supplies which run at 4950 Hz AC. One complete raster cycle is drawn in 202 µs. During the nominal 625 µs beam macropulse 3+ revolutions of the same diameter are drawn. There is 1 master and 3 slaves for the horizontal and vertical rastering which are connected respectively to the horizontal and vertical raster magnets in the IPF beam line. The master power supplies are synchronized together in phase offset by about 89 degrees.

The raster system provides three distinct functionalities, all implemented in a redundant configuration using two National Instruments cRIO systems, shown in Figure 2.

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A REAL-TIME, DISTRIBUTED POWER MEASURING AND TRANSIENT RECORDING SYSTEM FOR ACCELERATORS' ELECTRICAL NETWORKS

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Abstract

Particle accelerators are complex machines with fast and high power absorption peaks. Power quality is a critical aspect for correct operation. External and internal disturbances can have significant repercussions causing beam losses or severe perturbations.

Mastering the load and understanding how network disturbances propagate across the network is a crucial step for developing the grid model and realizing the limits of the existing installations.

Despite the fact that several off-the-shelf solutions for real time data acquisition are available, an in-house FPGA based solution was developed to create a distributed measurement system. The system can measure power and power quality on demand as well as acquire raw current and voltage data on a defined trigger, similar to a distributed oscilloscope. In addition, the system allows recording many digital signals from the high voltage switchgear enabling electrical perturbations to be easily correlated with the state of the network.

The result is a scalable system with fully customizable software, written specifically for this purpose. The system prototype has been in service for two years and full-scale deployment is currently ongoing.

INTRODUCTION

CERN's high voltage electrical network is composed of more than 100 substations that operate at voltage levels of 3.3 kV, 18 kV, 66 kV and 400 kV. With thousands of electrical equipment and a wide range of different technologies installed, the operation, control and supervision of the network constitutes a challenging task. Furthermore, the electrical network has a critical role in the accelerators' reliability, this being directly correlated to the network availability and quality of supply.

This paper presents a digital data acquisition system developed at CERN and called Transient Recording System (abbreviated CTRS). Its purpose is to perform transient analysis, measurements of network parameters (voltage, power), power quality and disturbances. One of main objectives of the CTRS is to correlate accelerators' instabilities to the electrical network behaviour.

The same hardware platform can be used to perform power flow analysis, just by swapping the on-board software.

Measurement of power flows is particularly important in the accelerators networks where the load profile is rapidly changing with spikes of several hundreds of kVA within a few seconds and with cycles lasting up to several minutes [1]. The power curves can be used for network analysis, either directly or in conjunction with computational models of the network.

Network disturbances also play an important role with the accelerators overall availability, having a great impact on the beam stability and often causing beam losses or perturbations. Understanding and identifying the correlations between power quality and beam stability helps to plan network consolidations and upgrades.

The transient recording function greatly benefits post-mortem investigation after faults on the electrical network, reducing the time to diagnose the failure as well as giving important data for subsequent analysis.

In addition, the system is capable of providing power quality data for statistical purposes. Being based on a scalable platform, additional features can always be developed and added even with the system in service.

A number of different solutions ranging from an entire off-the-shelf to a fully in-house system have been explored in the early stage of the project [2]. The final solution tries to take the best from the two worlds, featuring a hybrid system composed by some commercial components, several in-house hardware parts and the software and its source code owned by CERN [3]. This option permits to control every system feature, also allowing interfacing it easily with other CERN monitoring systems such as beam or machines status.

HARDWARE SETUP

The CTRS is a distributed data acquisition system (DAQ) able to monitor a scalable number of high voltage bays and other network-related analog or digital signals.

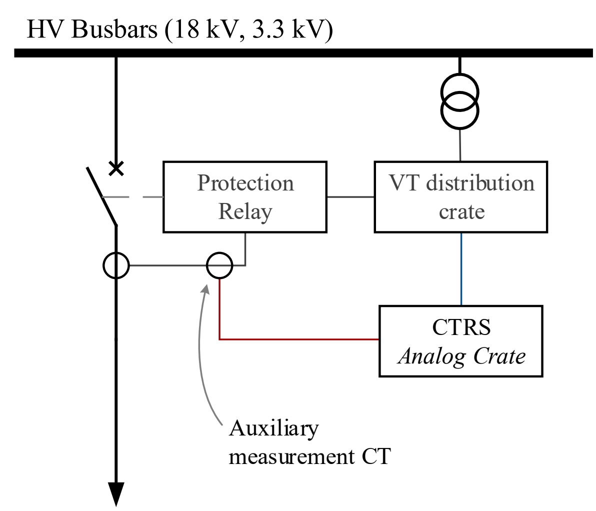

Figure 1: Base configuration for analog acquisition.

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FPGA-BASED PULSED-RF PHASE AND AMPLITUDE DETECTOR AT SLRI

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Abstract

In this paper, the prototype of phase and amplitude detector for pulsed-RF measurement is described. The hardware is designed in VHDL and implemented using Field Programmable Gate Array (FPGA) for digital processing. The main phase and amplitude detection algorithm is implemented using state machine in the MicroBlaze soft processor. The detector system is designed to measure the phase and amplitude of a 5-microsecond wide 2,856 MHz pulsed-RF at a repetition rate of 0.5 Hz. The front-end hardware for the pulsed-RF signal acquisition is also described with the interface to the FPGA-based controller part. Initial test results of the prototype are presented.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) is a dedicated synchrotron radiation facility in Nakhon Ratchasima, Thailand. Its 40-MeV linac has been operated since the first light in December 2001. The SLRI's linac is a 40 MeV electron linear accelerator consisting of five different parts to accelerate the electron beam. These parts are pre-buncher 1, pre-buncher 2, buncher, a 20-MeV accelerating tube 1, and 20-MeV accelerating tube 2. They are fed with a pulsed RF signal operating at 2,856 MHz as the accelerating field from a klystron. Currently, the phase and amplitude of the RF signal in the waveguide can be adjusted manually by the high power phase shifters and attenuators. With an increasing demand of higher electron beam quality, an improvement in phase and amplitude of the RF signal is necessary. The measurement system of the RF phase and amplitude in each part of the linac is needed for stability improvement.

In this paper, the prototype of phase and amplitude detector is described. The system is designed to measure the phase and amplitude of a 5-µsec wide pulsed RF signal at a repetition rate of 0.5 Hz. RF front-end hardware and FPGA-based detector system are presented in the next section. An algorithm implemented in the software part is described in the following section. System performance and conclusion are presented at the end of this paper.

HARDWARE

In order to measure the phase and amplitude of the pulsed RF signal correctly, both hardware and software of the detector system must be designed carefully. This section describes various hardware parts used in the design and implementation of the prototype. The RF front-end hardware is explained. A main processing system hardware based on FPGA is described and the system integration is also discussed.

RF Front-End Hardware

Each set of the RF front-end circuit is designed to measure the amplitude and phase of a 5-µsec pulsed RF from the klystron to the linac. Six RF front-end sets are needed to be installed in the linac system to perform the measurement at the five parts, as discussed in the introduction part, plus one location just after the klystron.

The amplitude measurement uses RF diode as a linear detector. The phase detection is designed to measure the phase differences between the pulsed RF and a cw RF reference line of the linac. Both of these signals have the same frequency. In the phase measurement, a double balanced mixer (DBM) is used as a phase detector. The detail of this function of the DBM can be found in [1]. A voltage-controlled phase shifter is used as a nulling detector. Other RF components comprise splitter, low-pass filters, and band-pass filters. The principle of the phase measurement technique can be referred to [2] and examples of the complete measurement system can be found in [3] and [4].

In this prototype development, the selected RF diode detector is an 8473B model with positive output from Agilent Technologies, the RF circuit components are selected from Mini-Circuits, and the voltage-controlled phase shifter is chosen from Lorch Microwave. Six of these front-end sets are tested in the laboratory with Agilent Technologies' RF Vector Signal Generator (VSG) model EXG N5172B. In addition, a narrow-pulse modulation capability is available on the VSG in order to generate the pulse modulated RF signal. For future installation in the linac cabinet system, two sets of the phase and amplitude detector are put in the chassis similar to the ones described in [4]. This makes the total of three RF chassis ready for cabinet installation. The RF circuit test set up is shown in Figure 1. Typical phase shift characteristics of voltage-controlled phase shifters is shown in Figure 2. The complete RF chassis is shown in Figure 3.

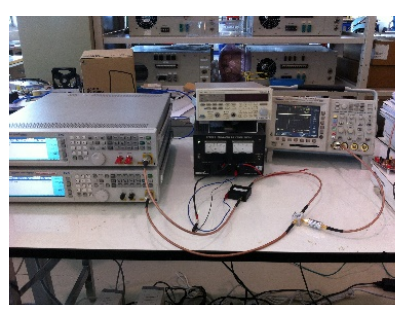

Figure 1: Laboratory test set up for RF circuit.

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FPGA-BASED MOTION CONTROL SYSTEM FOR MEDICAL LINEAR ACCELERATOR DEVELOPMENT AT SLRI

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Abstract

Linear accelerator technology has been widely applied to radiotherapy machines and there has been an increasing demand of the machines in Thailand over the recent years. An attempt to increase the availability of the low-cost machines has been proposed for the domestic use purposes. Currently, the prototype of the 6 MeV medical linear accelerator is under development at Synchrotron Light Research Institute (SLRI) in Nakhon Ratchasima, Thailand.

For beam shaping purposes a so-called secondary collimator is utilized with different size arrangement of the collimator jaws. The collimator motion control is one of the necessary machine subsystems for producing the desired field size of the beam. In this paper, the FPGA-based motion control system of the machine prototype is presented. The programmable logic part of the hardware is designed in VHDL for digital processing. The main motion control algorithm is implemented in the main processor of Zedboard FPGA. Communication between the motion control subsystem and the main control system software of the machine is also described.

INTRODUCTION

Cancer is one of the leading diseases that causes death all over the world including Thailand. The demand of cancer treatment machines has been increasing over the recent years to serve the country's need as the number of patients increases every year. The choice of choosing a radiotherapy machine for cancer treatment has been increased accordingly. In addition to saving patient's life from choosing the radiotherapy machine, it maintains a quality of life as the use of radiotherapy preserves a number of functions of human organs, for example, female breast (for cosmesis), prostate (for better sexual function), bladder (for more convenient urination) [1].

Linear accelerator has been widely utilized in radiotherapy machines. An attempt to increase the availability of the low-cost machines has been proposed for the domestic use. Currently, SLRI has developed a prototype of the 6 MeV medical linear accelerator (medical linac) for cancer treatment. Reverse engineering approach has been employed in this research and development via a donated machine. The prototype consists of a linear accelerating structure of the S-band standing wave type at 2,998 MHz operating frequency, a 3.1 MW magnetron driven by a solid-state modulator, and a hot-cathode electron gun [2]. A brief technical specification of the prototype is listed in Table 1.

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Table 1: Parameters of the Medical Linac [2]

Parameter	Value
X-ray beam energy [MV]	6
X-ray dose rate [MU/min]	400 - 600 Maximum
Field size [cm^2]	0x0 to 40x40
Linac frequency [MHz]	2,998
Type of accelerator	Standing wave
Gantry rotation	Vertically fixed

A drive stand and a gantry of the prototype provide housing for a modulator cabinet and its control system for magnetron and electron gun. An automatic frequency control (AFC) system is also installed in the drive stand.

A linac treatment head consists of an X-ray target attached to the end of the accelerating structure. A transmission ionization chamber is installed to measure a beam dose. A dosimetry control system is designed to monitor and control the beam by processing the signals from the ionization chamber. To confine the shape and size of the radiated beam, three-stage treatment beam collimators are used, fixed primary collimators, secondary collimators or so-called beam limiting jaws, and a multi-leaf collimator (MLC). A timing system is used to link various subsystems of the machine in order to provide proper synchronization in X-ray beam generation.

A central control system software is designed to interface with all subsystems for proper operation. It is run on the Main Control System with a display monitor and GUI. All subsystems are connected to the Main Control System in a private network as shown in Figure 1.

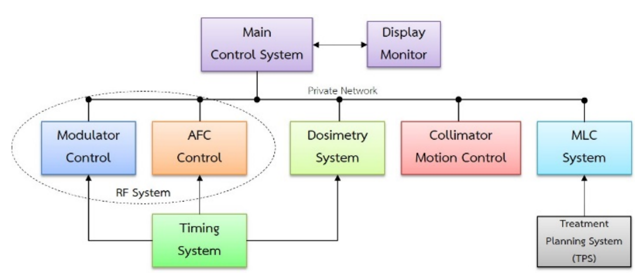

Figure 1: Network diagram of the machine prototype.

This paper describes a motion control system of the secondary collimators for radiotherapy machine. Secondary collimators consist of two adjustable pairs of jaws. They are installed in the linac treatment head. One pair is above the other and at right angles. Control system design, both

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COMMISSIONING AND VALIDATION OF THE ATLAS LEVEL-1 TOPOLOGICAL TRIGGER

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Abstract

The ATLAS experiment has recently commissioned a new hardware component of its first-level trigger: the topological processor (L1Topo). This innovative system, using state-of-the-art FPGA processors, selects events by applying kinematic and topological requirements on candidate objects (energy clusters, jets, and muons) measured by calorimeters and muon sub-detectors. Since the first-level trigger is a synchronous pipelined system, such requirements are applied within a latency of 200 ns. We will present the first results from data recorded using the L1Topo trigger; these demonstrate a significantly improved background event rejection, thus allowing for a rate reduction without efficiency loss. This improvement has been shown for several physics processes leading to low-p_T leptons, including $H \rightarrow \tau\tau$ and $J/\Psi \rightarrow \mu\mu$. In addition, we will discuss the use of an accurate L1Topo simulation as a powerful tool to validate and optimize the performance of this new trigger system. To reach the required accuracy, the simulation must take into account the limited precision that can be achieved with kinematic calculations implemented in firmware.

INTRODUCTION

The ATLAS experiment at CERN is one of the multipurpose experiments operating at the Large Hadron Collider (LHC) at the European Center of Nuclear Research in Switzerland [1]. At design specifications, the LHC provides proton-proton (*pp*) collisions at a center of mass energy of $\sqrt{s} = 14$ TeV and an instantaneous luminosity of $\mathcal{L} = 10^{34}$ cm^{-2}s^{-1} [1]. These protons collide at a rate of 40 MHz; however, bandwidth constraints impose limits on the number of events per second that can be recorded, and the majority of these events contain only *pp* scattering events. This motivates the need for an online trigger system that identifies certain signatures, including but not limited to, missing transverse momentum, lepton production, and high p_T jets [2].

The ATLAS experiment includes an online Trigger and Data Acquisition (TDAQ) system that selects events that will be saved to offline storage for later physics analysis. This system is comprised of two levels, the first being a hardware based, low-granularity level-1 (L1) system with a design latency of 2.5 µs [3]. This system constructs Regions-of-Interest seeding the software based algorithms used in the subsequent high level trigger (HLT) system, reconstructing the event with full detector read-out granularity. The L1 system is further divided into three subcomponents, the Calorimeter Trigger (L1Calo), the Muon Trigger (L1Muon) and the Central Trigger Processor (CTP). The L1 system reduces the 40 MHz collision rate to 100 MHz, and the HLT trigger reduces the rate further to 3-4 kHz [3].

The level-1 topological trigger system is a new element deployed to impose topological constraints to L1 triggers [4]. The goal of this system is to purify L1 event selection by imposing kinematic requirements motivated by the event topology of certain processes. These new electronic boards compute angular and kinematic quantities between various L1 Trigger Objects (TOBs) [4]. Its role in the L1 trigger is shown in the flowchart included in Fig. 1. The system is designed to receive and process up to 6Tb/s of real time data [4]. In 2016 the L1Topo system was first deployed online. This proceedings contribution details its commissioning and validation.

MOTIVATION

As higher luminosities are reached at the LHC, the production rate for physics signatures increase [5]. To cope with the increase in trigger rate, two solutions are traditionally employed: to record one out of N events, i.e. to prescale the trigger; and to tighten the selection criteria, e.g., to increase the transverse momentum threshold. Both approaches cause some loss of interesting data. For example, the $B^0 \rightarrow J/\psi\ \varphi$ analysis was approaching bandwidth limits for triggering on low p_T muons [6]. The B-physics program would benefit from improved purity in L1 event selection as proposed by L1Topo [6]. A non-exhaustive table is given in Table 1 to illustrate some physics applications for given topological quantities. As a concrete example, consider the following two variables implicated in di-muon pairs: the angular separation ΔR and the di-muon mass $M_{\mu\mu}$ as defined in equations (1) and (2). The application of these quantities is illustrated in Fig. 2.

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} \quad (1)$$

$$M_{\mu\mu}^2 = p_T^{\mu 1} p_T^{\mu 2} \cdot (\cosh(\Delta\eta_{\mu\mu}^{12}) - \cos(\Delta\phi_{\mu\mu}^{12})) \quad (2)$$

Table 1: Physics use Cases for Some Topological Quantities. The L1Topo Firmware Accepts a Multitude of Parameters such that Each Physics Use case can be Optimally Tuned

Topological Quantity	Physics Use Case
Dijet mass	Vector Boson Fusion / Scattering
Jet, Et-Miss $\Delta\phi$	Exotics, SUSY
Di-muon mass, radius	B-physics
Di-tau opening angle	Higgs

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RUN CONTROL COMMUNICATION FOR THE UPGRADE OF THE ATLAS MUON-TO-CENTRAL-TRIGGER-PROCESSOR INTERFACE (MUCTPI)

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Abstract

The Muon-to-Central-Trigger-Processor Interface (MUCTPI) of the ATLAS experiment at the Large Hadron Collider (LHC) at CERN will be upgraded to an ATCA blade system for Run 3, starting in 2021. The new design requires development of new communication models for control, configuration and monitoring. A System-on-Chip (SoC) with a programmable logic part and a processor part will be used for communication to the run control system and to the MUCTPI processing FPGAs. Different approaches have been compared. First, we tried an available UDP-based implementation in firmware for the programmable logic. Although this approach works as expected, it does not provide any flexibility to extend the functionality to more complex operations, e.g. for serial protocols. Second, we used a SoC processor with an embedded Linux operating system and an application-specific software written in C++ using a TCP remote-procedure-call approach. The software is built and maintained using the framework of the Yocto Project. This approach was successfully used to test and validate the MUCTPI prototype. A third approach investigated is the option of porting the ATLAS run control software directly to an embedded Linux instance.

THE ATLAS EXPERIMENT AT THE LHC

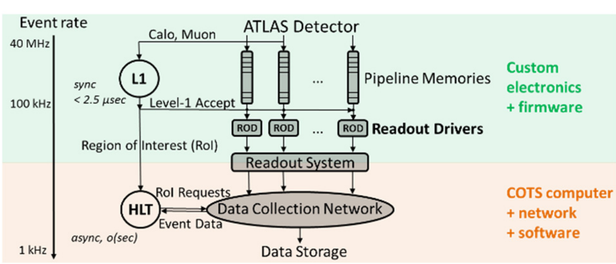

Figure 1: The trigger and data acquisition system of ATLAS.

The ATLAS experiment [1] is a general-purpose experiment at the Large Hadron Collider (LHC) at CERN. It observes proton-proton collisions at a centre-of-mass energy of 13 TeV. With about 25 interactions in every bunch crossing (BC) every 25 ns, there are 10^9 interactions per second potentially producing interesting physics. The trigger system selects those events which are interesting to physics and which can be recorded to permanent storage at a reasonable rate. The ATLAS trigger system (see Figure 1) consists of a Level-1 trigger, based on custom electronics and firmware, which reduces the event rate to a maximum of 100 kHz, and a high-level trigger system based on commercial-off-the-shelf computers, network components, and software which reduces the event rate to around 1 kHz.

THE LEVEL-1 TRIGGER SYSTEM

The Level-1 trigger system (see Figure 2) uses reduced-granularity information from the calorimeters and dedicated muon trigger detectors. The trigger information is based on multiplicities and topologies of trigger candidate objects. The muon trigger is based on Resistive Plate Chambers (RPC) in the barrel region and Thin-Gap Chambers (TGC) in the end-cap region. The Muon-to-Central-Trigger-Processor Interface (MUCTPI) [2] combines the muon candidate counts from the RPC and TGC taking into account double counting of single muons that are detected by more than one chamber due to geometrical overlap of the chambers and the trajectory of the muon in the magnetic field. It sends the results to the Central Trigger Processor (CTP) which combines all trigger object multiplicities from the calorimeter trigger and from the MUCTPI, as well as the topology flags from the Topological Processor to make the final Level-1 decision based on rules described in a trigger menu. The CTP then sends the Level-1 decision back to the detector front-end electronics.

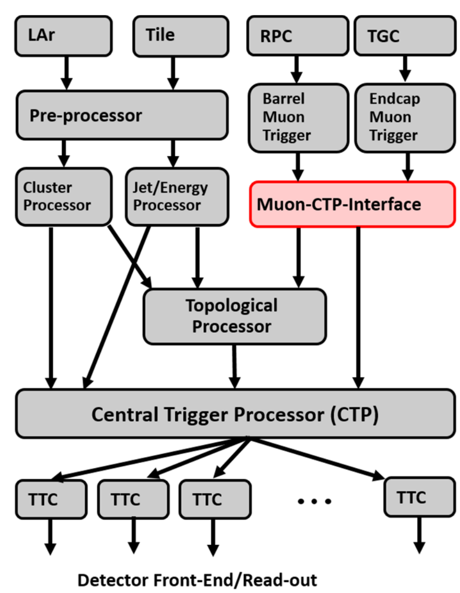

Figure 2: The Level-1 trigger system of ATLAS.

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REAL-TIME LIQUID SCINTILLATOR CALIBRATION BASED ON INTENSITY MODULATED LED

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Abstract

In many nuclear applications such as nuclear/high-energy physics and nuclear fusion, sensors are widely used in order to detect high energy particles. One of the available technologies is the scintillator, which is generally coupled with a photomultiplier and pulse amplifier. The detector acquisition chain is not stationary; mainly, it changes its gain as a function of the temperature, the nuclear irradiation and the magnetic field on the photomultiplier; therefore it needs to be periodically calibrated during its operation. A calibration method reported in the literature is based on the use of a pulsed LED that flashes on the photomultiplier by generating a train of reference pulses. A new technique may be the use of an LED with continuous sinusoidal intensity emission. This provides as an output of the detector chain a small sinusoidal signal which can be digitally processed in real time, by measuring the gain and the delay time of the detector chain. Moreover, this sinusoidal background signal can be removed in real-time, before any processing or storage of data. This paper presents the technique, reporting its simulation and the main characteristics of the developed firmware and the hardware.

Keywords: (Liquid Scintillators, Neutron and Gamma Detection, Intensity Modulation, Real-Time Calibration, ITER Radial Neutron Camera, Digital Signal Processing)

INTRODUCTION

In many nuclear applications such as nuclear/high-energy physics and nuclear fusion, there is an extensive use of sensors, in order to detect high energy particle.

One of the available technologies is the scintillator, which is generally coupled with photomultiplier tube (PMT) and pulse amplifier (see Figure 1). The high energy particles incident on the scintillator produces electrical pulses as output of the PMT chain. The pulses have different shape and amplitude depending on the particle type and energy. In general, the pulses due to high energy particles are composed of a rising and a falling exponentials, having respectively little rising time and large falling time. The rising and falling constants depend on the particle type. Many algorithms can be used in order to discriminate the type of particles, such as Charge Comparison [1][2], or Pattern Recognitions [3].

Anyway, the detector acquisition chain is not stationary; mainly, it changes its gain as a function of the PMT temperature and sensor irradiation; this gain variation can cause distortions in the neutron Pulse Height Spectrum (PHS). For this reason, the acquisition chain containing the PMT needs to be periodically calibrated during its operation.

Classical Method: Pulsed Led Calibration

In the literature is reported a calibration method based on the use of a pulsed LED that flashes on the photomultiplier, so generating a train of reference pulses as output of the PMT chain [4].

This method is able to improve the spectrometer characteristics, but it also has intrinsic limitations due to the simultaneous effect of the LED pulses with the neutron and gamma pulses. The LED must induce on the photomultiplier a signal having different shape with respect the Neutron and Gamma, in order to distinguish the pulses corresponding to neutron, gamma or LED. In the energy spectra, the effect of the LED pulses is located in a different area than the physic particles; moreover, for algorithm not based on the spectra calculation, the LED pulses can be discriminated due to their shape, being larger than the particles ones [5].

Anyway, by increasing the LED pulse duration, the joint probability to have at the same time a LED pulse and a particle pulse increases. This can be a problem because, when this overlapping event is not recognized, an error is caused in the PMT chain gain estimation, especially when the particle flux is high.

Another limitation concerns the measurement rate for the PMT chain; because, by increasing the rate of the LED pulses, the coincidence between particles and LED pulses increases, and this reduces the functionality of the instrument.

In general, the LED pulse frequency is around 1KHz [4], therefore the relative gain measurement rate is lower; this may be inadequate in the case of rapid variations in particles flow.

PROPOSED METHOD: INTENSITY MODULATION LED CALIBRATION

The new technique is based on the sinusoidal modulation of the LED. The frequency and the intensity of the modulation can be changed, taking into account the effect on the algorithm.

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RF LEAKAGE DETECTOR SYSTEM

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Abstract

FREIA Laboratory is a new facility for developing and testing the instrumentation for particle accelerators. There are two pulsed 400 kW 352 MHz RF sources, presently used for testing the superconducting RF cavities and there is a need to monitor the electromagnetic field in the experimental hall. The RF leakage detector system consists of number of physically identical nodes with one of them configured as a master and the rest as the slaves. Each node supports 3 separate RF measurement channels with a frequency span of 100 kHz to 1 GHz. A desired frequency band is selected using a front-end band-pass filter. The sensitivity of the sensor is -34 dBm and the dynamic range 48 dB. The slaves are battery powered for easy installation. Special care has been taken to minimize the power consumption resulting in battery life to be 0.3 to 1.1 year using 3xAAA batteries in continuous operation. The footprint of the module is 60x100x40 mm. The communication between the master and the slaves uses Wireless Link operating at the 868 MHz ISM band. The system is controlled by EPICS using the StreamDevice driver. The master RF module is connected via RS-232 line and MOXA NPort 5610 server to the control system network.

INTRODUCTION

High power RF sources are used in test laboratories and facilities all over the world as a mean to generate high amplitude, high frequency electromagnetic waves to power different test-setups. The sources are usually based around klystrons, tetrodes or solid-state amplifiers in the kW to MW range. In order to connect the sources rigid coaxial lines or waveguides are typically used and any breaks or disconnections in the RF distribution chain could generate very high ambient fields. In these kinds of environments user safety is of paramount importance since the power levels involved could pose serious risk in case of system malfunction.

In addition to the different interlock stages embedded within the sources and test equipment external measurement devices are also required in order to monitor the working environment for any leakages in the RF-distribution chain which could potentially lead to personnel injuries due to the high power levels in the system.

The RF leakage monitoring and detection system is responsible for continuous measurements of the working environment in order to detect any abnormal ambient levels. In order to provide good coverage of large indoor test-stands such as FREIA [1] the system presented in the paper relies on multiple distributed nodes. It provides good coverage and performance whilst at the same time keeps the overall system cost low. The system is also designed to be able to measure pulsed signals as well as be reconfigurable to cover different frequency bands and to provide multi-band measurements.

SYSTEM ENVIRONMENT

In order to design an RF leakage detection system for an indoor environment it is necessary to have some description of the expected field distribution which has to be measured. Typical high power radio-frequency (RF) test-stands are indoor environments with a high number nearby metallic components like waveguides, metallic cabinets, shielding plates, water pipes and more. These kinds of environments put additional requirements on RF leakage detection system due to the high number of scattering components created when the RF signal propagates from a leak in the system. It is therefore important to predict which power levels of the ambient field will actually be measured when operating the system.

Due to the stochastic behaviour of the field distribution it is best described in terms of its probability density function (PDF). Multi-scattering environments have been well studied over several decades, especially within the mobile communication industry. One of the most common ways of describing the field distribution within a fast fading environment is by modelling it as either Rayleigh of Rician fading. The Rayleigh fading distribution describes the case where all the scattered signals are equal in magnitude whereas the Rician distribution describes the case where one of the signal components is higher in magnitude and dominates. As such the Rician distribution is a more general form of the probability density function of the distributed field and can be describes as [2]:

$$p(x) = \frac{x}{\sigma^2} e^{-(\frac{x^2+A^2}{\sigma^2})} I_0(\frac{Ax}{\sigma^2}) \tag{1}$$

Where σ is the rms amplitude of the scattered signals and A is the rms amplitude of the dominant signal. If the amplitude of the dominant signal is very small compared to the scattered signals the PDF reverts back to that of the Rayleigh distribution. A plot of the expected signal variations can be seen in Fig. 1. This would be the worst operating case in terms of measuring the ambient fields as the variation in the signal level is at its highest. If the dominant signal is much higher than the scattered signals the expected fading variations will be reduced and the ambient signal will experience less variations. In a real world scenario the signal is not expected to suffer quite as deep fading nulls and might be expected to mainly vary in the range of -30 to +6 dB.

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A MicroTCA BASED BEAM POSITION MONITORING SYSTEM AT CRYRING@ESR

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Abstract

At FAIR the commissioning of the re-assembled CRYRING accelerator, formerly hosted by Manne Siegbahn Laboratory Stockholm, is currently in progress. This compact low energy heavy ion synchrotron and experimental storage ring will be the main instrument for an extensive research programme [1] as well as a testing platform for the future beam instrumentation and control system concepts decided on for FAIR. Besides many other measurement systems CRYRING is equipped with 18 beam position monitors (BPM), for which a new data acquisition system (DAQ) was developed. Based on the upcoming MicroTCA form factor in combination with FPGA mezzanine card (FMC) technology the DAQ system was designed to be state-of-the-art, reliable, modular and of high performance. Testing „Open Hardware“, here the ADC FMCs and FMC carrier boards, was another intention of that concept. The DAQ layout and obstacles that had to be overcome as well as first measurements will be presented.

INTRODUCTION

The updated CRYRING accelerator [2] is presently under commissioning in the Experiment Cave B on the GSI Campus. A schematic overview over site and accelerator design is given in Fig. 1.

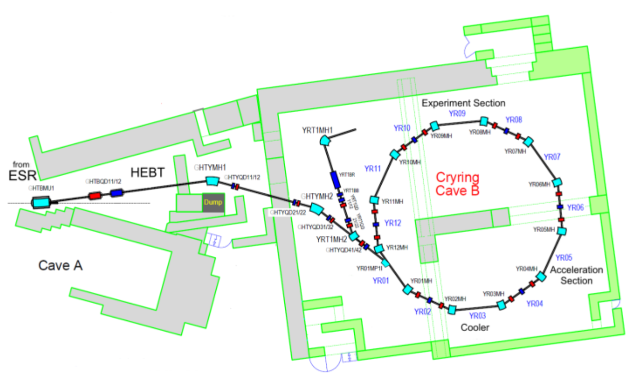

Figure 1: Scheme of CRYRING installation in Cave B.

As described in [3] the CRYRING is equipped with plenty of beam instrumentation devices to measure beam profiles, intensity, position and orbit. The latter one is based on a beam position monitor (BPM) system with 18 either horizontal or vertical oriented BPMs, which provides fundamental information for accelerator commissioning and optimization. CRYRING was delivered to GSI without BPM data acquisition electronics, so an adequate read-out had to be found. First choice would have been the Libera Technology [4], which is standard for all FAIR BPM systems. At time of that decision making the required Libera Hadron Platform B was not ready for purchase. As an alternative the very promising form factor FPGA Mezzanine Card (FMC) came up, which was well featured by CERN and DESY in the accelerator community. FMC in combination with the upcoming Micro Telecommunications Computing Architecture (µTCA) standard, which provides significant improvements with respect to data bandwidth on the backplane, redundancy and high availability compared to traditional VME solutions, was defined as being worthy to be evaluated.

INFRASTRUCTURE

Control System

The CRYRING installation at GSI is a dedicated testing machine for FAIR hard- and software developments. The control system is a CERN style FESA [5] based 3-tier architecture with a JavaFX GUI at the application level. The timing system consists of the Open Hardware (OHWR) GSI White Rabbit Timing Master and the FAIR Timing Receiver Nodes (FTRN) hosting the GSI specific event decoding firmware [6].

Acquisition Hardware

The BPM DAQ housed in a Schroff 12-slot MTCA.4 chassis combines a Concurrent Technology AM902-32 CPU with Dual PCIe x4 support on AMC ports 4-7 (FatPipe1) and 8-11 (FatPipe2) and five AMC FMC Carriers (AFC-V2). Those are equipped with 250 MSPS, 16 bit, 4 channel ADC FMC boards.

Figure 2: BPM DAQ system in µTCA form factor.

Both AFC and ADC board types were developed in cooperation between the Brazilian Synchrotron Light

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TIMING SYSTEM USING FPGA FOR MEDICAL LINEAR ACCELERATOR PROTOTYPE AT SLRI

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Abstract

A prototype of medical linear accelerator is under dvelopment at Synchrotron Light Research Institute (SLRI). In order to maintain the proper operation of the machine, the pulse signal is used to synchronize the various subsystems such as electron gun, RF trigger, and magnetron trigger subsystems. In this project, we design the timing system using a Xilinx Spartan-3 FPGA development board with VHDL in order to achieve the desired characteristics and sequences of the timing signals for those subsystems. A LabVIEW GUI is designed to interface with the timing system in order to control the time delay and pulse width via RS-232 serial interface. The result of the system design is achieved with the pulse resolution of a 20 nsec per step for four timing channels. The time delay and pulse width for each channel can be set independently based on the SYNC reference signal.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) in Thailand has development a prototype of the 6 MeV medical linear accelerator (medical linac) for cancer treatment. This project has been proposed to help increase the availability of low-cost radiotherapy machines in Thailand. Reverse engineering approach has been employed in this project via a donated machine to develop a prototype of this machine. The linear accelerating structure has operating frequency at 2,998 MHz, a 3.1 MW magnetron driven by a solid-state modulator, and a hot-cathode electron gun. A drive stand and a gantry of the prototype provide housing for the modulator cabinet for magnetron and electron gun and automatic frequency control (AFC) system in order to provide resonant frequency tuning for the magnetron.

A linac treatment head consists of an X-ray target attached to the end of the accelerating structure. A dosimetry control system is designed to measure and control the X-ray beam dose by processing the signals coming from an ionization chamber installed in the treatment head. Three-stage treatment beam collimators are used to adjust the shape and size of the beam. The collimators are 1) fixed primary collimators, 2) secondary collimators, and 3) a multi-leaf collimator (MLC). A timing system is used to link various subsystems of the machine in order to provide proper synchronization of the X-ray beam generation.

A central control system software is designed to give access and control all subsystems. It is run on the Main Control System with a display monitor and GUI. All of the subsystems are connected to the Main Control System in a private network as shown in Figure 1 [1].

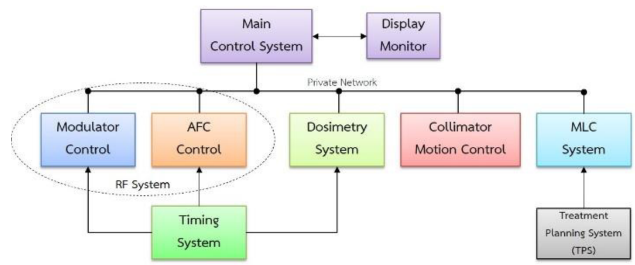

Figure 1: Network diagram of the machine prototype [1].

This paper describes a timing system using FPGA for the medical linac project. System design, both hardware and software, is explained in the next section. The following section discusses some result and discussion. Conclusion is presented in the final section.

SYSTEM DESIGN

In order to produce the required X-ray beam efficiently, the timing system that provides synchronization of the machine subsystems is indispensable. The accuracy of the timing signals connecting the subsystems is very crucial. Each signal has its own specific timing requirement. This section describes the main design and implementation, both hardware and software, of the timing system developed in this project.

Hardware

For this project, Xilinx's Spartan 3 FPGA development board [2-3] is chosen to be the main hardware for the timing system. The main clock of the system runs at 50 MHz which is the primary reference clock signal of the FPGA. This contributes to the resolution of a 20 nanoseconds (nsec) in the time domain characteristics of the timing signals synthesized by the digital circuit in the FPGA. Since synchronization of all subsystems of the medical linac depends on the pulse timing signals connecting them, we can choose to set up a pulse width and a delay time of the individual signals independently at the outputs.

In the first version of this system, there are four independent output channels, SYN, Electron Gun, RF Trigger, and Magnetron Trigger. For interface between the FPGA board and PC, the serial communication through RS-232

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NEW DATA ACQUISITION SYSTEM IMPLEMENTED BASED ON MTCA.4 FORM FACTOR FOR KSTAR DIAGNOSTIC SYSTEM

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Abstract

In Korea Superconducting Tokamak Advanced Research (KSTAR), various diagnostics systems were developed with various form factor digitizer such as VME, CPCI, PXI, VXI. and PCIe. The DAQ systems are measuring the various plasma properties such as plasma current, magnetic current, electron density, electron temperature, plasma image, impurity, and so on.

These complicated form factors installed on KSTAR have difficulties with hardware management, software management and performance upgrades. In order to control real-time systems using several diagnostic signals, the real-time control system is required to share the data without delay between the diagnostic measurement system and the real-time control system without branch one signal. Therefore, we developed the Multifunction Control Unit (KMCU) as the standard control system MTCA.4 form-factor and implemented the various diagnostic DAQ system using KMCU V2, that is KMCU-Z30. This paper will present the implementation of KSTAR diagnostic DAQ systems configured with KMCU based on MTCA.4 and their operating results.

INTRODUCTION

Korea Superconducting Tokamak Advanced Research has operated and installed various diagnostic devices, and has executed to add and upgraded the DAQ systems according to KSTAR upgrade and installation plan every year since 2008 [1]. As shown in the Table 1, the KSTAR has many diagnostics and various DAQ systems. We had some technical issues and requirements during the operation that is maintenance of hardware and software, and software development. There is a need to incorporate new technologies such as data processing using FPGA and data analysis using GPU into the DAQ system. To overcome these technical issues, we have developed a standard system with MicroTCA.4 form-factor [2][3]. The KMCU-Z35 supports simultaneous two point streaming data transmission but the newly KMCU-Z30 supports simultaneous three point streaming data transmission [2][3]. In 2017, the KSTAR diagnostic DAQ systems were rebuilt with KMCU-Z30, which has several advantages.

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UPGRADE DATA ACQUISITION SYSTEMS

The new DAQ systems were set up with KMUC-Z30 MTCA.4 form-factor controller and digitizers of the D-TACQ [4] in the 64 bit Linux OS platform. It is standalone operation capability for a small size diagnostic.

H/W Upgrade the DAQ Systems

In 2017, three DAQ systems were changed from KMCU-Z35 to KMCU-Z30, and four diagnostic DAQ systems were changed to the KMCU-Z30 of MTCA.4 form-factor. In addition, a new DAQ system was newly added to measure MSE data composed of MIT polychrometer device. As shown in Figure 1, eight KMCU-Z30s are used for the MD DAQ system with ACQ424ELF and are connected to the host PC via PCIe uplink. And the Probe DAQ system was built using the front SFP+ with aurora link, AFHBA400, to operate independently in the same chassis.

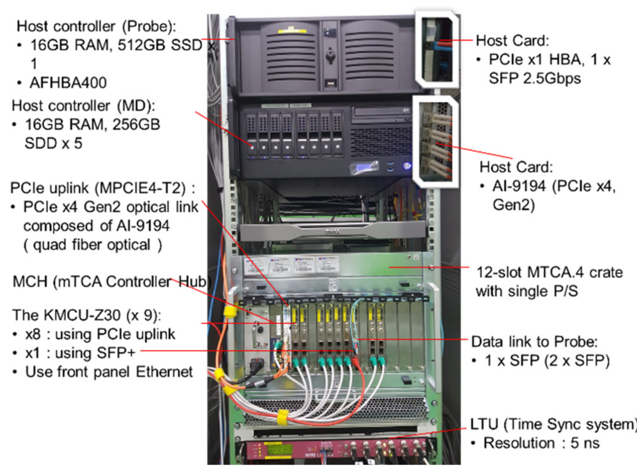

Figure 1: Configuration of MD (with PCIe uplink) & Probe DAQ system (with SFP+) in single create.

As shown in Figure 2, the H-Alpha DAQ systems were configured via the aurora link with a KMCU-Z30 installed in a VT812 chassis.

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PILOT APPLICATION OF NEW CONTROL SYSTEM AT SPring-8 RF TEST STAND

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Abstract

The SPring-8 upgrade project is in progress. The SACLA linac will be used as the injector of the SPring-8 storage ring. The MADOCA control framework was created 20 years ago and has contributed to the stable operation of both SPring-8 and SACLA. However, we must integrate separated control systems of two machines for the upgrade. In addition, some new ICT standard protocols designed recently have the potential to simplify the implementation of the framework. With these background, we have developed a new messaging system MS-MQTT and a new DAQ system MDAQ, based on the concepts of simple, easy management and unified operation covering SPring-8 and SACLA. For the equipment control hardware, we have adopted the modern architecture of MTCA.4 and EtherCAT. We are developing a universal driver for MTCA.4 modules. A pilot application of the new control system including the new hardware was performed at the RF test stand. The result of high power RF operation showed that the high stability required for the RF amplitude and phase in the cavity was achieved using the new system. We confirmed that the new framework can control SPring-8-II.

INTRODUCTION

SPring-8 is a third-generation X-ray synchrotron radiation source that has been operating since 1997. It consists of a 1 GeV linac, an 8 GeV booster synchrotron and an 8 GeV storage ring. SACLA is an X-ray free-electron laser source that has been operating next to SPring-8 since 2012. A low emittance electron beam is generated from an 8 GeV linac of SACLA. SPring-8 and SACLA are currently operated independently.

In 2014, a conceptual design of upgrading SPring-8 to an ultralow-emittance (~ 100 pmrad) ring, SPring-8-II, was decided [1, 2]. One of the important concepts of the upgrade is to use the linac of SACLA as the injector of the storage ring of SPring-8-II. This means that we must operate two machines cooperatively. Another important concept is to minimize the blackout period during users are forced to stop their experiments. We should carry out the upgrade plan carefully with as many preliminary studies of the new system as possible.

The MADOCA control framework [3] was created 20 years ago to control the SPring-8 storage ring which works as a DC machine. When we constructed SACLA, it was natural for us to adopt MADOCA for the SACLA control system [4]. However, we had to add a synchronous data acquisition (DAQ) system that was not in the original framework [5]. Because SACLA is a pulsed machine with a repetition rate of 60 Hz, equipment data arising from the pulsed electron beam should be collected synchronously. To keep the operation of two machines independent, we prepared different databases for them. And we also separated control networks of two machines by a firewall.

For SPring-8-II, we must integrate both control systems to enable seamless operation of two machines [6]. We redesigned some points to be improved in current control framework to facilitate the integration. The design concepts were simple, easy management, unified operation and positive use of new ICT standard systems/protocols introduced in the last decade.

For example, in the messaging, the message server used to communicate between hosts is run in each host. The server reads a list of signal names and corresponding host names from a file prepared in each host. Because the server uses queues without flow control, the mixing of reply messages could occur. We created new messaging system not to use any files and no mixing of reply messages using MQTT. In the DAQ system, a signal list to collect data from equipment is also prepared in each host. The collected data are gathered in a collector host then written to the database. The fixed-period DAQ system and the synchronized DAQ system added to SACLA later are operated independently in terms of the databases. We created a unified DAQ system using Cassandra and MariaDB

The situation is the same for the hardware. Although we still use VME, RS-232C and so forth, we decided to introduce the leading-edge hardware architectures of MTCA.4 and EtherCAT. For MTCA.4 we inherited the idea of a universal driver from DESY and modified it for our usage.

In this paper, we describe the pilot application of the new control system to prove the operation feasibility at the RF test stand of SPring-8.

NEW CONTROL FRAMWORK

MS-MQTT

The MQTT is a publish-subscribe-based "lightweight" messaging protocol suited for IoT. MS-MQTT is a newly developed messaging scheme that uses MQTT to access equipment from an operator console. Its features are (a) only one MQTT broker (server) in the control network, (b) no server process in each client host, (c) a simple structure with easy management, (d) no mixing of reply messages owing to no queue or flow control, (e) increased speed using multiple threads and sequence control by distributed processing due to asynchronous processing of messages and (f) simultaneous message transmission to multiple hosts.

When a control process is launched, it subscribes topics that include all signal object names treated in the process

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THE TIMING SYSTEM OF HIRFL-CSR

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Abstract

This article gives a brief description of the timing system for Heavy Ion Research Facility in Lanzhou-Cooler Storage Ring (HIRFL-CSR). It introduces in detail mainly of the timing system architecture, hardware and software. We use standard event system architecture. The system is mainly composed of the events generator (EVG), the events receiver (EVR) and the events fan-out module. The system is the standard three-layer structure. OPI layer realizes generated and monitoring for the events. The intermediate layer is the events transmission and fan out. Device control layer performs the interpretation of the events. We adopt our R&D EVG to generate the events of virtual accelerator. At the same time, we have used our own design events fan-out module and realize distributed on the events. In equipment control layer, we use EVR design based on FPGA to interpret the events of different equipment and achieve an orderly work. The timing system realizes the ion beam injection, acceleration and extraction.

INTRODUCTION

HIRFL-CSR (Heavy Ion Research Facility in Lanzhou-Cooler-Storage-Ring) is a multi-purpose CSR system that consists of a main ring (CSRm), an experimental ring (CSRe), and a radioactive beam line (RIBLL II) to connect the two rings. Figure 1 show an Overall Layout of HIRFL-CSR [1]. The two existing cyclotrons SFC (K = 69) and SSC (K = 450) of the HIRFL will be used as its injector system. The heavy ion beams with the energy range of 8–30 MeV/u from the HIRFL will be accumulated, cooled and accelerated to the high-energy range of 100–400 MeV/u in the main ring, and then extracted fast to produce RIB or highly charged heavy ions. The secondary beams (RIB or highly charged heavy ions) will be accepted and stored by the experimental ring for many internal-target experiments or high-precision spectroscopy with beam cooling. On the other hand, the beams with the energy range of 100–900 MeV/u will also be extracted from CSRm by using slow extraction or fast extraction for many external-target experiments.

CSR is a double ring system. In every operation cycle, the stable-nucleus beams from the injectors are accumulated, cooled and accelerated in the main ring (CSRm), then extracted fast to produce RIB or highly charged ions. The experimental ring (CSRe) can obtain the secondary beams once for every operation cycle. The accumulation duration of CSRm is about 10 s. considering the ramping rate of magnetic field in the dipole magnets to be 0.1–0.4 T/s, the acceleration time of CSRm will be nearly 3 s. Thus, the operation cycle is about 17 s [2].

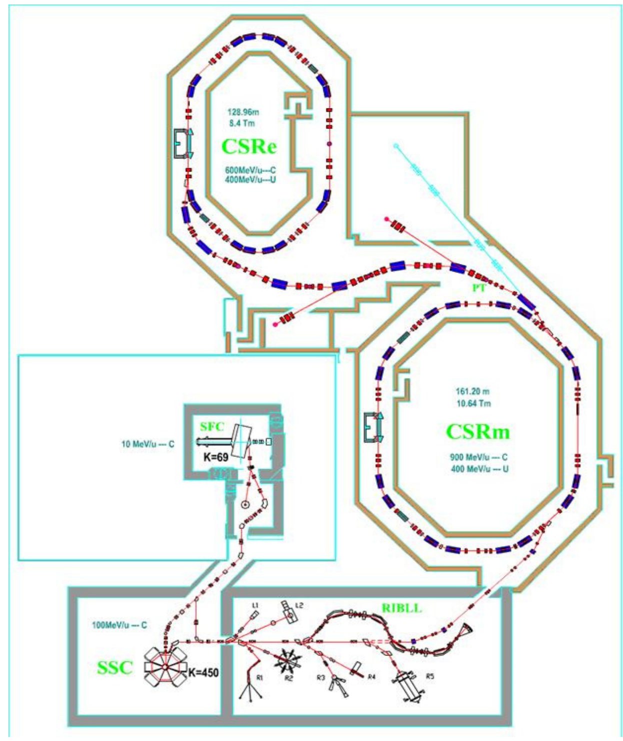

Figure 1: Overall Layout of HIRFL-CSR.

SYSTEM INTRODUCTION

The CSR is a synchrotron system, and the injection, acceleration, accumulation and derivation of the cluster must be precisely synchronized to achieve a successful operation cycle. CSRm infuses the CSRe with a beam once every other cycle, and CSRe can use the storage (or deceleration) of the beam to continuously target the target experiment. This precise synchronization is performed by the timing system and the magnetic field power control system. The time of the cluster in the CSR main ring is approximately 0.5us ~ 3us [3].

The timing system not only completes the normal control function, but more importantly the synchronization between the control equipment. For example, a successful independent cycle (from injection to derivation) of the CSR main ring requires a strict synchronization between CHOPPER, BUMPER, RF, QUADRUPLE, KICKER, and so on. The synchronization control function is the most complex and difficult key part of the control system. The success of the CSR control scheme lies in the ability to realize the synchronization of relevant equipment in the accelerator system and the most complicated and difficult key part of the system. Only by accurately pressing the accelerator requirement to achieve the synchronization function, the CSR can modulate the ideal beam with the expected target. Figure 2 shows the

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THE TimIQ SYNCHRONIZATION FOR SUB-PICOSECOND DELAY ADJUSTMENT

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Abstract

Synchrotron facilities provide short, regular and high frequency flashes of light. These pulses are used by the scientific community for time resolved experiments. To improve the time resolution, demands for always shorter X-ray pulses are growing. To achieve this goal, Synchrotron SOLEIL and MAX IV laboratory have developed special operating modes such as low-alpha and femtoslicing, as well as a single pass linear accelerator. For the most demanding experiments, the synchronization between short light pulses and pump-probe devices requires sub-picosecond delay adjustment. The TimIQ system has been developed for that purpose. It is a joint development between Synchrotron Soleil and MAX IV Laboratory. It is aimed to be used on three beamlines at Soleil and one at MAX IV. Based on IQ modulation technics, it allows shifting a radio frequency clock by steps of #100 fs. This paper is a description of this system and of its performances.

INTRODUCTION

Synchrotron facilities provide high frequency, high intensity and short pulses of light which are used by beamlines for pump-probe experiments. In such an experimental scheme, a sample is excited with an optical laser pulse, and the high frequency synchrotron light pulses are used to study the sample evolution over time [1] [2]. To study always faster phenomena, shorter x-ray pulses are required. SOLEIL provides low-alpha [3] and femtoslicing modes [4] for this purpose. At MAX IV the linac is built both for injecting the two storage rings as well as to provide short electron pulses for the Short Pulse Facility (SPF) [5]. At the SPF the electron pulses are sent through an undulator to provide 100 femtosecond (fs) x-ray pulses to the FemtoMAX beamline [6].

The synchronization of such experimental setups is getting more and more challenging. Delays and time offsets between the acquisition devices, the laser and the electron beam inside the storage ring (SOLEIL) or inside the accelerator tunnel (MAX IV) must be tuned very accurately, in range of few tenths of femtoseconds . For this purpose, SOLEIL and MAX IV have developed the TimIQ system. Based on IQ modulation technics, it allows delaying the laser's oscillator clock with sub-picosecond resolution.

IQ MODULATION

A sine wave signal is represented as a circle in the Cartesian coordinates with an in-phase (I) and a quadrature (Q) component. Changing one of those component changes the phase (ϕ) and the amplitude (A) of the signal (see Fig. 1).

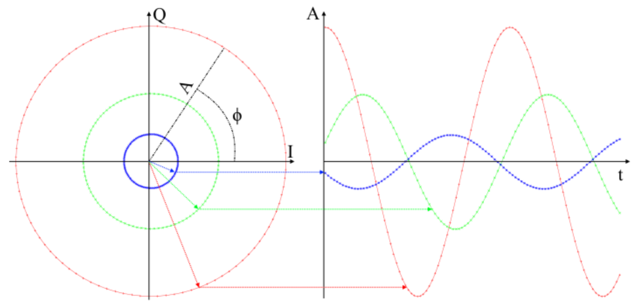

Figure 1: IQ modulation of a sine wave.

An IQ modulator device, also called a vector modulator, allows to adjust the phase and the amplitude of a radio frequency signal by modifying its I and Q components. Not only does it allow achieving very fine delay adjustment, but it also allows drifting infinitely the signal without any discontinuity: I and Q have the same value after a 360° phase shift. This is a major advantage over phase shifters and delay lines which have a limited phase shift range.

Many integrated circuit manufacturers provide IQ modulator chips making the design of this kind of solution for delay adjustment relatively straightforward. Fig. 2 illustrates how these chips work.

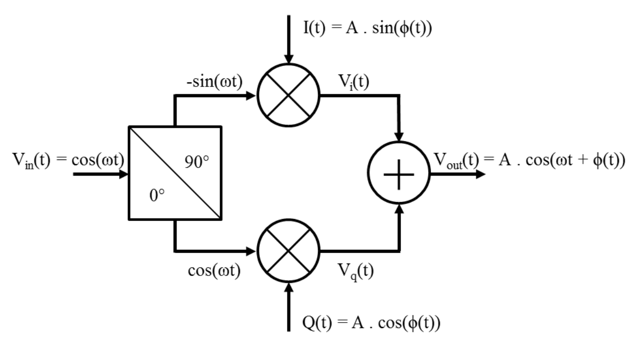

Figure 2: IQ modulator device schematic.

The input signal $V_{in}(t)$ is split in two branches. One of them is shifted by 90°. After multiplication by Q(t) and I(t), they are summed together to get the shifted output signal.

$$V_{in}(t) = \cos(\omega t)$$
$$V_q(t) = Q(t) \cdot \cos(\omega t) = A \cdot \cos(\phi(t)) \cdot \cos(\omega t)$$
$$V_i(t) = I(t) \cdot \cos(\omega t + \pi/2) = - A \cdot \sin(\phi(t)) \cdot \sin(\omega t)$$
$$V_{out}(t) = A \cdot \cos(\phi(t)) \cdot \cos(\omega t) - A \cdot \sin(\phi(t)) \cdot \sin(\omega t)$$

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DECOUPLING CERN ACCELERATORS

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Abstract

The accelerator complex at CERN is a living system. Accelerators are being dismantled, upgraded or change their purpose. New accelerators are built. The changes do not happen overnight, but when they happen they may require profound changes across the handling systems. Central Timings (CT), responsible for sequencing and synchronization of accelerators, are good examples of such systems.

This paper shows how over the past twenty years the changes and new requirements influenced the evolution of the CTs. It describes experience gained from using the Central Beam and Cycle Manager (CBCM) CT model, for strongly coupled accelerators, and how it led to a design of a new Dynamic Beam Negotiation (DBN) model for the AD and ELENA accelerators, which reduces the coupling, increasing accelerator independence. The paper ends with an idea how to merge strong points of both models in order to create a single generic system able to efficiently handle all CERN accelerators and provide more beam time to experiments and LHC.

TIMING AT CERN

Raison d'être

The General Machine Timing (GMT) or just Timing is one of the core components of the CERN control system. It has two main functions: (1) it is responsible for the precise synchronization of the equipment guiding beams in the accelerators, and (2) beam scheduling, or sequencing, i.e. deciding which particle beam to produce in a given accelerator at a given time.

How Does it Work? Cycles, Beams and Sequences

The synchronization is achieved through services called central timings (CT). For each accelerator they produce events which are distributed via a timing network. The events are received by dedicated hardware which is able to produce electrical pulses or to trigger real-time (RT) software tasks, both used to control the equipment around the accelerator with the required precision. In parallel to the events, the CT also sends telegrams. While events concern a point in time (what happens at that very moment), the telegram describes what is happening during a period of time. As such it gives context information to events occurring during its validity. For example, telegrams are used to distribute information about particle types in an accelerator, or to which accelerators/experiments the particles are going to be sent next. Telegrams are distributed in regular intervals called basic periods (BP), which hence constitute a limit to their granularity. For most of the accelerators a BP length is 1.2 seconds.

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Although a very interesting subject, this paper will not delve deeper into the synchronization. Instead, it will take a closer look at the sequencing. To understand it better, we need to introduce a few key concepts used when scheduling particle beams. The first one is called *cycle*. A cycle precisely describes the behaviour of an accelerator during a period of time. Typically this includes preparation of the accelerator to receive particles, particle injection, acceleration and extraction towards the next machine. The description is provided through a list of timing events. Each event, when received by a timing client, may be interpreted as a request to perform a specific action. For instance, it may trigger ramping of magnets, or request preparation for a coming injection.

At CERN, cycles of the small accelerators (Booster, PS, LEIR) last between one and three seconds while SPS cycles take around ten seconds, and AD cycles around two minutes. LHC cycles, although the same from the physical point of view, often take over ten hours to execute. Because of that they are handled by the timing system in a different way, and are not going to be the subject of this article.

It is clear that a cycle describes behaviour of one accelerator in separation. To describe how particles should be accelerated from the very beginning in Linacs, up till the very end when they are collided in experiments, a structure called *beam* must be prepared. The structure may be represented as an organised list of cycles of accelerators through which particles are going to be passed. The involved cycles, their number and structure are selected in a way to guarantee the characteristics of the beam as required by the experiments.

The big and flexible CERN accelerator complex [1] makes it possible to run a number of experiments in the same period of time. Depending on the agreed physics program, the operation team has many options regarding which beams to execute and in what order. Sequencing is the very process of selecting and ordering the beams. The following chapters present the two main sequencing models supported at CERN. The emphasis is put on each model's functionality, and strong and weak points. The results of the analysis are used later on to propose a unification of the two systems, with the main goals of providing more beam time to the experiments and simplifying the Timing software stack.

For the overview of the presented concepts have a look on the Figure 1.

THE CBCM MODEL

The CBCM model [2], is used by accelerators in the so called LHC Injector Chain (LIC) group: Linac2, PS Booster, Linac3, LEIR, PS and SPS. These machines usually work closely together to produce the beam, notably for the LHC [3]. The CT that implements the logic has been in op-

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TIMING SYSTEM UPGRADE FOR TOP-OFF OPERATION OF HLS-II*

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Abstract

The Hefei Light Source II (HLS-II) is a vacuum ultraviolet (VUV) synchrotron light source. A major upgrade of the light source was finished in 2014, and the timing system was rebuilt with event-system to meet synchronization requirements of the machine. The new timing system provides about 100 output signals with various interfaces. The time resolution of this system is 9.8 ns for most devices and 9 ps for the electron gun and the injection kickers. The measured jitter of the output signal is less than 27 ps (RMS). In order to improve the performance of light source, the top-off operation mode has been planned. As part of this plan, both the hardware and the software of the timing system are upgraded. By obtaining real-time data of beam measurement of storage ring, the automatic selection of the bucket is implemented. With any designated bunch pattern, top-off injection is achieved, and the storage ring beam can be uniform filled well.

INTRODUCTION

The Hefei Light Source (HLS) at the National Synchrotron Radiation Laboratory (NSRL) is a second-generation synchrotron radiation light source, providing broad band radiation from IR to VUV for various user programs. In order to further increase its brightness, the light source was overhauled from 2010 to 2014. The upgraded light source, named HLS-II, is comprised of an 800 MeV linac, an 800 MeV storage ring and a transport line connecting the linac and storage ring.

In the upgrade, the HLS-II timing system was completely rebuilt to meet the synchronization requirements of the machine. It provides about 100 output signals to trigger accelerator subsystems, including the electron gun, solid-state amplifiers, modulators, injection septum and kicker magnets of the storage ring, etc. In addition, the timing system also provides RF and revolution frequency clocks for beam diagnostic stations. These clocks are phase-locked with the storage ring RF system to make the diagnostic devices work properly.

As the event-driven timing system developed by the Micro-Research Finland (MRF) Oy is widely used in many accelerator facilities all over the world, the MRF cPCI-series products are chosen for building the HLS-II timing system. The hardware schematic diagram of the system is illustrated in Fig. 1. As shown in the figure, the HLS-II timing system employs an event generator (EVG) card, cPCI-EVG300, as the master card to generate event codes. The RF signal with a frequency of 204 MHz is used as the input signal for the EVG card, and for phased-lock with the RF system. The input signal passes through a divider in the EVG card, and is used as the event clock to generate event codes. The event codes are sent to all event receiver (EVR) cards installed in Input/output controllers (IOCs) via a cPCI-FOUT12 fan-out card. Among these EVR cards, cPCI-EVR300 cards are used to generate common trigger signals, while cPCI-EVRTG cards are used to generate trigger signals with fine delay adjustment for the electron gun and injection kickers, and to reconstruct the RF and revolution frequency clocks for beam diagnostic stations.

Five IOCs are distributed in different locations to provide trigger signals for nearby systems. Each IOC of the timing system employs an Adlink cPCIS-6418U chassises to host a cPCI-6880 CPU board and MRF timing modules. The IOCs software, include hardware drivers, database records and operation interfaces, are stored in a remote virtualized server cluster, and shared through NFS protocol [1].

By commissioning and operation since 2014, the good performance of the HLS-II timing system is well confirmed. The test results show that the relative jittering between the EVR output and the RF signal is close to a normal distribution, the jitter width is less than 27 ps, and the maximum peak-to-peak value is about 180 ps.

BUNCH-BY-BUNCH INJECTION

Bunch-by-bunch injection is essential for stable operation and critical for user programs. To realize this injection scheme, the HLS-II timing system is configured to provide synchronization signals with proper delays for various systems [2]. As the timing modules only work with a frequency lower than 125 MHz, a frequency divider is used to acquire a 102 MHz signal from the 204 MHz input signal. This 102 MHz signal is used as the clock signals for the delay modules, and used as the input signal of a counter to produce the 1 Hz injection signal for the bucket chooser which is actually a delay unit. Both the frequency divider and counter are inhabited in the EVG card. The clock and injection signals are also used by various beam diagnostic apparatus to synchronize their measurements. Using pre-programed delays, the bucket chooser produces signals to trigger the electron gun, linac power supply system, and the storage ring injection system to aim the electron beam at a designated bucket.

Since the bucket chooser uses a 102 MHz signal as its clock, while the storage ring RF signal is 204 MHz, the delay time between two ticks of the bucket chooser equals to 2 bucket length. However, the harmonic number of the storage ring is 45, the bunch-by-bunch injection can be accomplished using proper bucket chooser delays. The count of delay ticks for the n^{th} bucket is given by Eq. (1).

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THE TIMING DIAGRAM EDITING AND VERIFICATION METHOD

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Abstract

Preparation and verification of the timing diagrams for the modern complex facilities with diversified timing systems is a difficult task. A mathematical method for convenient editing and verification of the timing diagrams is presented. This method is based on systems of linear equations and linear inequalities. Every timing diagram has three interconnected representations: a textual equation representation, a matrix representation and a graph (tree) representation. A prototype of the software using this method was conceived in Python. This prototype allows conversion of the timing data between all three representations and its visualization.

INTRODUCTION

Nowadays large experimental facilities often have a lot of devices and subsystems which require careful orchestration and synchronisation. Therefore configuration of timing subsystem often requires elaborate formation of the time diagrams. These time diagrams are mostly compiled and checked manually. Such procedure, being a difficult task by itself, becomes even more complex when several subsystems are interrelated or specific timing requirements have to be met. We propose a method for describing, compiling and storing time diagrams, checking their consistency and setting the relevant delay values in hardware.

FORMALISM

Time diagram is essentially the relationship between the times of different events on the installation. Let us assume for the sake of simplicity that all the clocks are synchronized. If it is not the case, the time skews could easily be taken into account by adding some additional equations. We will also reduce all the units to the common order and omit the dimension, e.g. we could count all the times in ns. The relationship between the time of two events could be then described by the following linear equation:

$$t_2 = t_1 + b, \tag{1}$$

where t_2 and t_1 – times of the events, and b – is the delay. The value of b can be positive, specifying that the second event happens after the first, negative meaning that the second event happens before the first, or zero, indicating that events are simultaneous.

Let us consider a time diagram of a traffic light as an example. It consists of three events: at time moment 0 the green signal is lit, after 5 seconds, the yellow is ignited and 5 seconds later the red signal is lit. Let us designate these events as t_{green}, t_{yellow}, t_{red}. Their interrelation is described by the following system:

$$\begin{cases} t_{green} = 0 \\ t_{yellow} = t_{green} + 5 \\ t_{red} = t_{yellow} + 5. \end{cases} \tag{2}$$

Using matrix notation, it could be written as:

$$\begin{pmatrix} 1 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{pmatrix} \begin{pmatrix} t_1 \\ t_2 \\ t_3 \end{pmatrix} = \begin{pmatrix} 0 \\ 5 \\ 5 \end{pmatrix} \tag{3}$$

Let us note that we have numerated the events, threrefore we have to keep their corresponding names in a vector:

$$v = \begin{pmatrix} ''Green'' \\ ''Yellow'' \\ ''Red'' \end{pmatrix} \tag{4}$$

In general case, the time diagram of an installation could be described by a system of linear equations which could be written in the following form:

$$At = b, \tag{5}$$

where t - the vector of the event times, A - the system matrix, and b - the delay vector. We also need a vector v of the event names.

For the time diagram to be correct, the matrix A has to be invertible, in this case the system 5 is solvable. If matrix A is not invertible, then there was an error in time diagram specification. Let us formulate several other properties of the matrix A:

1. Diagonal elements are 1.
2. Other elemets are either 0, or -1.
3. For a large system A must be a sparse matrix (most of its elements are 0).

Last property is rather important in practice, because it allows to choose an effective way of the matrix storage and linear equations system solution.

EVENTS GRAPH

The matrix representation of time diagram is quite convenient for storage and computation of the event times but it doesn't allow to visually explore the relationship of events. Let us deduce the following matrix:

$$G = E - A, \tag{6}$$

where E - is an eye matrix of the same dimension as A.

We can note that the matrix G is an adjacency matrix of a directed graph. The vertex of a graph represents an event

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TIMING SYSTEM AT ESS

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Abstract

The European Spallation Source (ESS) timing system is based on the hardware developed by Micro-Research Finland (MRF). The main purposes of the timing system are: generation and distribution of synchronous clock signals and trigger events to the facility, providing a time base so that data from different systems can be time-correlated and synchronous transmission of beam-related data for for different subsystems of the facility. The timing system has a tree topology: one Event Generator (EVG) sends the events, clocks and data to an array of Event Receivers (EVRs) through an optical distribution layer (fan-out modules).

The event clock frequency for ESS will be 88.0525 MHz, divided down from the bunch frequency of 352.21 MHz. An integer number of ticks of this clock will define the beam macro pulse full length, around 2.86 ms, with a repetition rate of 14 Hz. An active delay compensation mechanism will provide stability against long-term drifts. A novelty of ESS compared to other facilities is the use of the features provided by EVRs in μTCA form factor, such as trigger and clock distribution over the backplane. These EVRs are already being deployed in some systems and test stands.

INTRODUCTION

ESS [1] is a collaboration of several European countries to build the leading facility in Europe in neutron science. It is being built in Lund (Sweden) and will start initial beam operations in 2019 and complete construction by 2025. It will produce neutrons by the spallation process, that basically consists of shooting a high energy proton beam to a tungsten target. The neutrons generated are used by a number of neutron instruments to do science in a broad number of disciplines. The proton pulses are up to 2.86 ms long and generated with a frequency of 14 Hz. The Integrated Control System Division (ICS) provides control systems for the whole facility, including the global timing system used to synchronise the operation of ESS subsystems to make it operate as a single facility [2]. The timing system has the following functionality that performs with deterministic latency: distribution of trigger events and clock signals across the facility, timestamping of the events, actions and data, and broadcasting of beam-related parameters.

TIMING SYSTEM ARCHITECTURE

The ESS timing system consists of an EVG, EVRs and fan-out (FOUT) modules. Its main functionalities are:

- Trigger event distribution.
- Fast beam data distribution.
- Timestamping.
- Distribution of clock signals.
- Delay compensation for stability against long term thermal drifts.

A central top-level EVG generates a bitstream containing timing events, data and synchronous clocks, which is sent to the EVRs through several levels of FOUTs over an optical link. The EVG sends events from sequencers stored in memory, from multiplexed counters that can also be used to trigger the sequencers, from software or from external inputs. When no other event is scheduled, the EVG sends a null event, that is periodically replaced by timestamping-related special events and a heartbeat. The time used for timestamping is derived from GPS time. It is incremented internally but periodically re-synchronised with GPS to avoid drifting too far away from the GPS-defined time. In each event clock cycle the EVG also can send either data bytes from a memory buffer or a distributed bus (DBUS) with 8 simultaneous clock signals sampled at half the event clock frequency(each of them is sent every other cycle). Figure 1 shows the structure of the event clock cycles in the bitstream.

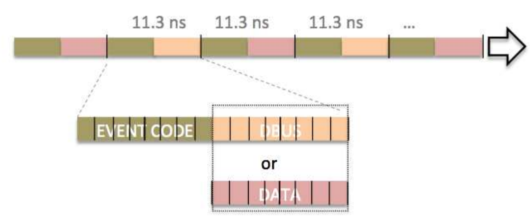

Figure 1: Frame structure of the timing system bit stream.

The EVG creates the event clock by dividing the frequency of the RF master oscillator of 352.21 MHz by 4, thus being 88.0525 MHz. The proton beam pulse frequency of 14 Hz is created by counting 6,289,464 cycles of the event clock, of 11.357 ns each. Figure 2 shows a rough sketch of the machine timeline, where an event at 14 Hz defines the beam cycle, and other important events are sent in relation to it.

The EVRs receive the bitstream, decode it and perform the necessary actions, mainly generating output triggers with parameters, such as delay, width or polarity, controlled by software. Software triggers and interrupts are also generated by EVRs, as well as sharing the beam parameters. The EVRs also perform the timestamping with the "wall-clock" time distributed by the EVG and which is kept internally in between pulses. Figure 3 shows the timing distribution system.

Beam Parameter Data

In addition to the timing events, the timing system has the capability to broadcast important parameters of the proton beam to the entire facility in a fast and reliable manner. The data is written to a 2 kilobyte data buffer of the EVG and then sent to the EVRs one byte every clock cycle when the

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TiCkS: A FLEXIBLE WHITE-RABBIT BASED TIME-STAMPING BOARD

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Abstract

We have developed the TiCkS board (Time and Clock Stamping) based on the White Rabbit (WR) SPEC node (Simple PCIe FMC carrier), to provide ns-precision time-stamps (TSs) of input signals (e.g., triggers from a connected device) and transmission of these TSs to a central collection point.

TiCkS was developed within the specifications of the Cherenkov Telescope Array (CTA) as one of the candidate TS nodes, with a small form-factor allowing its use in any CTA camera.

The essence of this development concerns the firmware in its Spartan-6 FPGA (Field-Programmable Gate Array), with the addition of: 1) a ns-precision TDC (Time-to-Digital Convertor) for the TSs; and 2) a UDP stack (User Datagram Protocol) to send TSs and auxiliary information over the WR fibre, and to receive configuration & slow control commands over the same fibre.

It also provides a PPS (Pulse Per Second) and other clock signals to the connected device, from which it can receive auxiliary event-type information over an SPI link (Serial Peripheral Interface).

A version of TiCkS with an FMC connector (FPGA Mezzanine Card) will be made available in the WR OpenHardware repository, so allowing the use of a mezzanine card with varied formats of input/output connectors, providing a cheap, flexible, and reliable solution for ns-precision time-stamping of trigger signals up to 400 kHz, for use in other experiments.

CTA: CHERENKOV TELESCOPE ARRAY

The Cherenkov Telescope Array (CTA) [1] will be a gamma-ray observatory in the very-high-energy range (VHE, above around 30 GeV), consisting of over 100 imaging atmospheric Cherenkov telescopes (IACTs) distributed over two sites, one in each hemisphere; La Palma, Spain and the Atacama desert in Chile. The telescopes detect the few-nanosecond Cherenkov light flashes from the showers of particles (EAS, Extended Air Showers) initiated by gamma rays from cosmic sources, but also those produced by charged cosmic rays, which are thus background noise.

CTA will use a SoftWare Array Trigger (SWAT) to detect time coincidences – within a window up to 100 ns – between the signals from each telescope's Camera Trigger Management electronics (CTM). This allows the rejection of non-coincident images from Night-Sky Background light or isolated muons, and the "event-building" for stereoscopic events. Such a SWAT can be more flexible than a hardware trigger using transmission of analogue trigger signals and delay lines to correct for differential delays due to different sky-pointings.

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The SWAT needs accurate relative TSs from each telescope's CTM, which it can correct in software for the telescope pointing directions, and identify coincidences within a flexible coincidence window, with a flexible topology and coincidence logic.

The White Rabbit (WR) technology has been adopted by CTA for this time-stamping. The TS relative accuracy for trigger coincidence identification for event-building is only at the tens of ns level. But, the timing information in the "wave-front" of Cherenkov photons hitting the array may contain further information, though likely redundant with the imaging information. Nonetheless, since the WR technology permits this, a 2 ns rms relative accuracy requirement was adopted CTA's timing nodes TSs.

WHITE RABBIT TECHNOLOGY

White Rabbit [2] is an Open Hardware and Software project to provide sub-nanosecond synchronization accuracy combined with the flexibility and modularity of real-time Ethernet networks, based on timing synchronization over mono-mode fibres. It was initiated by CERN, the GSI Helmholtz Centre for Heavy Ion Research, and other partners from universities and industry starting in 2009. It is hoped that White-Rabbit will become a high-performance standard implementation of a future revised Precision Time Protocol.

For the purposes of CTA, WR permits to distribute the time from a central clock system to WR "nodes" in each telescope camera, over a hierarchical network of WR-compatible switches located at the array control centre. The WR-nodes time-stamp trigger signals from CTMs; both for "read-out" events for which there should be corresponding image data, and for "busy" triggers for those cameras which have dead-time (since the overall trigger pattern is useful at the event-reconstruction level).

Event and PPS counters in the camera's trigger electronics and its WR-node allow the image data to be combined with their time-stamps.

The White-Rabbit network itself may be used to collect the time-stamps from all telescopes at a central point, where the trigger coincidence logic can be implemented in a SoftWare Array Trigger (SWAT), and the coincidence information forwarded to each camera's data-processing pipeline to allow non-coincident trigger image data to be dropped.

TiCkS: TIME & CLOCK STAMPING

We have developed the TiCkS board (Time and Clock Stamping) based on the WR SPEC node (Simple PCIe FMC carrier) [3].

The signals which are exchanged with the trigger electronics of the camera, using LVDS pairs (Low Voltage Differential Signalling) for transmission, follow the agreed CTA interface definition:

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A RELIABLE WHITE RABBIT NETWORK FOR THE FAIR GENERAL TIMING MACHINE

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Abstract

A new timing system based on White Rabbit (WR) is being developed for the upcoming FAIR facility at GSI in collaboration with CERN and other partners. The General Timing Machine (GTM) is responsible for the synchronization of nodes and distribution of timing events, which allows the real-time control of the accelerator equipment. WR is a time-deterministic, low latency Ethernet-based network for general data transfer and sub-ns time and frequency distribution. The FAIR WR network is considered operational only if it provides deterministic and resilient data delivery and reliable time distribution. In order to achieve this level of service, methods and techniques to increase the reliability of the GTM and WR network has been studied and evaluated. Besides, GSI has developed a network monitoring and logging system to measure the performance and detect failures of the WR network. Finally, we describe the continuous integration system at GSI and how it has improve the overall reliability of the GTM.

FAIR GENERAL TIMING MACHINE

The FAIR General Timing Machine (GTM) is responsible for the synchronization of Front End Controllers (FeC) with nanosecond accuracy and distribution of Control Messages (CM) for the hard real-time control of the GSI and FAIR accelerator complex.

The hard real-time control is achieved in several steps. First, the Settings Management [1] distributes the settings of the FeCs over a standard network. Second, the activities in the FeCs are prepared by the Front-End Software FESA [2]. Finally, the GMT generates on-time actions at the FECs thanks to the CM broadcasted by the Data Master (DM) [3]. These CMs are sent over the White Rabbit (WR) [4] network, which is also responsible for the synchronization of the FeCs, DM and WR switches.

The GMT have been designed to scale up to 2000 FeCs and synchronize them in the range of 1 to 5 ns with ps precision. The GSI and FAIR accelerator facilities requires the GMT to work reliably in routine operation 24/7.

The GMT is linked to other systems and must be able to react, within 10 ms, to interlock and external signals [5].

All systems connected to the timing system depend on it's high availability. Distribution of CM must be guaranteed for commissioning and testing even when the accelerator does not produce beam. Therefore the loss rate of CM in WR network cannot go beyond 1 CM per year.

Table 1: FAIR GTM Requirements

Requirements	**FAIR GMT**
Time Resolution	1 to 5 ns
Precision (Std dev.)	≤10 ps
GMT Reaction Time	≤10 ms
CM Failure Rate	$3.17\ 10^{-12}$
CM Loss Rate	1 CM/year
Num FeCs	≤ 2000
Links Distance	1 to 2000 m

BUILDING A RELIABLE GENERAL TIMING MACHINE NETWORK

The Figure 1 depicts the components and topology of the GTM network. The network is established by the interconnection of WR Switches and WR Nodes using fibre optic cables. The GTM network is meant to transport CMs to the FeCs and synchronize the WR Nodes of the FeCs. According to the requirements of the GTM, Table 1, the WR network has to provide and guarantee timing and data delivery even under abnormal operations and conditions. Therefore the reliability of the GTM WR network relies on:

- Ethernet traffic delivery within upper-bond latency.
- Synchronization of the network and FeCs.

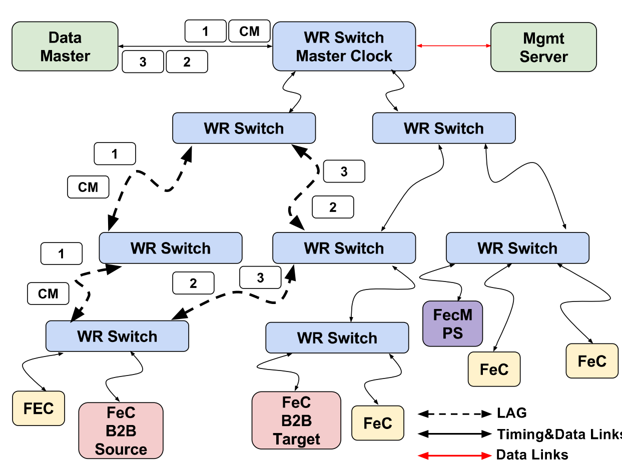

Figure 1: Overview of the FAIR general timing machine.

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TWO YEARS OF FAIR GENERAL MACHINE TIMING – EXPERIENCES AND IMPROVEMENTS

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Abstract

The FAIR General Machine Timing system has been in operation at GSI since 2015 and significant progress has been made in the last two years. The CRYRING accelerator was the first machine on campus operated with the new timing system and serves as a proving ground for new control system technology to this day. A White Rabbit (WR) network was set up, connecting parts of the existing facility. The Data Master was put under control of the LSA physics core. It was enhanced with a powerful schedule language and extensive research for delay bound analysis with network calculus was undertaken. Several form factors of Timing Receivers were improved, their hard and software now being in their second release and subject to a continuous series of automated long- and short-term tests in varying network scenarios. The final goal is time-synchronization of 2000-3000 nodes using the WR Precision-Time-Protocol distribution of TAI time stamps and synchronized command and control of FAIR equipment. Promising test results for scalability and accuracy were obtained when moving from temporary small lab setups to CRYRING's control system with more than 30 nodes connected over 3 layers of WR Switches.

INTRODUCTION

Motivation

The GSI-Helmholtz Center for Heavy Ion Research (GSI) in Darmstadt, Germany, is engaged in the ongoing development of a new type of control system (CS) for large physics experiments, which can utilize high accuracy timing. White Rabbit (WR), the underlying time synchronization technology, was an initiative started in 2008 by the European Center for Nuclear Research (CERN) and initially aimed at the modernization of the CS of the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. At the time, GSI took an interest in evaluating suitable technologies for a CS modernization and a new CS for the upcoming Facility for Antiproton and Ion Research (FAIR), a major extension to the GSI accelerator facilities. Research and development of WR successively became a close collaboration between CERN and GSI/FAIR.

System Layout

The FAIR CS approach aims for an alarm-based CS with clear separation of command dispatch and execution time. Furthermore, timed machine control and set-values supply use separate paths. This results in highly scalable system whose endpoints feature separate interfaces for configuration data, such as current ramps for magnets, and high accuracy timing and command, such as orchestrating the start times and successions of different current ramps. Figure 1 illustrates the concept: Settings Management derives both set-values and possible machine schedules from physical beam parameters. It provides specific set value data to individual endpoints (EP) to configure magnets, RF cavities, filters and other accelerator components (blue and red arrows). The hard real-time CS master, called Data Master (DM), is a deterministic scheduler employing high accuracy WR timing, sending commands to EPs in order to orchestrate the use of specific set-values at certain times (green arrows). The DM provides the flexibility to adapt the command stream to the facility's status, such as pending interlocks and beam requests, on the fly.

A hard-real time capable timing network deterministically distributes the DM's commands over a tree of fiber links and custom WR switches, while set-values are carried over standard gigabit copper network infrastructure. The timing network employs the deterministic Etherbone (EB) network protocol [1, p. 105-117] [2] to communicate with the EPs.

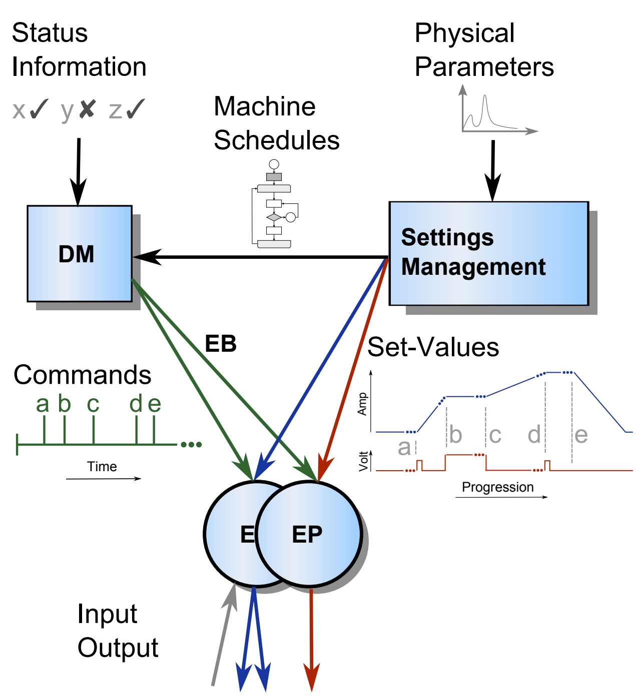

Figure 1: Schematic of FAIR CS. Left: Real-time Data Master (DM), Right: Settings Management Server. Endpoints (EP) receive both commands and set-values.

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NSLS-II BEAMLINE EQUIPMENT PROTECTION SYSTEM

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Abstract

The National Synchrotron Light Source II (NSLS-II) beamline Equipment Protection System (EPS) delivers a general solution for dealing with various beamline components and requirements. All IOs are monitored and controlled by Allen Bradley PLC. EPICS application and CSS panels provide high level monitoring and control.

INTRODUCTION

NSLS-II is a state-of-the-art 3 Gev electron storage ring. The facility is designed to accommodate approximately 60 to 70 beamlines when fully built out. Currently around twenty beamlines are in operation and six are under development.

The primary purpose of the beamline Equipment Protection System (EPS) is to protect the individual beamline components against x-ray damage, loss of vacuum, loss of coolant flow (water and liquid nitrogen), and elevated temperatures.

NSLS-II BEAMLINE EPS DEVICES

NSLS-II beamline EPS monitors and interlocks the devices in the front end and the beamline. These devices include photon shutters, masks, slits, vacuum gauges, vacuum pumps, vacuum isolation valves, temperature sensors, water flow sensors, leak detectors, cryocooler valves, smoke detectors, and so on.

All beamlines at NSLS-II have one Front End (FE) shutter and at least one beamline photon shutter. They are also part of storage ring Personal Protection System (PPS). The beamline EPS needs to communicate with the PPS PLC through related interface signals. Besides, beamline EPS PLC needs to communicate with FE vacuum PLC and cryocooler PLC through specified interface signals.

NSLS-II BEAMLINE EPS HARDWARE DESIGN

The beamline EPS hardware is based on a Programmable Logic Controller (PLC). Each beamline at NSLS-II is designed to have its own EPS system which consists of only one PLC.

The EPS I/O signals can be divided into two categories based on their location and signal type. The first category of signals includes vacuum relay signals, smoke detectors, and motion limit switches. These signals are connected to the intelligent chassis or the vacuum chassis. All other signals are in the second category, and they are wired to remote I/O boxes, or Armor blocks. The EPS hardware is designed with these two categories of signals in mind.

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Intelligent Chassis

Each beamline has only one PLC, e.g. one controller, which resides in the intelligent chassis. This chassis is a 4U high, 19 inch crate. It contains one controller, power supply modules, network modules, I/O modules and other modules. Figure 1 shows the front/rear panel, and chassis module layout.

Figure 1: Intelligent Chassis Front/Rear Panel and Module Layout.

Two 1606 power supply modules are used in the chassis. One XLS240E provides 24 VDC for this chassis and one XLS480E provides 24 VDC for distributed I/O modules. The beamline EPS PLC uses CompactLogix 1768-L43 controller which requires 1768-PB3 power module. The EPS system uses two independent TCP/IP networks. The 1768-EWEB communication adapter provides EtherNet/IP web server over beamline instrumentation subnet while 1768-ENBT module offers EtherNet/IP bridge on private network. All of the PLC data gathering and commanding is on the private network. The instrumentation network handles the communication to users and main control. This assures reliable status and control of hardware on a beamline. I/O signals inside the rack are handled by two 1769-IQ32T and one 1769-OW8I modules.

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THE MACHINE PROTECTION SYSTEM FOR THE INJECTOR II *

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Abstract

The IMP takes the responsibility for the development of Injector II. The target energy index of it is 25Mev, which is an intense beam proton accelerator with high operation risk. In order to implement cutting the ion source beam in time when the beam position offset happened, the Injector II Machine Protection System is developed based on FPGA controller and PLC. This system aims to prevent device damage from continuous impact of intense beam, as well as obtains and stores status data of key devices when failures occur to implement failure location and analysis. The whole system is now operating stable in field, and the beam cutting time is less than 10µs.

INTRODUCTION

The ADS injector II is a Chinese Academy of Sciences pilot special linear accelerator pre-research device [1] [2]. Its acceleration chamber mainly consists of an RFQ accelerating chamber and four CM superconducting cavities. CM1 and CM2 were installed with six HWR010 cavities respectively, CM3 was installed with five HWR015 cavities, and CM4 was installed with six SPOKE021 cavities provided by the Institute of High Energy Physics Chinese Academy of Sciences. The final beam energy (acceleration value) of the injector II proton linear accelerator is 10-25MeV.

During the design process of machine protection system (MPS) for the injector II, our physicists have defined that the response time of the fast machine protection system (FMPS) must be within 10µs based on the thermal power numerical simulation analysis of the niobium and copper materials and the highest beam power value of the injector II operation. It means that the process from reading fault signal inputs to issuing protection action outputs has to be completed within 10µs. In this case, the possible damage of the accelerated cavity equipment on field could be prevented from strong beam continuous bombardment. Therefore, we decided to build the injector II machine protection system using FPGA technology and PLC system design.

When the acceleration beam position is abnormal or the beam loss of the rear beam line is too large, the FMPS has to cut off the beam quickly and reliably by the ion source equipment, and at the same time, the corresponding power sources, power supplies, vacuum valves and other equipment along the beam line have to be shut down as well to achieve the safety protection of the field equipment.

OVERALL STRUCTURE OF THE SYSTEM DESIGN

The most important feature of the protection system should be fastness. According to the requirements from our physicists, The FMPS design must meet the protection response time within 10µs, which is between the point when the fault signal is received and point the shutdown signal is issued. In order to improve the signal immunity of the whole system, the optical fiber is used for all the signal transmission of the injector II fast protection system. Therefore, the 10µs time also includes the inherent delay time of light transmission in the fiber. In the case of glass fiber, for example, the average refractive index of glass is about 1.5, so the propagation speed of light in glass fiber is approximately

$$v = \frac{c}{n} = \frac{3\times10^8 m/s}{1.5} = 2\times10^8 m/s$$

It shows that light travels about two hundred meters in 1µs. Since the transmission time of light in optical fiber cannot be avoided, the time left for FMPS to make logical judgments is less than 10µs. Of course, the shorter the judgment time, the better for the system to meet the requirement of the response time.

Because there are many equipment needed to be protected in the injector II and they are scattered, and the field electromagnetic interference is also serious, we adopt the distributed network architecture [3] [4] for the machine protection system. In order to ensure the stability and reliability of the system operation, we use the MIS system, developed by Shanghai Institute of Applied Physics, as the main control system, which is responsible for the collection of key equipment status, logical judgment and the output of the beam cut-off action. The front-end FPGA controller is designed by ourselves and is responsible for the collection and preprocessing for the equipment's fault signals. The photoelectric conversion module is located at the low level of the device, which make the fault state of the device to split into two parts, one for cutting off the beam and the other for the PLC interlocking system. Thus, the redundancy of the control link can be achieved and the reliable operation of the whole system can be ensured. The whole structure of the protection system is shown as Fig. 1.

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THE FRIB RUN PERMIT SYSTEM*

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Abstract

The Facility for Rare Isotope Beams (FRIB) will accelerate many different ion species and charge states defining a wide spectrum of operating modes and parameters. The role of the Run Permit System (RPS) here is to examine if a requested state is suitable for the production of beam. The decision to permit beam is based on input from configuration management databases, machine and personnel protection systems, and beam characteristics and destination. From this information an appropriate set of operating parameters are deployed to hardware to support the requested mode. This paper will describe the interfaces, implementation, and behavior of the RPS at FRIB.

INTRODUCTION

The Facility for Rare Isotope Beams, currently under initial commissioning, will be capable of accelerating heavy ions up to a beam power of 400 kW [1]. Capable of accelerating a wide variety of ion species at variable beam energies, machine protection risks are of significant concern. In one of several parallel efforts to address these risks, a Run Permit System is under development and testing, which operates in concert with Personnel Protection System (PPS), Machine Protection System (MPS), and the Global Timing System (GTS).

The FRIB Run Permit System software performs several functions, acting over a set of *Critical Signals* defined here as the set of control system channels that the RPS writes or subscribes to in order to affect beam production:

- Determines if conditions are such that beam production may commence
  - Configuration management systems indicates approval of hardware for use
  - Critical Signal thresholds are distributed (eg: power supply operating ranges)
  - The absence of PPS, MPS, and Critical Signal alarms or faults
- Indicates to dependent systems that beam production may commence or continue by issuance of the *Run Permit* signal
- Determines if conditions are such that beam operations may continue in concert with PPS and MPS mechanisms - failure of Critical Signals revoke the Run Permit
- Prevents modifications to Critical Signals during beam operations

RPS COMPONENTS

Technologies

The control system software of FRIB is implemented using the EPICS toolkit, CS Studio is utilized to construct graphical user interfaces, and the RPS itself is a Python application relying on *pyepics*, *pcaspy*, *pymongo*, and *transitions* [2-7]. The database backend of the system uses *MongoDB* [8].

Machine and Beam Modes

Two of the more important concepts employed by the RPS are the notions of *Machine Modes* and *Beam Modes*. Machine Modes are hosted by the PPS and define the geographic scope of permissible beam propagation. Beam Modes are properties hosted by the Run Permit System and define the permissible range of beam power or energy, timing structure, and ramping strategies. Table 1 and Table 2 itemize samples of both.

Table 1: Machine Mode samples

ID	Description	Beam Modes
M0	Maintenance	B0
M1	Beam delivery up to linac	B0, B8
M4	Beam delivery up to experimental systems	B0, B1, B2, B5

Table 2: Beam Mode samples

ID	Time Structure/Power	Scope
B0	No Beam	Entire Machine
B1	CW/10-400 kW	Entire Machine
B8	Variable/2-650 eμA	Front End

Machine Mode, Beam Mode, ion species, and charge state together form a *state-set*, which is utilized by the RPS to query a database for the list of control system process variables (PV) and values curated for that state. Armed with this list, the RPS may then distribute the values to the hardware in preparation for beam delivery.

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APPLYING THE FUNCTIONAL SYSTEM INTERACTION PROCESS AT ESS

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Abstract

The European Spallation Source ERIC is being built in Lund, Sweden to complement the existing neutron sources in Europe and worldwide. ESS will be the brightest neutron source ever built upon completion and aims to have an availability of 95% during steady state operations.

The purpose of Machine Protection at ESS is to protect the equipment in order to support the high availability. Due to the distributed nature of Machine Protection numerous design teams are involved to implement Protection Functions. The Machine Protection development at ESS follows the Functional Protection lifecycle for System-of-Systems developed at the facility. This paper focuses on the application of the Functional System Interaction Process part of the Functional Protection method.

To obtain the system interaction model, behavioural requirements and allocate Protection Functions, System Interaction Use Case workshops are held. The feasibility of different system architectures and protection function implementations are discussed and simulated by going through foreseen operational sequences, use cases. The different architectures and use cases are documented using Enterprise Architect.

INTRODUCTION

ESS

In 2014 the construction of the European Spallation Source (ESS) ERIC started in Lund, Sweden. ESS will be a user facility and 2000-3000 users a year are expected to visit in order to conduct neutron experiments. An important factor to make ESS attractive to users is the number of experiments that can be performed. The brightness of the source is vital for conducting experiments, as increased brightness shortens the experiment time. This in turn enables an increased amount of experiments to be conducted during the same time period. To achieve the high brightness a 5 MW proton beam will be sent to a four tonne tungsten target where neutrons will be created by spallation. An increased availability also increases the number of experiments that can be performed. ESS aims to have an availability of 95% during steady state operation [1].

The role of Machine Protection at ESS is to protect the machine against damage and unnecessary activation. Damage of equipment could lead to unplanned downtime, longer maintenance periods and increased cost. Activation of equipment could lead to premature failure and additional radiation cool down before maintenance. Machine Protection therefore supports the availability goals by protecting the machine [2].

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ESS Machine Protection

The term “machine”, in the context of ESS Machine Protection, includes all elements in the Accelerator, Target Station and Neutron Science Systems necessary for neutron production and neutron science experiments [3].

The Machine Protection objectives can only be achieved if a large number of systems, developed by different groups and divisions, interact in a well-orchestrated way. A systematic approach taking into account the independence of the systems, yet focusing on the emergent properties, is crucial for a successful Machine Protection implementation. This is why a System-of-Systems engineering approach has been selected [4].

Machine Protection at ESS can be divided into two main categories: local protection and global protection. A local protection function is a Protection Function where the sensor, logic and actuator chain is contained within the same system. A global protection function is a Protection Function where the sensor, logic and actuator chain is distributed over multiple systems. Global Protection Functions at ESS are often related to beam induced damage and beam loss [5].

The local protection is the responsibility of the system designer while the global protection is in the scope of the Machine Protection Group. Global Protection Functions tend to cut across different ESS divisions and systems. The Beam Interlock System (BIS) monitors the state of the machine and contains the main part of the global protection function logic. If a local protection system or BIS detects a state that might influence the proton beam in a way that causes a damage or activation risk to equipment, the proton beam generation is switched off in a controlled way to minimize damage and activation potential. The BIS is the only system at ESS that is purely dedicated to Machine Protection. All other systems have other primary purposes and implement Protection Functions in addition to their main functions.

FUNCTIONAL PROTECTION

What is Functional Protection?

Functional Protection is a technical risk management method suitable to apply on a System-of-Systems or other complex systems. The method was developed at ESS and can be integrated into the design and early commissioning phases of accelerator facilities to enhance their reliability

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NEW BEAM PERMIT PROCESS FOR THE PROTON SYNCHROTRON COMPLEX

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Abstract

Injecting beams in CERN facilities is subject to the CERN safety rules. It is for this reason that the Beam Permit approval procedure was improved by moving away from a paper-based workflow to a digital form. For each facility, the Beam Permits are signed by the various responsible specialists (Access systems, safety equipment, radiation protection, etc…). To achieve this, CERN's official Engineering Data Management System (EDMS) is used. The functionality of EDMS was extended to accommodate the additional requirements, whilst keeping a user-friendly web interface. In addition, a new webpage within the CERN OP-webtools site was created with the purpose of providing a visual overview of the Beam Permit status for each facility. This new system is used in the CERN Control Centre (CCC) and it allows the Operations team and all people involved in the signature process to follow the Beam Permit status in a more intuitive, efficient and safer way.

INTRODUCTION

Safety Permits

A Safety permit is a safety procedure that accompanies the major milestones in the lifecycle of a beam facility. It considers the activities and operations foreseen for a particular stage and their associated hazards.

It is a signed document composed by a checklist signed off by the corresponding responsible persons. It constitutes permission to carry forward.

This quality assurance process aims to ensure that proper consideration is given to the risks of a particular activity and an operation.

Safety permits follow the principle of quality assurance in terms of traceability and archiving.

This standardised process shall be applied at an appropriate level to the lifecycle of a beam facility that best suits the needs of that facility [1].

Examples of existing safety permits:

- Beam permit (e.g. CERN beam facilities).
- Hardware permit (e.g. PS Complex).
- Powering permit (e.g. LHC).
- Laser permit (e.g. AWAKE).
- RF permit (e.g. LIGHT).
- Source permit (e.g. GIF++).
- Cool-down permit (e.g. LHC).
- Irradiation permit (e.g. MEDICIS).

EDMS

The Engineering and Equipment Data Management Service has served the High Energy Physics Community for over 15 years. It is CERN's official PLM (Product Lifecycle Management), supporting engineering communities in their collaborations inside and outside the laboratory. EDMS is integrated with the CAD (Computer-aided Design) and CMMS (Computerized Maintenance Management) systems used at CERN providing tools for engineers who work in different domains and who are not PLM specialists.

The functionality of EDMS is focused on support for engineering and quality assurance processes, collaborative aspects of work and long term data preservation [2].

Main features of EDMS are:

- Structured data.
- Lifecycles.
- Version control.
- Collaborative work.
- Fine-tuned access rights.
- Personalization.

OP-Webtools

This web portal was created about ten years ago with the idea of giving a single access point to services used in the daily operation of CERN's accelerators, like beam documentation, shift planning etc. Since then it grew in scope and number of applications providing a solid framework for a rapid development of web applications.

BEAM PERMITS IN EDMS

At the beginning of 2015, The CERN Beams Operations group (BE-OP) decided to move Safety Permits from paper (annex A) to a digital system. Some possibilities were on the table. As CERN already had some document management application services, the creation of a new tool was discarded. The last two candidates to harbour Safety Permits were EDH (Electronic Document Handling System) and EDMS. The Beams Departmental Safety Officers (BE DSO) in agreement with the BE-OP group leader decided eventually to use EDMS as the new tool for Safety Permits management. The simplicity and flexibility to introduce the requested process in the system made the choice easy. Once the decision was taken, the first Safety Permit was created in EDMS.

First documents were based on the basic approbation process used in EDMS (old method) where documents went through three steps ("In Work", "Engineering

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LIA-20 EXPERIMENT PROTECTION SYSTEM

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Abstract

In Budker Institute of Nuclear Physics (BINP) is being developed an electron linear induction accelerator with beam energy 20 MeV (LIA-20) for X-ray flash radiography. Distinctive feature of this accelerator in protection scope is existence both machine, person protection and experiment protection system. Main goal of this additional system is timely experiment inhibit in event of some accelerator faults. This system based on uniform protection controllers in VME form-factor which connected to each other by optical fiber. By special lines protection controller fast receives information about various faults from accelerator parts like power supplies, magnets, vacuum pumps and etc. Moreover, each pulse power supply (modulator) fast send its current state through a special 8 channel interlock processing board, which is base for modulator controller. This system must processing over 4000 signals for decision in several microseconds (less than 50 us) for experiment inhibit or permit.

INTRODUCTION

LIA20 – is an electron linear induction accelerator for X-ray flash radiography with energy up to 20 MeV and 2 kA beam current. It will produce three pulses (two short and one long) in one shot and divide the long pulse on nine parts for researching an experiment object from nine directions. A final radial beam dimension after lens correction will be 1 mm. LIA20 is an evolution of a LIA2 [1] which was designed as injector on energy 2 MeV for big accelerator.

The experiment is very expensive and has long preparation time therefore LIA20 should has a special experiment protection system (EPS). This system should inhibit start of the experiment when accelerator does not operate in normal mode. An accelerator structure defines some specific parameters for the experiment protection system. First, reaction time on accelerator malfunction should be less than 50 us for inhibit experiment in time. Secondly, total accelerator length with a beam dividing hall is approximately 150 m., therefore optical lines for protector devices are necessary. LIA 20 has many systems with a big quantity of units thus protector device should be multi-channel (16 or more).

EXPERIMENT PROTECTION SYSTEM

The experiment protection system based on a specific VME designed modules – preventers. It's a 6U height VME module with channels for receiving signals from devices or another preventers. This module based on FPGA controller with capability of adjusting inner parameters. All preventers and devices connected together via special "workability" channels. Each preventer has 8 "workability" channels on its front panel and this number can increase up to 24 by installation a 16-channel rio-module. Also preventer has one "workability" channel for connecting to another preventers, one CAN channel and special channel for connecting bus with modulator controllers so-called "fault-bus".

Logic Structure

Experiment protection system general structure is represented in Fig.1. It's a "star" network with a three layers – low, middle and high.

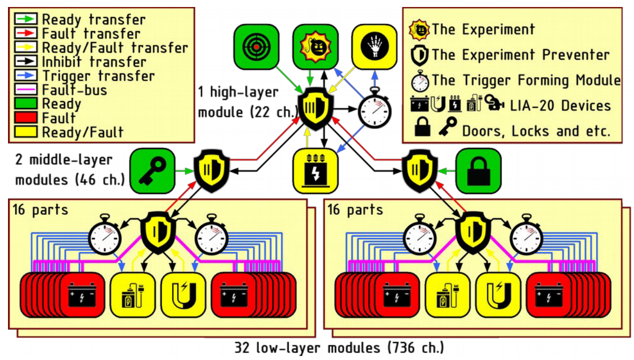

Figure 1: LIA20 EPS logic structure.

There are 32 preventers on a low layer of the network, which are located in a regular VME crates. This preventers are collect signals from devices (degausser, HV charger, lens power supply, thyratron heating unit and etc.) over "workability" channels and from modulator controllers over special "fault-bus". They send a "fault" signal to middle-layer preventer after processing all "workability" channels. There are two preventers on the middle-layer. They can receive signal not only from low-layer preventers but from not regular devices or system, for example, from doors, locks or another devices from personal safety system. In its turn middle-layer preventers send "fault" signal to single high-layer preventer, which are located in the central VME crate. Also this terminal preventer receive "workability" signals from a cathode heating power supply, vacuum and gas system, target and detector system. Main goal of this preventer (and whole system) is inhibit experiment start unit and inhibit its trigger signal when something wrong in accelerator or detector system.

How was mentioned above the preventer and devices are connected together over "workability" channels. Every "workability" channel consist of three lines – "ready" signal transfer line, "fault" signal transfer line and "inhibit" signal transfer line. A device ready for work when it already done all preparatory procedures (heating, charging, "cold" turning-on and etc.) and waits external events, which define device further behaviour. The device transfers "fault" signal when it cannot working in normal mode. If device receive an inhibit signal it must be stopped in safe manner all work.

A device final malfunction is defined on a "fault" signal and a "ready" signal received in time. A "fault" signal has

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DEVELOPMENT OF PULSE FAULT SEQUENCE ANALYSIS APPLICATION WITH KSTAR DATA INTEGRATION SYSTEM*

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Abstract

The Korea Superconducting Tokamak Advanced Research (KSTAR) interlock related systems are configured with various system such as fast interlock, supervisory interlock, plasma control, central control, and heating devices using various types of hardware, software, and interface platforms. For each system, monitoring and analysis tools are already well-developed. However, for the analysis of system fault behaviour, these heterogeneous platforms do not help finding the relation of failure. When the interlock events are latched or pulse is stopped by PCS, events are transmitted to different actuators and it could make other events via various interface. In other words, it could lead another factor of fault causes on different systems. Through this application, we will figure out the sequence of fault factor during the pulse-by-pulse KSTAR operation. The KSTAR Data Integration System (KDIS) is configured with KSTAR event-driven architecture and data processing environment. This application has been developed on the KDIS environment and synchronized with KSTAR event. This paper will present the development of shot fault sequence analysis application and its environment configured with KDIS.

INTRODUCTION

Since 2008, KSTAR [1] has completed its 10th plasma experiment by 2017. As the stability of device operation increases, the requirements for accessing operational information through data have increased. As part of such a requirement, we have developed fault analysis application to improve operational efficiency.

BACKGROUNDS

KSTAR Interlock Related System

In order to analyse fault sequence, the study of KSTAR interlock events and actions related system should be proceeded. Interlock system is complicated because it has various dependencies and configurations. KSTAR interlock system is composed of Fast Interlock System (FIS) [2] [3] for heating system protecting PFC from heating beams and Supervisory Interlock System (SIS) [4]. In addition, there are related systems such as local interlock system, central control system, plasma control system, and plasma monitoring system. Focused on the central interlock system, the interface diagram between interlock related systems is drawn in Fig. 1.

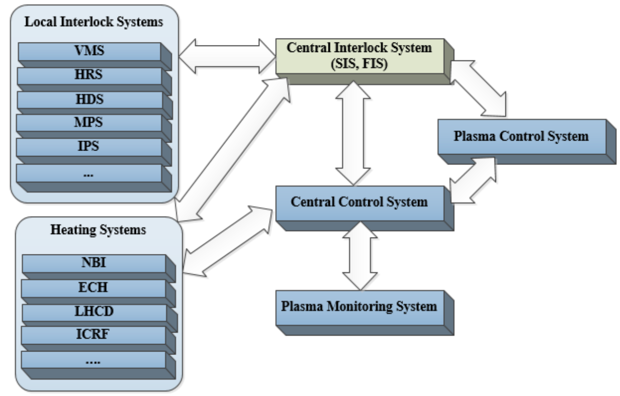

Figure 1: Interlock related system interface.

KDIS and Data Repository

The KDIS [5] has been developed as an integrated data system for KSTAR including scheduled processes on stream and batch data according to KSTAR events with a user interface service, hardware and software infrastructures, applications, and libraries under the open source architecture as shown in Fig. 2. The fault analysis application is developed and executed under the KDIS environment as a task. This application is launched by KDIS job scheduler according to an operational state of KSTAR.

In order to integrate data from the heterogeneous system, we use Channel Archiver [6], MDSPlus [7], and log files from the system. KDIS has all the interfaces between systems. KDIS provides an environment for integrating relevant data.

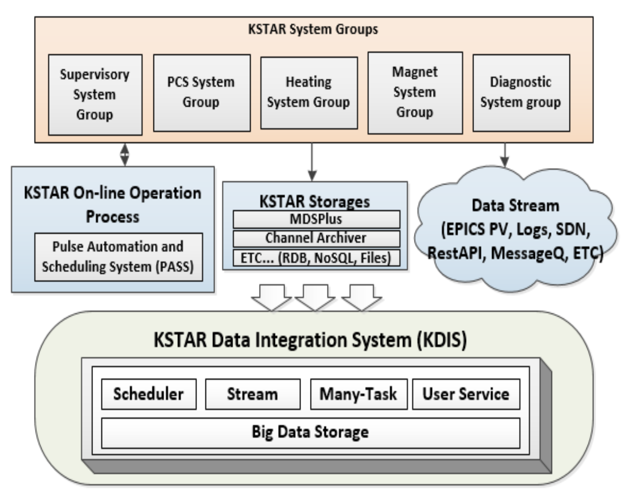

Figure 2: KSTAR system and KDIS.

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ESS ACCELERATOR OXYGEN DEPLETION HAZARD DETECTION SYSTEM

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Abstract

At the European Spallation Source ERIC (ESS), cryogenic cooling is essential for various equipment of the facility. The ESS Superconducting LINAC and the ESS Cryomodule Test Stand, will require major cryogenic services in order to be supplied with liquid nitrogen and helium [1]. Since the use of cryogenic fluids can be associated with Oxygen Depletion Hazard (ODH), the ESS Protection and Safety Systems group will install an ODH Detection System which is a PLC-based alarm system. This system will monitor real time Oxygen concentration levels in designated areas, with the aim to alarm personnel if the oxygen level is detected below certain thresholds. This paper gives an overview about the requirements, system architecture, hardware and software of the ODH Detection System in ESS Accelerator buildings [2].

INTRODUCTION AND REQUIREMENTS

In general, no use of asphyxiant cryogenic fluids or compressed gases is permitted at ESS without a formal evaluation of the ODH Class which shall be conducted through a specific ODH process for all activities which are physically capable of exposing individuals to an oxygen depletion. Therefore, ESS has the mandate to perform ODH assessment for any building where ODH could be present, in order to determine the necessity to install ODH Detection System and additional mitigation actions based on the results from the safety study [3].

The ODH assessment process can be divided into three main steps as shown in Figure 1. It should be noted that the process is built around quantitative assessment followed by independent expert(s) review that will provide the final clearance of the activity/area/equipment before operation [4].

Following the ODH assessment, the areas will be classified as require ODH Detection System or not. To start with development of ODH Detection System, a hazard register will be created where hazards, their initiating events, likelihoods, mitigation, human actions, etc. will be recorded. This will be followed by a Fault Tree (FTA) and Event Tree Analysis (ETA) to understand the ODH Detection Systems points of failure and also explore the consequences of failure of this system [5].

In ESS Accelerator buildings, through an ODH assessment five areas have been identified where ODH Detection System is required, the Helium Compressor Building (HCB), the Cryogenic Transfer Line Gallery (CTLG), the Cold Box Hall (CXH), the Cryomodule Test Stand and the Accelerator tunnel.

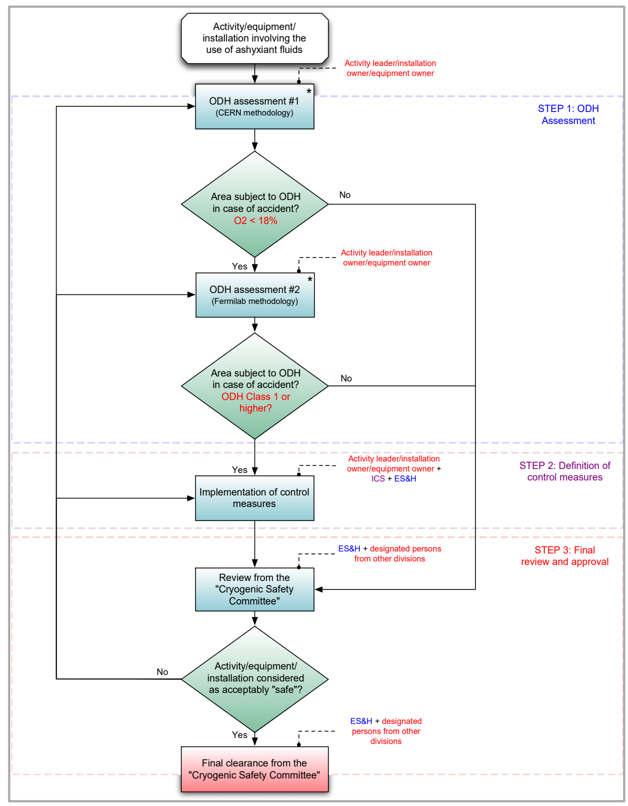

Figure 1: Flowchart of the ESS ODH assessment.

The following are the sources of ODH in the areas already mentioned:

- Warm Helium in the HCB, the CTLG and the CXH.
- Nitrogen in HCB.
- Nitrogen in the CXH.
- Liquid helium in the CXH, CTLG and Accelerator tunnel.

If the Oxygen concentration drops between 19.5% and 18%, the ODH detection system will send a warning signal to the Main Control Room and the Cryogenic Control Room where operators will be notified. The ODH evacuation alarm (red beacon lights + siren sounders) will be activated upon detection of low level of oxygen (≤18%) from at least one of the ODH monitors. The alarms will remain active as long as the digital signal from the ODH monitor is active.

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TECHNICAL AND ORGANISATIONAL COMPLEXITIES WITH A DISTRIBUTED MP STRATEGY AT ESS

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Abstract

The reliable protection of the ESS equipment is important for the success of the project. This requires multiple systems and subsystems to perform the required protection functions that prevent undesired hazardous events. The complexity of the machine, the different technical challenges and the intrinsic organisational difficulties for an in-kind project such as ESS impose serious challenges to the distributed machine protection strategy. In this contribution, the difficulties and adopted solutions are described to exemplify the technical challenges encountered in the process.

THE EUROPEAN SPALLATION SOURCE

The European Spallation Source (ESS) is a European project with the aim of designing, constructing and operating an Accelerator-driven neutron source in Lund, Sweden. The purpose of this installation is to enhance neutron science by replacing the use of reactor-based neutron sources and to be an important center of science in Europe. The first spallation neutrons are expected in 2020 and ESS is planned to operate for 40 years before decommissioning.

ESS is a greenfield facility where a very high percentage of the components are designed and fabricated in different European countries in the form of in-kind, rather than cash. This makes it more complex to manage and to identify clear responsibilities and interfaces. For the distributed machine protection (MP) system of systems, the characteristics of this project present important organizational challenges.

MACHINE PROTECTION AT ESS

Machine protection is embedded in all systems, from power supplies to the large target system and neutron instruments. The main goal of MP is to stop the escalation of any misbehaviour of the machine, bringing it back into a stable and protected state.

In the case of a power supply, any internal problem, for example a broken fan, will be detected by a rise in temperature. The power supply will be stopped to avoid worse consequences, such as damage of connected components, fire, etc.

In the case of larger systems such as ESS, MP mainly avoids the escalation of events that could lead to beam induced damage. This means that if any critical misbehaviour of one the systems involved in generating, focusing, accelerating, steering, bunching, or chopping the beam is detected, these systems have to inform the so-called Beam Interlock System (BIS) to stop beam operation, bringing the machine to a protected state. Another key part of the protection is done through the beam monitoring systems, which directly detect and observe the different beam properties (e.g. position, current, pulse length, profile, position). In case these systems detect the beam parameters to be outside pre-defined boundaries, they will trigger an interlock and inform the BIS. There are other important functions in the MP systems, such as the correlation of the different beam modes that limit certain beam parameters to a maximum allowed beam power, the beam destinations (e.g. target, tuning beam dump) and the different elements that interact with the beam. As an example, if an insertable beam instrument can withstand only a low-power beam without being damaged, the BIS will not allow its insertion unless the correct beam mode for that device has been selected.

System of Systems

Machine Protection is done in a distributed way, where single protection functions are performed by different parts of the machine. These are managed by different divisions or groups and designed and built by different laboratories around Europe. This requires a new way of organizing the responsibilities, which can be achieved by applying the System of Systems (SoS) approach. This work was presented in [1] and it is currently followed at ESS.

The systems that belong to the MP SoS can be seen in Figure 1. All of these systems play a role in the operation and the protection of the machine. These systems belong to different groups and divisions. The protection-related systems are mainly related to the correct operation of the different ESS systems. The Proton Beam Monitoring systems detect if the beam is in its expected state or if there is some unexpected behavior. The Beam Stop Actuation systems stop the beam operation in a reliable way (upon request by the BIS). Other systems, such as safety or controls also have a connection to the BIS. Finally, other systems are required to ensure everything is synchronized, and these have been grouped (in this context) to be the MP management systems.

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A MAJOR PERFORMANCE UPGRADE TO THE TRANSVERSE FEEDBACK SYSTEM AT THE ADVANCE PHOTON SOURCE*

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Abstract

With the success and reliability of the transverse feedback system installed at the Advance Photon Source (APS), a major upgrade to expand the system is under way. The existing system is operating at a third of the storage ring bunch capacity, or 432 of the available 1296 bunches. This upgrade will allow the sampling of all 1296 bunches and make corrections for all selected bunches in a single storage ring turn. To facilitate this upgrade a new analog I/O board capable of 352 MHz operation was developed along with a revolution clock cleaning circuit. A 352MHz clock cleaning circuit was also required for the high-speed analog output circuit to maintain data integrity to the receiving DAC unit that is 61m away. This receiving DAC unit will have its transceiver data rate upgraded from 2.3Gbps to about 7Gbps transmitted over a fiber optic link. This paper discusses some of the challenges in reducing the clock jitter from both the system P0 bunch clock and the 352MHz clock along with the necessary FPGA hardware upgrades and algorithm changes, all of which is required for the success of this upgrade.

INTRODUCTION

The Advanced Photon Source (APS) experiences beam instabilities in both the transverse and longitudinal planes. The P0 feedback system, in its initial version, will correct these instabilities in a bunch pattern that has up to 24 bunches. This is accomplished by using a pick-up stripline, drive stripline, four drive amplifiers, a 3-tap comb filter for front-end signal conditioning, and an Altera PCIe Stratix II GX FPGA-based development board coupled with a Coldfire CPU. The Coldfire CPU uses EPICS [1] with RTEMS [2] for all the remote monitoring and control. Figure 1 shows a block diagram of the feedback system. This paper discusses FPGA performance, added features and modifications, as well as the imminent upgrade.

SYSTEM DESCRIPTION

The current system consists of a pick-up stripline, a front-end signal-processing unit, an Altera PCIe Stratix II GX FPGA-based development board, drive amplifiers, and a driver stripline.This system has been described in detail [3]. Figure 1 shows a block diagram of the current system without the remote DAC hardware. At the core of the FPGA processor are the 864 32-tap FIR filters running at 117.3 MHz. The algorithm used for the filter is based on the least square fitting method to determine filter coefficients [4]. The pickup and drive striplines are located in different locations of the storage ring, which is a major issue for the Y-channel since the distance between pickup and drive is seven sectors, or about 188 m, apart. A remote DAC linked to the main transverse feedback system via high-speed fiber optic cable utilizing a real-time data transfer protocol. Figure 2 shows the addition of the transceiver in the main transverse feedback chassis used to connect the remote DAC chassis.

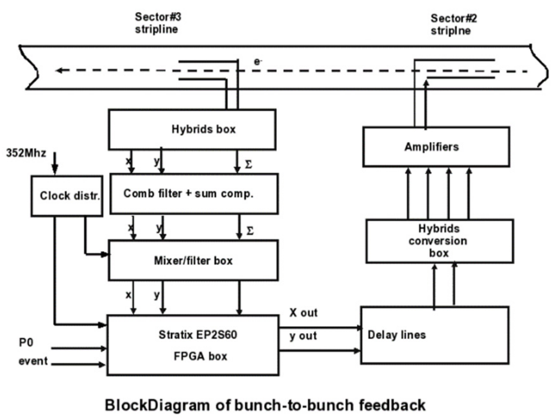

Figure 1: Block diagram of the feedback system.

CURRENT SYSTEM AND LIMITATIONS

The current FPGA system described above has been very successful for the Advanced Photon Source as it has been detailed in a previous paper [5]. This system is limited to 324 or 432 buckets depending on the operating frequency of 88 or 117.3 MHz that's configured for a particular bunch pattern. With the proven success of this system, an opportunity to expand the transverse feedback system to encompass all 1296 buckets has been proposed. This would require the system to operate at the full storage ring frequency of 352 MHz. At 432 buckets, the system is operating at 117.3 MHz, which is near the limitation of the ADC/DAC interface to the FPGA. The current ADC has a maximum sample rate of 125 MHz while the DAC can perform at 150 MHz. The current FPGA (Stratix II GX) is limited to a maximum transceiver rate of 6.376 Gbps of which 2.3 Gbps is needed to transport data to the remote DAC at system clock rate of 117 MHz. To transport data to the remote DAC with a system clock rate at 352 MHz, the transceiver needs to triple its transmission rate from 2.3 Gbps to 7.04 Gbps, which is beyond the Stratix II GX chip's capabilities. The current ADC and DACs are also not sufficient for 352-MHz operation. One solution is to have several ADCs and DACs in parallel to achieve 352-MHz operation. While standard methods can be used to multiplex the ADC front end, it becomes very complicated to mux several DACs to generate a 352-MHz analog control signal. This option also requires more board space,

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UPGRADE OF THE LLRF CONTROL SYSTEM AT LNL

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Abstract

For the SPES project at Legnaro National Laboratories (LNL), a Low-Level Radio Frequency (LLRF) has been designed to have flexibility, reusability and an high precision. It is an FPGA-based digital feedback control systemusing RF ADCs for the direct undersampling and it can control at the same time eight different cavities. The LLRF system was tested on the field with an accelerated beam. In the last year some improvements on the firmware, software and hardware of the control system have been done. In this paper the results carried out in the more recent tests, the future works and the upgrades of the system will be detailed.

INTRODUCTION

SPES (Selective Production of Exotic Species) [1] is a new facility under construction at LNL. The main goal is the production of neutron-rich exotic beams to perform research in nuclear structure and in interdisciplinary fields like medical and biological. Then the Radioactive Ion Beam (RIB) from SPES can be boost through the linear accelerator ALPI [2] and sent to the three experimental halls. Some upgrades which would make ALPI suitable as an RIB accelerator are in commissioning [3]. ALPI is a superconducting linear formed by 96 QWR cavities. The first group of cavities resonate at 80 MHz, while that of a second group resonate at 160 MHz. In order to boost also the RIB coming from SPES, ALPI must be modernized. Besides the resonators themselves, all their ancillary components need to be modernized: RF controllers, RF control system, RF power amplifiers, and couplers, pickup and tuners. The RF control system upgrade are here detailed. In particular this paper is focused on the digitalization of the signals, how this process is related to the control performance and on the firmware/software modifications done during the last year.

RF CONTROLLER

Each RF controller [4], [5] controls up to eight cavities. The RF signals picked-up from the cavities are undersampled by RF ADCs. The digitized signals are elaborated by a field programmable gate array (FPGA) which implements a proportional-integral controller. The signals processed by the FPGA are up-converted by DACs, hence the harmonic of interest is filtered-out and sent to power amplifiers and then to the cavities.

A block diagram of the LLRF controller for the cavities is shown in Fig. 1. It is based essentially on three boards:

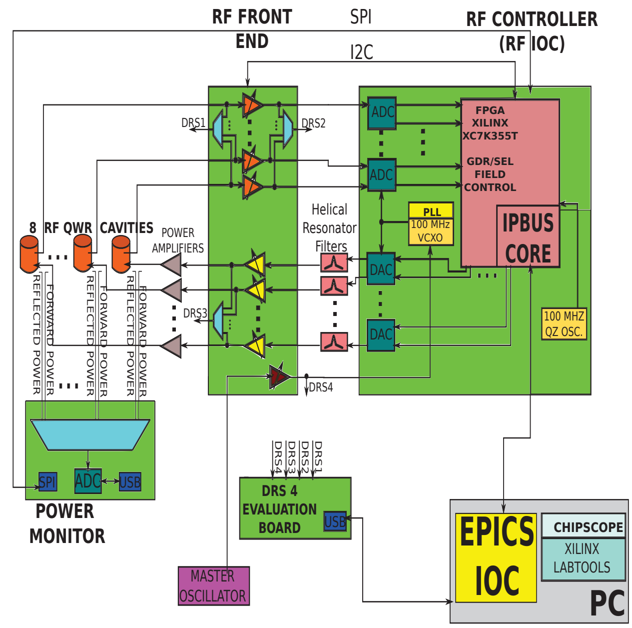

Figure 1: Block diagram of the LLRF system

the RF input-output controller (RF IOC), the RF front end (RFFE) and the power monitor (PM) [4]. The RF IOC implement the control law. The RFFE board adapts the amplitude level of the RF signals from the cavities to the ADCs of the RF IOC and from the DACs of the RF IOC to the power amplifiers. The PM board measures the reflected powers and the forward powers of the eight controlled cavities.

One of the most critical point next analyzed is the digitalization of the signals.

ADC

In order to simplify the hardware design the direct down conversion(DDC) was adopted. The signals picked up from cavities have frequencies that lie in the second or third Nyquist zone. DDC preserves the signal information if the sampling frequency is at least double the bandwidth of the RF signals [6]. This condition is complied. Furthermore the RF signals are sampling in quadrature in order to extract the in-phase and quadrature components. From these components it is direct get the amplitude and phase of the field resonating in cavities. The components are physical meaningful and can be controlled independently.

ADCs have to guarantee an high resolution and an high sampling rate. The sampling rate is important since the DDC was chosen, while the high resolution is related to the stability of phase and amplitude in cavity. For a mod-

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CORRECTION OF 10 Hz ORBIT DISTORTION FROM DIAMOND'S I10 FAST SWITCHING CHICANE

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Abstract

The I10 beamline at Diamond Light Source is configured to study circular dichroism. To increase signal to noise ratio between the two beam polarisations and increase temporal resolution the beamline is fed by two separate IDs that are typically configured with opposite handed polarisations. A chicane of steering magnets with programmable power supplies is used to provide 10 Hz switching between the two photon beams by producing a dynamic closed bump that alternates the on-axis trajectory of the electron beam between the two IDs. In order to maintain the closed bump and make the switching transparent to the rest of the photon beamlines the phase and amplitude of the sine functions applied to the chicane magnets must be exactly correct. In this paper the linear scheme that was used to correct the residual 10 Hz orbit distortion is presented. Future work that uses the fully programmable nature of the magnet power supply controllers to correct high order distortions is also discussed.

INTRODUCTION

Diamond Light Source is a third generation synchrotron light source, with a 3 GeV storage ring, a 100 MeV linac and 3 GeV booster, allowing operation in top up mode [1]. Since commissioning Diamond have increased the number of photon beamlines and there are currently 33 which are either in operation or construction.

Adding to already established beamlines has allowed Diamond to explore more novel techniques when designing newer beamlines. One such technique in use for Diamond's I10 beamline is fast polarisation switching; chicane magnets are configured with an AC waveform to synchronously move the electron beam on or off axis between one of the two insertion devices (IDs) set to different polarisations, allowing rapid 10 Hz switching between the polarization of the on-axis beam [2]. This must be achieved without creating motion in the global electron beam which will be visible to other photon beamlines.

CONFIGURATION OF DIAMOND'S I10 BEAMLINE

Diamond's I10 beamline provides a platform for advanced dichroism experiments [3]. The two APPLE II undulators are capable of providing soft x-ray beams between 0.4 keV and 2 keV in arbitrary circular and linear polarisations [4, 5]. To determine the dichroism it is often necessary to resolve very small differences between the scans at different polarisations. By decreasing the time delay between the two spectra being obtained any time-based noise, such as thermal drift, can be minimized, and larger quantities of data can be collected and then averaged making better use of beamtime.

I10 CHICANE ARRANGEMENT

Third generation light sources have dedicated straight sections of storage ring designed for the placement of IDs; these are situated between the arcs of the machine which contain the bending and focusing magnets. In I10's straight there are two IDs and five dipole magnets, with a pair of fast dipoles situated either side of the IDs and one DC dipole between them as shown in Fig. 1. This provides the actuation necessary to change the path of the electron beam such that the angle can be controlled through each ID while ensuring that the exit trajectory of the electrons maintains a constant angle and position. The chicane magnets are each powered with an offset sine wave that switches the beam between its two states at 10 Hz. Preventing any global movement in the electron beam is particularly important for the other beamlines where the requirements for beam stability are high, with beam motion < 10 % of beam size; this ensures a stable x-ray beam for Diamond's users [6]. Any error in the steering through the chicane will allow the 10 Hz component to leak out of the chicane and into the global electron beam motion.

Magnet Details

The chicane magnets are horizontally deflecting magnets arranged symmetrically about the IDs. Despite the symmetric arrangement slight variations in manufacturing necessitate slightly different set-points for the magnitude of the sine waveforms of the complementary magnets. Each complementary pair of magnets has its waveform separated in phase by 180°. The field on the magnets is brought through a synchronised sine wave sweep so that the two extreme states shown in Fig. 1 are cycled between at 10 Hz. Carefully controlling the magnetic field through the sweep ensures that a closed bump is created along the chicane and no electron beam motion is seen globally around the storage ring.

Power Supply Controllers

All of Diamond's magnets are controlled by programmable power supplies [7]. These have the ability to play through a waveform stored in memory using a custom amplitude and time-step. All of these parameters, including the waveforms, can be configured from EPICS. The chicane magnets are programmed so that they have offset sine waveforms, shown in Fig. 2, for creating the 10 Hz bumps, and waveforms for ramping up, down, and degaussing.

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ONLINE COUPLING MEASUREMENT AND CORRECTION THROUGHOUT THE LHC CYCLE

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Abstract

With high intensity beams, a precise measurement and effective correction of the betatron coupling is essential for the performance of the Large Hadron Collider (LHC). In order to measure this parameter, the LHC transverse damper (ADT), used as an AC dipole, will provide the necessary beam excitation. The beam oscillations will be recorded by the Beam Position Monitors and transmitted to dedicated analysis software. We set up the project with a 3-layer software architecture: The central part is a Java server, orchestrating the different actors: The Graphical User Interface, the control and triggering of the ADT AC dipole, the BPMs, the oscillation analysis (partly in Python), and finally the transmission of the correction values. The whole system was developed in a team using Scrum, an iterative and incremental agile software development framework. In this paper we present an overview of the system, experience from machine development and commissioning as well as how scrum helped us to achieve our goals. Improvement and re-use of the architecture with a nice decoupling between data acquisition and data analysis are also briefly discussed.

INTRODUCTION

A proper tune control requires a machine coupling which is significantly smaller than the tune separation. $|C^-|$, the complex coupling coefficient corresponds physically to closest approach of the 2 tunes, Q_x and Q_y. For the LHC this requirement yields an operational tolerance for the global machine coupling of $|C^-| \ll 0.03$ for injection optics and $|C^-| \ll 0.003$ for collision optics [1,2]. The tune feedback, an essential feature for the beam stability, requires that the coupling is as low as possible. Otherwise it is impossible to correct the horizontal and vertical tune independently as a correction in one plane will also influence on the other. The transverse coupling has furthermore been linked to cause instabilities and the reduction of dynamic aperture [3].

MEASURING TRANSVERSE COUPLING

The method to measure transverse coupling described in this article is to excite the beam with the transverse damper (ADT) used as an AC dipole and record the beam position during 6600 turns. This leads to a coherent beam motion close to the betatron frequency. Unlike kickers, an AC dipole excitation can produce a sustained coherent motion with negligible emittance growth. For that reason, this became the preferred mode of excitation for such kind of measurements in the LHC. Turn-by-turn position data of the excited motion from beam position monitors (BPMs) allows prompt measurements of optics parameters. Coupling Resonance Driving Terms (CRDT) due to skew quadrupole fields can be determined from corresponding spectral components of the turn by-turn position [4–6]. The benefit of using the ADT to excite the beam is that it enables a well controlled excitation of an individual bunch(es), while the traditional AC dipole would excite all bunches in the machine [7,8].

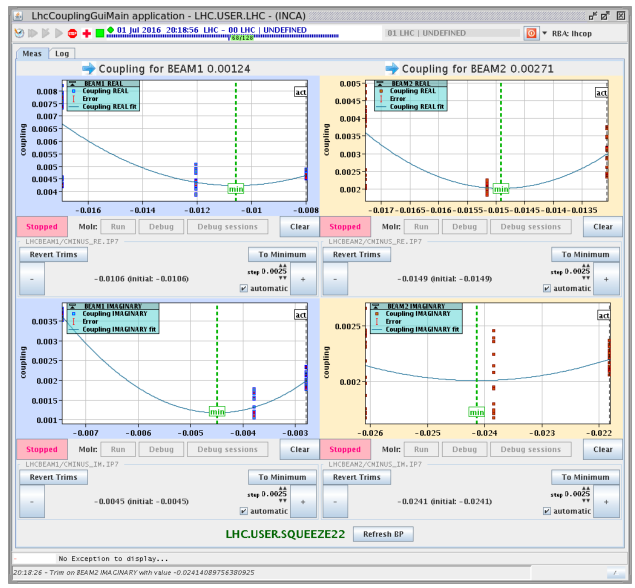

Figure 1: Old manual application.

MOTIVATION FOR NEW SOFTWARE

Before the described software was put in operation, there were essentially 3 methods to measure the coupling in the LHC:

- The first one was a lengthy process of trial with the 2 knobs controlling the coupling correction (real and imaginary part) trying to find a minimum in $|C^-|$. This has to be done for the 2 beams individually (Fig. 1). Also, the operational measurement of $|C^-|$ is not reliable in all machine configurations.
- In 2016 operation, a software taking advantage of the injection oscillations was used. This approach was intrinsically limited to corrections at injection energy and required a dump and re-injection of low-intensity bunch for each measurement.
- An expert tool was used by the optics team to measure optic parameters, including the coupling, using the LHC AC dipole. However, for machine protection reasons, powering the AC dipole is restricted to

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NEW CERN PROTON SYNCHROTRON BEAM OPTIMIZATION TOOL

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Abstract

This paper describes a new software tool recently developed at CERN called "New CPS Beam Optimizer". This application allows the automatic optimization of beam properties using a statistical method, which has been modified to suit the purpose. Tuning beams is laborious and time-consuming, therefore, to gain operational efficiency, this new method to perform an intelligent automatic scan sequence has been implemented.

The application, written in JavaFX, uses CERN control group standard libraries and is quite simple. The GUI is user-friendly and allows operators to configure different optimisation processes in a dynamic and easy way.

Different measurements, complemented by simulations, have therefore been performed to try and understand the response of the algorithm. These results are presented here, along with the modifications still needed in the original mathematical libraries.

INTRODUCTION

The accelerator complex at CERN is a succession of machines that accelerate particles to increasingly higher energies. Sequentially, each machine increases the energy of a beam of particles, before injecting into the next one. The CERN Proton Synchrotron (CPS) complex is the first group of accelerators serving as injectors for the Large Hadronic Collider (LHC). It comprises of one Linear Accelerator (Linac2) and two different synchrotron rings, the Proton Synchrotron Booster (PSB) and the Proton Synchrotron (PS), as well as several beam transfer lines.

Beam tuning is the process where operators change accelerator beam parameters in order to minimize or maximize beam observables.

Unfortunately, irregular beamline designs together with misalignment of the equipment challenge any simulation to achieve the best results. Simulating in advance the final accelerator tune is often very slow and not always efficient. In addition, some devices like quadrupoles, correction deflectors and kickers are very laborious to simulate with high certainty.

Very often, during beams setting-up or machine development, operators may have the challenge to find optimum settings, especially when the phase space of available parameters is large.

The problem of tuning different parameters versus one or more detectors can be compared to a numerical analysis optimization concept. In fact, in this field of mathematics, optimization is devoted to the study of the theory and methods to search the smallest or largest value of a function:

$$\min_{x \epsilon X} f(x) \;\; \text{or} \;\; \max_{x \epsilon X} f(x)$$

where:

- $f: \mathbb{R}^n \rightarrow \mathbb{R}$ is the multivariable function
- $X \subseteq \mathbb{R}^n$ is the set of possible solutions

When the problem is looking for minimum or maximum of a function, most of the known algorithms are based on the concept of the derivative and on the gradient information. In general it is not always possible to have an analytical expression of the function (which is abstract) and, as a consequence, the derivatives cannot be calculated. For this use cases one has to look into algorithms that use some function samples in a defined set of points in order to calculate different iterations. Direct-search methods are used for both deterministic and stochastic applications and, since they are effective techniques in deterministic applications especially when derivatives are unavailable, they have been targeted as primary choice for the development of the tool.

These methods are generally robust with respect to small perturbations in the function's values and therefore, are used often in applications where noise is present, which is often the situation faced in operations.

NELDER MEAD ALGORITHM

In the group of direct-search methods, the most popular one is called Nelder-Mead algorithm [1].

The algorithm uses a regular simplex, which is a polytope in n-dimensional space with $n+1$ vertices, each of which are connected to all other vertices (e.g. a triangle in $\mathbb{R}^2$, a tetrahedron in $\mathbb{R}^3$, etc.).

In order to perform an optimization, the algorithm begins with the function's values on a set of $n+1$ points in the parameter space of n variables (simplex) and it moves across the surface to be analysed in the direction of steepest ascent (for maximization) or steepest descent (for minimization) by replacing the worst vertex in the simplex with its "mirror image" across the face formed by the remaining vertices. The algorithm, while running, can change in five different ways during an iteration, as illustrated in Fig. 1 in two dimensions.

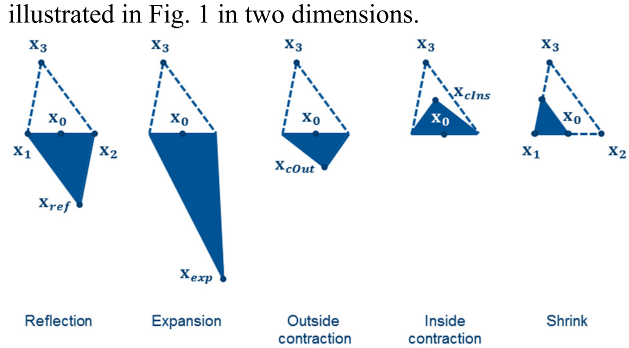

Figure 1: Nelder Mead iterations.

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DEVELOPMENT OF THE POWER SUPPLY CONTROL SYSTEM FOR J-PARC HADRON EXPERIMENTAL FACILITY*

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Abstract

The Hadron Experimental Facility is designed to handle an intense slow-extracted proton beam from the 30-GeV Main Ring of the Japan Proton Accelerator Research Complex (J-PARC). We have developed a new control system of a magnet power supply to work with a Programmable Logic Controller (PLC). The control PLC handles the status of the interlock signals between a power supply and a magnet, and monitors the output voltage and the current. The PLC also controls a programmable reference voltage for the DC output current. We have measured the stability of the DC output current of the power supply handled with the control PLC. In addition, we have developed an automatic orbit-correction program, which cooperates with the control PLC. The horizontal position of the proton beam can automatically be adjusted at the centre of the beam dump, and the temperature rise of the copper core during the beam operation can be minimized. The optimized current of a horizontal steering magnet can be corrected with the measured horizontal displacement of the proton beam. As a result of the test of the automatic orbit-correction program with the measured data during the beam operation, the availability of the control system was partially confirmed. The present paper reports the current status of the power-supply control system which can automatically correct the beam orbit to the beam dump.

INTRODUCTION

The Hadron Experimental Facility [1] (HEF) at the Japan Particle Accelerator Complex (J-PARC), shown in figure 1, is designed to handle an intense slow-extraction proton beam from the 30-GeV Main Ring (MR). The period of beam extraction from the MR to the HEF is 2 seconds and the operation cycle is 5.52 seconds. Eighty-two DC power supplies for the primary and secondary beam line magnets are remotely controlled with the control system based on GP-IB and the Agilent VEE program [2].

We have developed a new control system of magnet power supplies to work with a Programmable Logic Controller (PLC). In addition, we have developed the automatic orbit-correction program which cooperates with the control system. Figure 2 shows schematic diagrams of the present and new control systems.

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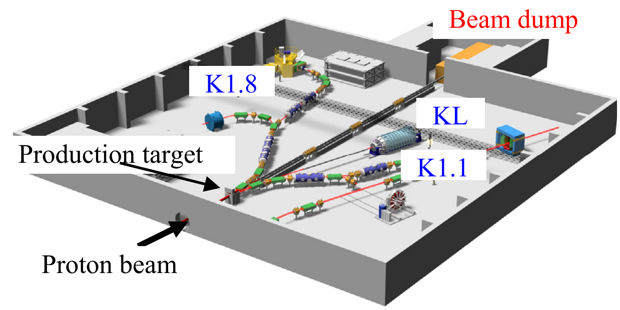
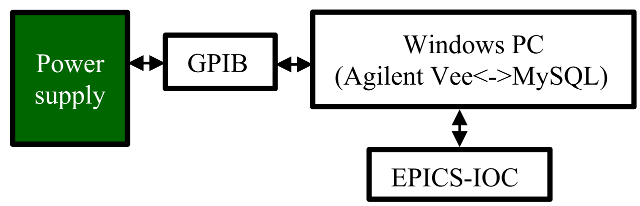
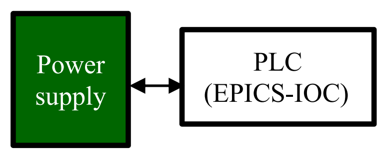


Figure 1: Illustration of the HEF.



(a) Control system of existing power supplies.



(b) New control system with PLC.

Figure 2: Schematic diagrams of power-supply control system.

CONTROL SYSTEM

The new control system for the magnet power supplies at the J-PARC HEF has been developed to cooperate with the Yokogawa's FA-M3V PLC. The PLC has the merits of its extensibility, portability, and easy transfer to Experimental Physics and Industrial Control System (EPICS) records.

The New Control System with Yokogawa FA-M3V PLC

The test setup with the Yokogawa FA-M3V PLC shown in figure 3 consists of a sequence CPU, a Linux CPU, a relay input, a relay output, an A/D converter and a D/A converter modules. Table 1 shows the model number of the PLC modules. The sequence CPU controls the discrete status of the magnet power supply. The Linux CPU, which is an embedded EPICS IOC on Yokogawa's FA-M3V PLC

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THE BUNCH ARRIVAL TIME MONITOR AT FLASH AND EUROPEAN XFEL

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Abstract

In modern free electron laser facilities like FLASH I/II and European XFEL at DESY a high resolution intra bunch train arrival time measurement is mandatory, providing a crucial information for the beam based feedback system. For this purpose a Bunch Arrival Time Monitor (BAM) was developed, based on an electro-optical scheme where an ultra-short pulsed laser is employed. A BAM is composed of several subsystems, including stepper motors, power management, dedicated readout board, management board for voltage settings, temperature sensors and temperature controller and optical amplifier. Part of the electronics is developed using the MicroTCA standard. We will present in this poster the basic requirements for the BAM, software design and implementation developed to manage the subsystems and their interactions.

INTRODUCTION

At the FLASH and European XFEL a beam based feedback for the electron bunch is mandatory to ensure the expected photon beam quality delivered at the experimental stations. Crucial information for the feedback system is provided by the Bunch Arrival Time Monitors (BAMs) which measure along the acceleration section of the machine the timing of the electron bunch with respect to a pulsed laser provided by a central Master Laser Oscillator (MLO), which is synchronized with the RF signal [1].

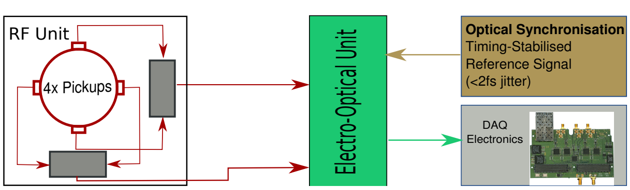

Figure 1: Basic Layout of the three BAM main components. The reference signal is provided by an external source, the laser-based synchronization system.

BASIC LAYOUT OF THE BAM

In this section we describe shortly the main components of the BAM system and their working principles. As Fig. 1 shows, the BAM system is composed of three parts, the RF unit, the electro-optical unit and the data acquisition system. The electro-optical unit is the core of the system. It combines the signals from the RF unit and a reference signal provided by an external source to perform the arrival time measurement. The result of this combination is then sent to the Data Acquisition System (DAQ).

- **The RF Unit** The electromagnetic field induced by the electron bunch is captured by four broadband pickups. Two opposite pickups are combined to reduce the dependence of the signal on the bunch transversal position [2].
- **The Electro-Optical Unit** Timing-stabilized laser pulses are provided as a reference signal to this unit. This signal serves also as clock for the DAQ electronics. The peak height of the pulses is modulated upon cross-correlation with an RF-signal, thus providing a temporal response from which the arrival time can be detected [3].
- **DAQ and Control** Dedicated electronics, firmware and software were developed to configure and control the single subsystems and for data acquisition [4]. Part of the electronics was developed using Micro Telecommunications Computing Architecture (MTCA) standard [5].

THE RF UNIT

Dependency on the transversal beam position is reduced by combining the signal of two opposite pickups. We will refer as RF signal the result of this combination. The RF signal amplitude is still function of the bunch charge as shown in Fig. 2. Higher bunch charge generates a higher amplitude, so bunch charges of several hundreds of picocoulomb can drive the bias voltage in the non monotonic region of the Electro-Optical Unit. To avoid that, one RF signal is filtered by a low-pass filter with a cut-off frequency of ca. 20 GHz and the maximal amplitude is also limited, thus allowing the measurement for higher bunch charges. This RF signal is called high charge channel, while the other is the low charge channel. The low charge channel has a cut-off frequency of ca. 40 GHz and has a theoretical resolution of 5-10 fs, while the high charge channel has a resolution of only 10-20 fs.

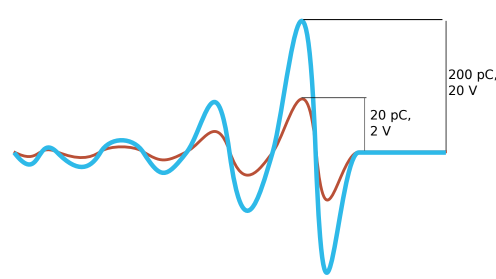

Figure 2: Dependency of the signal amplitude on the bunch charge. The amplitude increases with the bunch charge.

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THE STATE MACHINE FOR THE ACCELERATOR SYSTEM WORKING IN THE NATIONAL SYNCHROTRON RADIATION CENTRE SOLARIS

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Abstract

A state in which accelerator system works at a given moment of time is determined by the state machine. The idea of the project has been based on FSM – finite state machine, in which each of the states is precisely determined by assigned specified operations on subsystem devices of the accelerator system such as e.g. magnets of storage rings, RF transmitters etc. To ensure high reliability, the main part of the project has been based on PLC – Programmable Logic Controller. StateMachine wich is a TangoClass has been written in Python using the facadedevice library, that allows information from the control system to be delivered to the PLC system. By using an universal Tango Class AllenBradleyEIP the state machine shering an informationa about accelerator system to the Tango control system. This information is archived in Cassandra database system by using the Tango HDB++ archiving system.

DESCRIPTION OF ACCELERATOR'S SYSTEM WORKING IN SOLARIS

The Linear Accelerator with the Transfer Line

The linear accelerator working in Solaris has the lenght of 40 m and is capable of accelerating electrons from initial energy of 2.8 MeV (energy after leaving the electron gun) to maximum energy equal 600 MeV. After leaving the linear accelerator electrons are transferred to the storage ring by the transfer line. A system of two dipole magnets placed on ends of the transfer line provides for beam deflection in the vertical plane at an angle 27°, whereas six quadrupole magnets are responsible for beam focussing. The transfer line is ended by the septum magnet which connects the injector with the storage ring.

The Storage Ring

The storage ring in Solaris has been created in DBA technology (double-bend achromat), thus making possible to accomplish the design assumptionsit in which the small as possible emittance at the smallest size of the machine. The storage ring has circumference of 96 m and is capable of accumulating the current up to 500 mA at energy of 1500 MeV. For the construction of the storage ring, twelve of DBAs were used, connected with 3.5 m straight sections. Ten of straight sections are reserved for insertion devices and the other two are intended for beam injection and RF systems. The main Solaris storage ring parameters are presented in Table 1.

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Table 1: The Main Storage Ring Parameters

Energy	1.5 GeV
Nominal current	500 mA
Circumference	96 m
RF frequency	99.931 MHz
Natural emittance	5.598 nmrad
Energy spread	$0.745 \cdot 10^{-3}$
Radiation losses/turn	114.1 keV
Betatron tunes (H/V)	11.22/3.15
Corrected chromaticities (H/V)	+1/+1
Momentum compaction factor	$3.055 \cdot 10^{-3}$
Total lifetime	13 h

THE IDEA AND A SCHEME OF THE STATE MACHINE

Operation of the accelerator system is characterized by its states, which enable or deny specific actions on the accelerator system. In Solaris for specifying a state of the accelerator system the state machine is responsible for, which has been implemented in based on finite state machine model [1]. In this implementation 11 states have been defined:

1. **Shutdown** - all devices of the accelerator system are switched off;
2. **Ring off** - no beam in the storage ring. After passing to this state, all subsystems of accelerator system are switched on and requirements of PSS - personal safety system and MPS - machine protection system are checked. At the moment of positive information about correct switched on of all systems and fulfillment of requirements PSS and MPS systems, there is automatic transition to **Ring standby** state;
3. **Ring standby** - all devices of the accelerator system are switched on, but an electron beam is not accumulated in the storage ring;
4. **Ring preparation for injection** - all insertion devices are open, in turn safety shutters are closed;
5. **Injection** - a state in which injection and electron accumulation are made;
6. **Ramping** - a state in which electron beam energy is increasing;
7. **Beam delivered** - the state machine comes to this state automatically from the **Ramping** state after energy of a beam is equal 1500 MeV;

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A DUAL ARM ROBOTIC PLATFORM CONTROL FOR NAVIGATION, INSPECTION AND TELEMANIPULATION

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Abstract

High intensity hadron colliders and fixed target experiments require an increasing amount of robotic tele-manipulation to prevent excessive exposure of maintenance personnel to the radioactive environment. Telemanipulation tasks are often required on old radioactive devices not conceived to be maintained and handled using standard industrial robotic solutions. Robotic platforms with a level of dexterity that often require the use of two robotic arms with a minimum of six degrees of freedom are instead needed for these purposes. In this paper, the control of a novel robust robotic platform able to host and to carry safely a dual robotic arm system is presented. The control of the arms is fully integrated with the vehicle control in order to guarantee simplicity to the operators during the realization of the robotic tasks. A novel high-level control architecture for the new robot is shown, as well as a novel low level safety layer for anti-collision and recovery scenarios. Preliminary results of the system commissioning are presented using CERN accelerator facilities as a use case.

INTRODUCTION

Nowadays, intelligent robotic systems are becoming essential for industrial facilities as for harsh environments, in order to increase equipment availability and safety. In such scenarios, robots should perform repetitive and well-defined tasks as well as unplanned and dangerous tasks, which humans either prefer to avoid or are unable to do because of hazards, size constraints, or the extreme environments in which they take place, such as outer space or radioactive experimental areas. In particular, operating robots for maintenance and inspection in dangerous environments on costly machines requires skilled and well-trained dedicated shift operators. The control of these robots is usually not intuitive and slow: this is mainly caused by the not intuitive human-robot interfaces present on industrial robots and by the lack of adaptability of the standard robots to various intervention scenarios. The European Organization for Nuclear Research (CERN) [1] is the world largest high-energy physics laboratory. At CERN, there are more than 50 km of underground-unstructured accelerators area with thousands of different items of equipment that needs to be monitored and maintained. Due to the presence of human hazards mainly produced by radiation and high magnetic fields, as well as the risks related to an underground facility (e.g. lack of oxygen, fire risks etc.), the accelerators equipment at CERN have the needs to be monitored, inspected and maintained remotely, possibly using robots.

The use of robots in CERN's unstructured environments is particularly challenging: accessing to the equipment is often difficult and time consuming, long distances must be covered, and the equipment to be monitored or manipulated can be in uneven positions.

These aspects require intelligent robotic systems able to travel long distance, equipped with multiple robotic manipulators, possibly with a user-friendly human-robot interface (HRI). The control system of these robotic systems must be designed to overcome the challenges highlighted so far with the following constraints:

- Safe and robust, in order to perform operations without creating any risk for equipment, humans and the robot itself.
- Lightweight and real-time, in order to be deployable on an embedded computer.
- Modular, in order to be adaptable to any kind of robotic configuration.
- Seamlessly connected to a multimodal human-robot interface.

CERNbot (Figure 1), a novel robotic base system has been built at CERN with the goal of guaranteeing autonomous inspection and supervised telemanipulation in the accelerators areas.

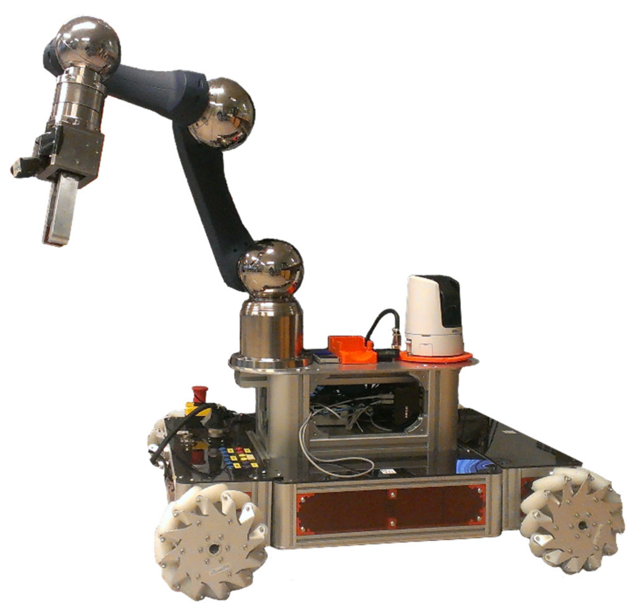

Figure 1: CERNbot.

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USING LABVIEW TO BUILD DISTRIBUTED CONTROL SYSTEM OF A PARTICLE ACCELERATOR

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Abstract

New isochronous cyclotron DC-280 is being created at the FLNR, JINR. Total amount of the process variables is about 4000. The variety of field devices of different types is 20. This paper describes architecture and basic principles of the distributed control system using LabVIEW DSC module.

INTRODUCTION

Charged particle accelerator is a large automation subject that contains hundreds of devices and thousands of signals to control and monitor. To simplify design and maintenance of a control system it is convenient to divide it into parts or subsystems. Every subsystem is dedicated to number of common tasks. They are simply as follow: produce, inject, accelerate, extract and transport the beam to the target. Based on our experience, we decided to consider 3 subsystems: Injection (ECR source, axial injector), Accelerator (cyclotron, extraction, transport) and Low level RF. Each subsystem includes its own vacuum control, water cooling, beam diagnostics and so on.

This approach gave as:

- Independent step by step development, debugging and commissioning of every subsystem.
- Fast response of the system as a whole due to the distribution of computing among several computers.
- Modular structure is easier to maintain and upgrade.

LABVIEW? WHY NOT?

This question we asked at the start of the project. Fifteen years ago it would be too risky solution. LabVIEW has not been widely accepted for control systems of accelerators and large experimental control systems due to limitations in performance, scalability, and maintainability of large LabVIEW designs. Some of this limitations were far-fetched, some real.

Since 1999 we have been using SCADA FlexControl that runs under QNX operating system [1, 2]. Over time, the lack of support for both products forced us to consider replacing the development tool. At present, we see continuously increasing of processing power and significant evolution of the LabVIEW. For example, appearance of the Datalogging and Supervisory Control (DSC) module made it full featured SCADA. It includes tools for logging data to a networked historical database, tracking real-time and historical trends, managing alarms and events, and adding security to user interfaces [3]. It has powerful mathematical, graphical support and experience of thousands of users. Support is provided for a huge number of device drivers and protocols. It has good connectivity and openness which are very important for us due to big variety of the hardware we use.

Ten years' experience of using LabVIEW for various projects, completion of National Instrument training courses, has encouraged us to select LabVIEW as the development tool for new control system.

SHARED VARIABLES

The control system of DC-280 is a project that is distributed over a network. Its essence (all signals) can be described by means of process variables. Every subsystem consists of variables which are deployed on the dedicated host. To share data across the network or between applications, LabVIEW offers NI Publish-Subscribe Protocol (NI-PSP). NI-PSP is a proprietary technology that is optimized to be the transport for network shared variables and provides fast and reliable data transmission for large and small applications. It is installed as a service on the computer when you install LabVIEW [4]. It provides network-published shared variables that publish data over a network through a software component called the Shared Variable Engine (SVE). The SVE manages shared variable updates. Publishers send updates to a server, SVE, and subscribers receive those updates from the server. Shared variable can be connected to a front panel control or to another variable. We use this concept to provide communication between device drivers, applications on localhost and remote computers of the control system of DC-280 cyclotron.

ARCHITECTURE

The control system of DC-280 has client-server architecture. Every parameter of a subsystem is deployed as shared variable in memory of the dedicated computer where SVE hosts it.

SVE is the server for a shared variable and all references are the clients, regardless of whether they write to or read from the variable. All applications are clients or subscribers to the SVE. Being network published, variables of every subsystem can be accessed from any node. The set of all process variables are distributed across the nodes of each subsystem. They are deployed at the system start up and available for the operator panel or automation algorithms.

DEVICE DRIVERS

In order to unify device driver development we use modular and object oriented approach with plug and play ideas. To provide simultaneous managing of many devices of the same type or manufacturer we use Driver Loaders. For example, to control of 20 power supplies from

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MOTION CONTROL SYSTEM FOR THE EUROPEAN SPALLATION SOURCE TARGET WHEEL

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Abstract

The European Spallation Source (ESS) linear accelerator will deliver high energy proton bunches to tungsten sectors on a rotating 'target wheel', which will produce neutrons for scientific research through a nuclear spallation process. The motion control system of the target wheel presents engineering challenges, such as: velocity and phase stability requirements to precisely align individual tungsten sectors with proton bunches from the accelerator; a high moment of inertia due to the composition and distribution of mass on the wheel; limitations on the physical space to integrate control components, and components for associated safety systems; and, some components being exposed to a high radiation environment. The motion control system being prototyped employs components that satisfy the constraints on the physical space and radiation environment. Precise velocity and phasing of the target wheel are achieved by using a grating disc incremental encoder coupled to the main wheel shaft, to enable the transit of each tungsten sector to be synchronised with a reference signal from the centralised ESS timing system, which also controls the production of proton bunches from the accelerator.

INTRODUCTION

The European Spallation Source (ESS) European Research Infrastructure Consortium (ERIC) is an ambitious project to build the world's most brilliant neutron source near Lund, Sweden. A 2 GeV 5 MW linear proton accelerator will deliver proton bunches to a rotating spallation target wheel with a pulse repetition rate of approximately 14 Hz. Interaction of the protons with the spallation material produces neutrons that will be utilised for research by a suite of 22 neutron instruments.

The target wheel and shaft systems are contained within the target monolith, which is located in the target building at the end of the accelerator-to-target area (see Fig. 1). The wheel is a disc composed of 36 sectors of tungsten blocks contained within a steel shroud and cooled by flowing helium. It is located deep within the target monolith at the base of a 7 m long shaft that positions the wheel at the level of the incoming proton beam. The target wheel is being produced by ESS partners in Spain, ESS Bilbao.

During normal operations, the wheel rotates around a vertical axis at a rate of 23 rpm to bring adjacent sectors into alignment with the impact consecutive proton bunches to optimize neutron production. The rotation of

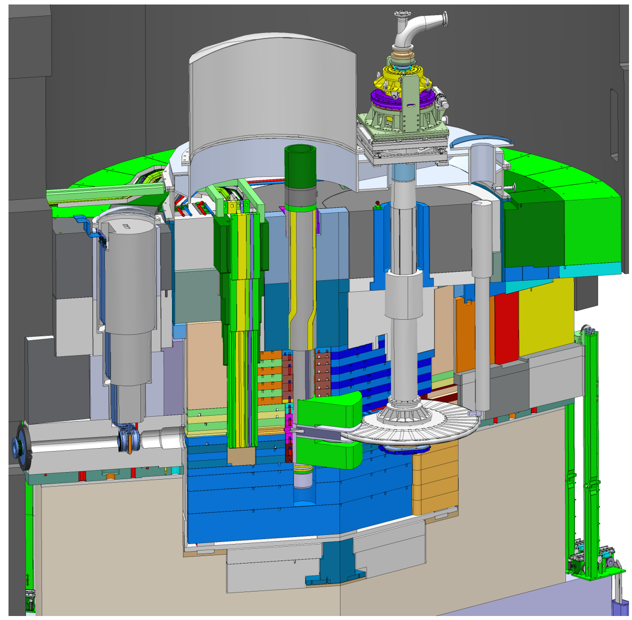

Figure 1: CAD model of the ESS Target, showing the target wheel, moderator and other components within the monolith.

the wheel is timed with the arrival of the proton beam such that the beam interacts with any given sector once every 2.6 seconds.

In the following sections we describe constraints on the design of the motion control system for the target wheel, the motion control solution that has been selected and the physical components of that solution, and finally we describe a mechanical test assembly which will facilitate development of the motion control system.

DESIGN CONSTRAINTS

Physical and environmental aspects of the overall target assembly influenced the design of the target wheel motion control system. Some constraints of particular relevance are described below.

Radiation Environment

One important design constraint is to shield the motion control components from the intense neutron flux and other radiation generated by the target.

The required level of shielding from fast neutrons (>0.1 MeV) is achieved through locating as much steel as possible between the target and the motor and other control components, to close all possible gaps and finally to employ neutron-absorbing material in the monolith lid structure, on which the target rotation and motion control components rest.

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DESIGN AND DEVELOPMENT OF THE CONTROL SYSTEM FOR A COMPACT CARBON-14 AMS FACILITY *

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Abstract

A compact AMS facility which is special used for further analyzing atmospheric pollution especially in north China via carbon-14 measurement was developed at CIAE (China Institute of Atomic Energy), This machine is a single acceleration stage AMS, running with the highest accelerate voltage of 200kV, The control system is based on distributed Ethernet control system, using standard TCP/IP protocol as main communication protocol. In order to connect to the main control network freely, device-level data-link layers were developed also. A LabVIEW client, developing virtual machine applied environment, provides friendly graphical user interface for the devices management and measurement data processing.

INTRODUCTION

AMS is the most sensitivity technique for long lived radioisotopes and is widely used in many fields. 14C is the most popular isotopes for AMS measurement. Although there is a large AMS system with a terminal voltage of 13MV at CIAE, it can't meet the needs of requirements due to its low transmission efficiency and poor stability in the measurement of 14C. So, a system dedicated to 14C measurement was established by CIAE AMS group. This system is a kind of single stage AMS which only have the ion energy of 230keV. Developing the low energy compact AMS system is the trend of 14C measurement. The single stage AMS system was first developed by NEC with the ion energies of 250keV, and then a compact tandem 14C AMS system(MICADAS) was developed by ETH with the terminal voltage of 200KV.The results of these system shown that they can provide the comparable results to the 0.5MV tandem AMS system in the measurement of 14C, meanwhile these system only require about half floor space and the manufacturing cost is much lower than the 0.5MV AMS system. Accordingly, a single stage AMS system dedicated to 14C measurement is designed and established in our AMS lab. The size of the instrument is $4.6\times2.4m^2$ overall dimension. Negative ion source, 90^0 injection magnet and electric quadrupole lens are located at the high voltage deck, gas stripper canal, 90^0 analyzing magnet, 90^0 electrostatic spherical analyzer and a surface barrier detector are located at the ground potential.

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CONTROL DESIGN SCHEME

This AMS facility covers a wide range of different interface devices, from simple traditional serial port to popular LXI interface. The control system include equipments with many functions, such as ion source, cooling system, stripping gas, beam transport devices, motion control, detectors, etc.

Because this machine is compact and needs a concise appearance, wireless LAN based on Industrial IEEE 802.11 is adopted in the control system. Devices with multiple interfaces are connected to the local network via intermediate converters, such as MOXAAWK3121 series. Control system architecture is shown in figure 1.

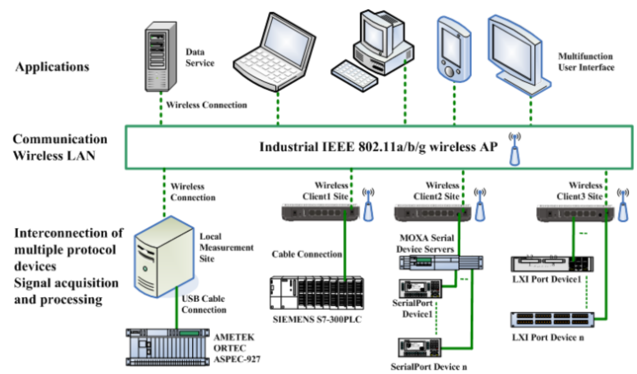

Figure1: This AMS facility control system architecture.

HARDWARE

Wireless LAN mainly comprises one wireless AP site in main control room and three wireless client site in different voltage potential deck. Wireless client sites complete communication with device-level control equipments, realize collection and transmission of control signal, and complete the data transmission with the AP site. Wireless AP site works as a server, realizes communication with other wireless client sites connections.

In device-level, Programmable Logic Controllers(PLCs) are the main components of this control system, adequately applied to many devices control, such as most power supplies, beamlines control, vacuum/temperature diagnostics, motion control, etc.

As the control system has a variety of interface devices, such as serial port232, serial port485, ModBus. We used

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PLC BASED VACUUM CONTROLLER UPGRADE AND INTEGRATION AT THE ARGONNE TANDEM LINEAR ACCELERATOR SYSTEM

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Abstract

The installation of a new Electron Beam Ion Source (EBIS) to the Argonne Tandem Linear Accelerating System (ATLAS) at Argonne National Laboratory requires a vacuum system capable of providing pressures in the region of 1e-10 Torr. Historically, vacuum interlocks have been provided via analog logic chassis which are difficult to upgrade and maintain. In order to provide sufficient interlocks to protect high voltage components of the EBIS, a new programmable logic controller (PLC) based Vacuum control system has been developed and integrated into the rest of the accelerator supervisory control system. The PLC interfaces not only with fast acting relay based interlock signals but also with RS-485 based serial devices to monitor and control lower priority parameters such as pump speeds, vacuum pressure readout and set points, run hours and more. This work presents the structure and interface logic necessary to communicate with a range of vacuum gauges, turbo-molecular pumps and ion pump controllers. In addition, the strategy to interface vacuum control with the rest of the accelerator control system is presented.

INTRODUCTION TO ATLAS

The ATLAS accelerator is located at the United States Department of Energy's Argonne National Laboratory in the suburbs of Chicago, Illinois. It is a National User Facility capable of delivering ions from hydrogen to uranium for low energy nuclear physics research in order to perform analysis of the properties of the nucleus. As a result of the wide variation of beams delivered [1], retuning of the entire machine is necessary on a near weekly basis. After a series of upgrades, ATLAS will consist of two possible ion source lines, a common injection and beam transport line, and 8 different target areas. This wide range of possible machine configurations combined with the thousands of individual devices which support them present a very real challenge to operators to arrive at a final tune quickly.

Historical Vacuum Chassis

For several decades the ATLAS Vacuum Control System has been implemented via in-house custom built hardware chassis utilizing a combination of analog logic circuitry and complex programmable logic device (CPLDs). Several different versions of these chassis exist, depending on their intended purpose (Table 1). For example, some chassis do not provide a remote vacuum pressure reading while others may or may not control a turbo molecular pump, causing additional effort to integrate into the control system.

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Table 1: Variations of Vacuum Chassis at ATLAS

Rev #	Comments	Turbo?
1 A-D	Original Design, Built in 1984	No*
2 A-C	For Targets, No Remote Pressure	Yes
3 A-C	For Cryostats, No Remote Status	Yes
4A	Proposed, Full Remote Status	Yes

* Turbo control and monitoring added later

These chassis utilized silk-screen type front panels which must be re-spun for any change in device layout. An example of the current interface is below (Figure 1).

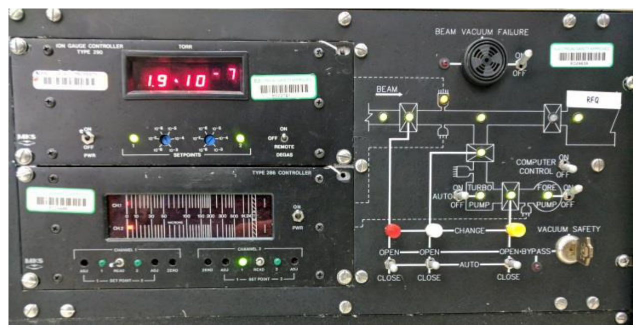

Figure 1: Example of silk screened front panel.

VACUUM PROJECT MANAGEMENT

A first order problem which was considered during a change in system design philosophy is how to define the scope of the project. Requirements of a basic vacuum interlock system, the range of possible vacuum component vendors, and interfaces with the final customers needed to be considered and documented. Limiting the possible component vendors supported by ATLAS was accomplished via a publicly accessible website containing a list of vendors and equipment supported. (Figure 2) [2].

Category	Manufacturer	Model/Type	Order Info	Supplier	Details
Cryo Pump	BROOKS CTI-CRYOGENICS	CRYO-TORR 8	8033351G002	Vacuum One	CF flanged, Vapor Pressure Gauge,Temp Probe, 1.33 CF Accessory port
Heater Blanket	BROOKS CTI-CRYOGENICS	Kit	8080002K012	Vacuum One	Used for Regeneration of CT 8 Pump, 120VAC
Temp/Controller 1	BROOKS CTI-CRYOGENICS	196443 Microprocessor Based	211998-0001	Vacuum One	10' cable, 2 Set Point Control, Digital Display, 3U chassis mount
Temp/Controller 2	BROOKS CTI-CRYOGENICS	196443 Microprocessor Based	211998-0002	Vacuum One	35' cable, 2 Set Point Control, Digital Display, 3U chassis mount
8200 Compressor	BROOKS CTI-CRYOGENICS	CRYO-TORR 8200	8032549G002	Vacuum One	208VAC 1PH, 1 CT8 pump operation, 1 year absorber life

Figure 2: Example of supported vacuum equipment.

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DESIGN AND IMPLEMENTATION OF POWER SUPPLY CONTROL SYSTEM ON HI-13

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Abstract

On the HI-13 tandem accelerator, steer power supply and quadrupole lens power supply provides three different types of control interface, Remote control system of these power supplies implemented by using Siemens S7 series PLC, serial server, OPC server and WINCC, Long-time operation show that the control system is easy to be operated and its performance is reliable.
Keywords:HI-13, power supply control system, WINCC

INTRODUCTION

The beam must be focused by multiply quadrupole lens and the steers during transmission process for reasons of beam dispersion and deviation. Power supplies build an electrical or magnetic field by output changeable voltage or current. The new remote control system based on PLC and WINCC implement an totally upgrading of the old control mode which was dependent on manual adjustment of the mechanical potentiometer and step motors and facilitates convenient operation, intuitional display and precision improvement.

CONTROL DESIGN SCHEME

The bottom control built with SIEMENS S7PLC and programming is complete with STEP7 ladder diagram language. The interface based WINCC establish a connection with the PLC via the visual graphics, essential monitoring status of power supply could be clearly shown on the interface. Otherwise, different user authority be distributed and browser authority or program changing authority was definite for different users.

Steer Power Supply Control

In the HI-13, there are two kinds of steer power supply, one is the electrostatic steer power supply, the other is the magnetic steer power supply.

Electrostatic Steer Power Control The electrostatic steer power supply provides voltage output for the electrostatic steer, and its output is 0 ~ ± 7.5KV and 0 ~ ± 1KV, with ripple of 0.05% and stability of 0.05%.

8 Electrostatic steer power supply provide power for low energy terminal steers and high energy terminal steers respectively. Each power supply provides a DB9 interface, using analog method, whose definition is shown in Figure 1.

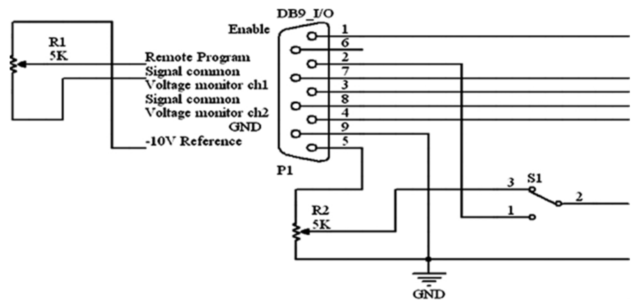

Figure 1: DB9.

Among them, pin 2 provides a remote voltage (0 ~ 10V) control mode, Pins 3 and 4 provide the voltage output return value (0 to 10V) for channels 1 and 2, pin 5 provides a 10V voltage reference, and when it is greater than 10V, it indicates that a fault has occurred. In this case, To disable the power supply to no longer work. The group of power control system use Siemens S7-300 series PLC, all input and output are connected through the IO module. The PLC hardware consists of three analog input modules (SM331), one analog output module (SM332), one digital output module (SM322), one CPU module (CPU315-2DP) and one communication module (CP343) [1].

The WINCC driver uses the SIMATIC S7 Protocol Suite-> TCP / IP [2].

Magnetic Steer Power Control The magnetic steer power supply provides a current output for the magnetic steer with an output of -2A to + 2A.

There are 4 power supply in total, the bottom data is transmitted through RS485 protocol, with communication speed is 57600bps, the starting position is 1, the data bit is 8, the stop bit is 1, the parity is: even check, the hardware connector is RJ45, Interface, PIN1: TX +, PIN2: TX-, PIN4: GND.

The four power supplies are connected to the MOXA 5430 serial server via a network cable, MOXA 5430 is a 4-port communication device that allows control of four RS485 serial devices via TCP / IP based Ethernet. Before using it, you need to set the mode of each port to Server mode, and set the communication parameters of each serial port such as rate, start bit, data bits and so on.

PLC use Siemens S7 1500 series, CPU is 1515-2 DP, and its IP address is in the same network segment with MOXA 5430. In STEP7 programming [3], using the open communication library TCON function module to connect the CPU as the client with MOXA 5430, the TSEND function module to send the control word, and the TRCV function module to receive the return information. In order

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DO YOU REALLY NEED A LOW CURRENT AMPLIFIER TO DRIVE A LOW CURRENT MOTOR?*

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Abstract

NSLS2 is standardized on Geo Brick LV 5A motor controller from Delta Tau [1], suitable to drive majority of stepper and servomotors. Standardization allows less spare inventory and common skill set to maintain. However, some applications, especially instruments in the space-confined end stations require using small, or even miniature motors. What are the limitations in customizing the 5A unit for driving low current motors?

Delta Tau Geo Brick LV (GBLV) is a turbo PMAC family motion controller [2]. It comes in different amplifier configurations: a combination of 5A, 1A, and 0.25A amplifiers. This research is focused on performance and limitations of 5A driver with low ~200 mA and very low ~40 mA current motors.

MOTIVATION

A typical photon beamline uses many motorized instruments. Some of axes are driving heavy loads and some are miniature stages. In other cases, scientific equipment is designed as a combination of big and small motors with high and low driving currents. Driving this motors usually require different controls solutions. A typical monochromator, for example, often has a combination of bigger and smaller motors with drive currents from several Amp to 100 mA. Using integrated or separate divers to control equipment is not only maintenance expensive, but in some cases impossible due to the tight spaces. In this paper, we present research data about using NSLS2 standard 5A Geo Brick LV (turbo PMAC) motor-controller of driving small current motors instead of custom solutions. The idea has presented itself when we successfully drove 125 mA stepper motor with 5A Geo Brick LV unit having no other possibilities at that moment.

EXPERIMENTAL SETUP

The following stages and motors were selected: Newport MFA-CC stage with DC servomotor UE1724SR and rotary encoder 2,048 cts/rev, rated speed 2.5 mm/s; MFA-PP stage with 2 phase stepper motor UE16PP, 1 full step = 0.485 µm, rated speed 2.5 mm/s; Faulhaber AM2224-V-12-75-10 2 phase stepper motor, AM1020-V-12-250-00 2 phase stepper motor, see Table 1.

* This research used resources of the National Synchrotron Light Source II, a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by Brookhaven National Laboratory under Contract No. DE-SC0012704."

Table 1: Motors Under Test

SUT	Motor	Current
MFA-CC stage	UE1724SR	200 mA
MFA-PP stage	UE16PP	250 mA
Faulhaber mtr	AM2224-V-12-75	125 mA
Faulhaber mtr	AM1020-V-12-250	45 mA

The motors were driven with 5A Geo Brick LV motor-controller; model BHB8-C0-442-00000000. The actual current was measured by Tektronix TCP0030A current probe and Tektronix MSO4054B oscilloscope giving 1 mA resolution. Two Faulhaber steppers were driven in the open loop mode, see Figure 1.

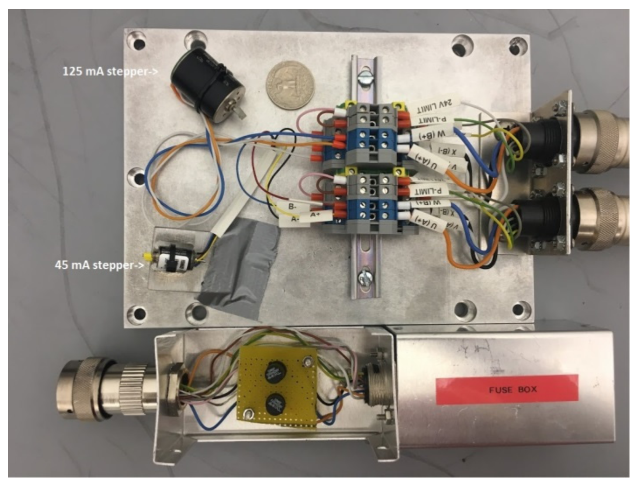

Figure 1: Low current Faulhaber steppers under test.

For current surge protection all motors were connected to Geo Brick LV via a fuse box, see Figure 1.

OPEN LOOP PERFORMANCE

Performance of a stepper motor depends on many parameters, not always analytically predicted. They are: electrical characteristics of the motor coils, such as coil resistance, inductance, back EMF, drive current, bus voltage; mechanical properties, such as generated torque, system response time, load; dynamic run conditions, such as speed and even a motor driver. Optimizing selected controller PID parameters for the experiment requirements is a mission of a control engineer.

Driving a low-current motor with an amplifier designed for high current ones is generally a poor design decision simply because the ADC count used by the PID control

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ONLINE SIMULATION FRAMEWORK THROUGH HTTP SERVICES *

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Abstract

The development of HTTP service interfaces [1] to the BNL Collider-Accelerator Department (C-AD) controls system opens up the ability to more quickly and easily adapt existing codes developed for other systems for use at RHIC. A simple particle accelerator online model built for commissioning the NSLS II [2] was adapted for use with the Low Energy RHIC electron Cooling project (LEReC) [3] and the Coherent Electron Cooling (CeC) [4] proof of principle experiment. For this project, a set of Python modules and a Python application were adapted for use in RHIC by replacing NSLS II control system interfaces with Python modules that interface to the C-AD controls HTTP services [5]. This paper will discuss the new interfaces and the status of commissioning them for operations.

INTRODUCTION

Traditionally, sharing code from other facilities has been a labor intensive process. Control systems from different facilities have different communications interfaces, database interfaces, and even the general, non-control systems tools can greatly differ. To some level making control systems open source projects, as has been done with EPICS [6] and TANGO [7], makes this process easier. The C-AD controls system Accelerator Device Object (ADO) model [8, 9] is similar to TACO (the predecessor to TANGO) and over twenty years of refinement has become a robust, reliable, and very high performance system. Unfortunately, it is not open source and so it can be challenging to adopt code from other laboratories.

As much as these various control systems are different, they are, in general, very much the same, following what has long been known as the 'standard model' for accelerator controls [10, 11]. In general, for all of these control systems, the abstraction of a 'Device' is a fundamental structure. The details on how the parameters from a given Device are published to the rest of the control system are different, but in each system, if you know the name of a parameter, you can *get* or *set* the value and properties of that parameter.

The C-AD controls system has recently adopted a RESTful set of communication protocols that allow applications from many different platforms and operating systems to access controls Devices. These HTTP server interfaces also ease the task of adopting application level code from other facilities and control systems. In this report, we will discuss the process of adopting a Python application built for commissioning NSLS II for use in RHIC through the use of HTTP server interfaces.

* Work performed under Contract Number DE-SC0012704 with the auspices of the US Department of Energy.
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CONTROLS INTERFACE

The Device Server allows direct *set* and *get* communication to the ADO parameters while the Data Server provides access to logged data. For more detailed descriptions of the Controls interfaces see [1, 5]. The dataflow model for the simulation framework using the RESTful interface is shown in Fig. 1.

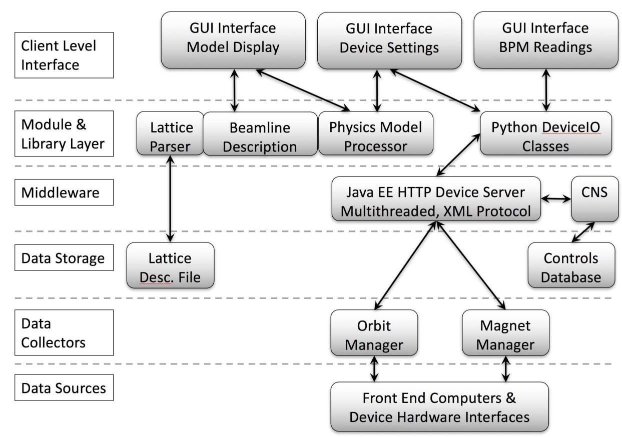

Figure 1: Data Flow and Interfaces for Simulation Framework.

For the online simulation framework, the names of the devices for a given model instance are listed in a model lattice description file, which has a syntax similar to standard accelerator physics model engines, such as madx or mad8 [12]. An example is shown in Fig. 9, in the appendix (ellipses indicate more similar elements follow.) The general format is *element_name: element_type, parameters*.

For this model lattice description to be connected to the control system, the *element_name* simply needs to be the ADO parameter name for that element.

LEREC & CEC

Both LEReC and CeC are electron accelerator systems, with a significant level of complexity. Each has electron guns with low energy sections and beam transport systems composed of standard accelerator components, including transport solenoids. Each is instrumented with current monitors, beam position monitors, and various types of profile monitors.

Figure 2 shows the layout of LEReC. The same electron beam is used to cool beams in each of the two RHIC rings. Since the ion beams in RHIC travel in opposite directions, the electron beam first passes by the ion beam in the RHIC Yellow ring and then is bent 180° and passes by the ion beam in the RHIC Blue ring, and then dumped. For the model

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ESRF RAMPING INJECTOR POWER SUPPLY CONTROLLED BY TANGO

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Abstract

A new design of ESRF booster power supply system has been developed and installed. A multiple power supplies control through network including real time control is now operational at ESRF. It manages 4 power supplies to generate 3 waveforms defined with 3x1600 values in a setpoint file. The power supplies states are managed by PLCs. The ramping waveforms are managed by a real time program running on a FPGA board. A high level control on top of them is assumed by a TANGO [1] multiple classes system. This paper presents how these three levels of controls are interlinked and shows the results achieved.

OVERVIEW

Originally, a ten Hertz resonating circuit was supplying the current in the three main ESRF booster magnets chains. Although this equipment ran more than 25 years without major trouble, there are in the circuits huge specific transformers for which the time to repair is of one month and, furthermore, some components of the power circuits are now discontinued. Decision was made that this whole equipment was to be replaced by a new one, based on ramping of the current. The new functionality brought to the current behaviour is the possibility to correct any point in the slope (6400 Hz). This allows the stabilization of the tunes during the ramping to improve the efficiency of the electron beam cleaning in the booster [2].

General Layout

From the mains electrical network to the current delivered to the magnets, the path is the following (see figure 1):

- Transformers to adapt the voltage from the mains
- Rectifiers with digitally controlled thyristors
- Capacitor to store the energy and prevent the flicker
- Voltage controlled PWM power bridges

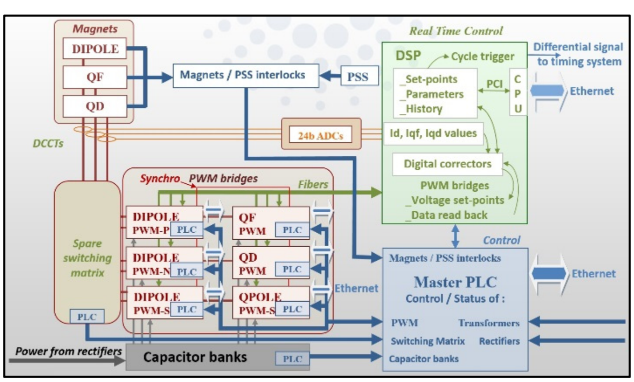

Figure 1: Layout.

From the latter stage, the voltages delivered are remotely controlled to finely adjust the current. The four PWM bridges units are connected to the FPGA board dedicated to the real-time control by means of optic fibers driven by Rocket IOS, Aurora (Xilinx) and serial ebone (ESRF) [3] (see figure 2).

The main advantage of this architecture is the easyness to perfectly synchronize the current in the three magnets families: dipole, focusing quadrupole and defocusing quadrupole. Indeed, the three control loops run inside the central FPGA and therefore, the computed voltages are sent synchronously to the four units every 156µs. The four units reply with informations that are stored in an history file available by the Tango server.

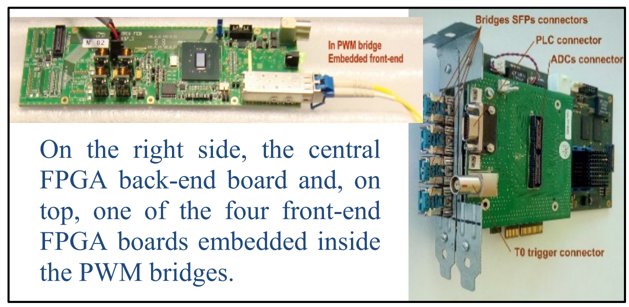

Figure 2: Real time control hardware.

All pieces of equipment are equipped with a dedicated PLC connected to a server through Ethernet. These PLCs are controlling the states of the different units and reporting to a master PLC itself controlled by a remote Tango application. All commands and safety aspects are managed by the master PLC while the history of events goes directly from each PLC to the Tango server.

TANGO CONTROL

The main challenge was to drive 4 power supplies synchronously through PLCs and FPGA.

Implementation

As shown on figure 3, on top level a TANGO device manages and sequences different features.

The 15 PLCs (power supplies, switching matrix,…) are controlled by a TANGO device server through TCP/Modbus sub devices.

The FPGA board is controlled by another TANGO device through a library developed at ESRF. It manages 58 attributes to be able to adjust each loop parameters, start/stop ramping, measures, status,…. It is able to load the waveform file in FPGA memory as set point. During the ramping phase, it get a set of 23x1600 measures and status from

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INTEGRATION OF SAMPLE ENVIRONMENT SYSTEMS AT ESS

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Abstract

Sample Environment Systems (SES) are used to control the environment of a sample. At ESS all SES will be integrated into the control system to enable recording of data and allow user control. In this paper a specific SES is introduced and the ingoing hardware components are described. An overview of the control structure of the system is given which is followed by a walkthrough of the systems and tools used in the integration. How signal naming have been approach is touched and the use of the software tools developed at ESS is explained. The status of the current setup is presented and finally the plans for the continued work on the system is detailed.

INTRODUCTION

ESS will be one of the brightest neutron sources built. To be able to utilise the full capacity of the ESS source all systems must be as reliable, easy to setup and as maintainable as possible to minimize experiment changeover times. For most experiments SES will be used to control e.g. the temperature, magnetic field, pressure, humidity, etc. of the sample measured. Consequently the SES will usually be changed between experiments or even during the same experiment. Due to the multitude of different SES systems and frequent usage at different instruments it is very important to have a robust control system.

This paper presents the current approach taken at ESS for the SES integration and control.

The particular setup described in this paper consists of a top-loading Closed Cycle Refrigerator (CCR) optimized for neutron scattering experiments between 10K and 300K. It was designed as a small, transportable CCR that can be used for transmission measurements on various neutron scattering instruments to determine neutron scattering cross sections of materials for developing scattering kernels. In addition to these features, the CCR also has sapphire windows at the sample height to allow transmission of optical light for performing spectroscopy. In our current application, the CCR is used to analyze the ortho- and parahydrogen fraction in liquid hydrogen using Raman spectroscopy. This is a test stand for the future online monitoring of ortho-/parahydrogen fraction in the ESS hydrogen moderators.

THE SAMPLE ENVIRONMENT SYSTEM

At ESS a SES is defined as the Sample Environment Equipment (SEE), which contains the sample and will be placed in the beam, and the Auxiliary Equipment (AE) which are the components the SEE need to run such as compressors, temperature controllers, logic controllers etc.

With this definition the CCR described above is the SEE, see Fig. 1. This will hold the sample and be placed in the beam during measurement. This particular SES also includes AE components. Connected to a Helium compressor, the CCR will provide cooling power to cool down the sample. To minimize heat transfer from the environment to the sample it is placed inside a vacuum housing, which is evacuated using the vacuum pumps, listed in Table 1. Control of the temperature is done using a temperature controller. The temperature controller measures the temperature of the sample and runs an internal PID control loop. The output from the PID loop is used to regulate a heater mounted inside the CCR enabling control of the sample temperature. A vacuum gauge is connected to the CCR to be able to verify that required vacuum for operation is reached. In this setup also a spectrometer is included consisting of a laser unit and a spectrometer for light spectroscopy as described in the introduction. In order to control these devices as a SES an industrial PC is mounted with the equipment, running the controls as explained in following sections. A schematic overview of the SES is shown in Fig. 2.

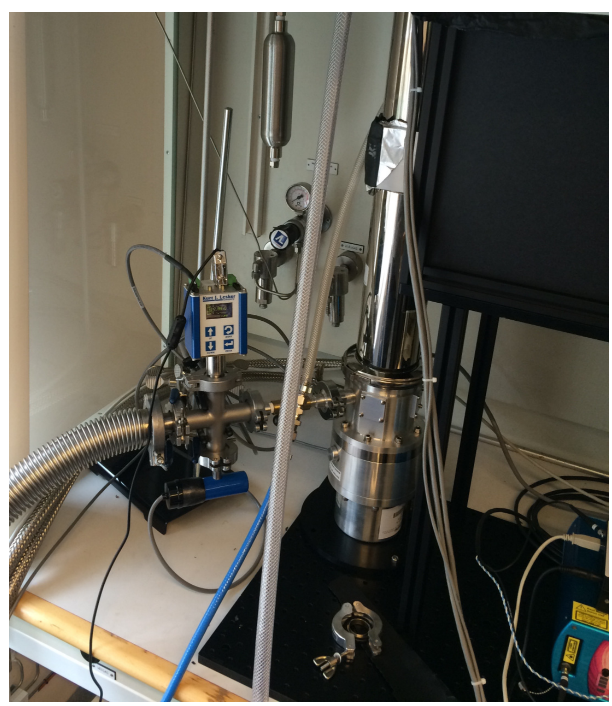

Figure. 1: Photo of the SES. The tube shaped object in the middle is the CCR. In the lower right corner the laser power unit is visible. In the upper right quarter the laser probe safety enclosure is seen. To the left the vacuum

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A DATABASE TO STORE EPICS CONFIGURATION DATA

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Abstract

The operation of extensive control systems cannot be performed by adjusting all parameters one by one manually. Instead, a set of parameters is loaded and applied in bulk. We present a system to store such parameter sets in a type-safe fashion into and retrieve them from a configuration database.

The configuration database is backed by an SQL database. Interfaces to store and retrieve data exist for the C++, Java and Python programming languages. GUIs are available both as a standalone program using C++ and Qt, and integrated into Control System Studio (CSS) [1]. The version integrated into CSS supports data validators implemented as Eclipse plug-ins that are run before each commit.

The format of the configuration data that can be stored is XML-like, and export and import to/from XML is implemented. The database can hold several completely independent "files" of configuration data. In each file, several branches can be stored, each branch consisting of a chain of commits. Each commit can easily be retrieved at any time. For each entry, the modification history can easily be queried.

INTRODUCTION

The context of the software presented here is the slow-control system of the Belle II pixel detector (PXD) [2].

The format of the data that is stored is similar to the structure of XML files: A tree structure of nodes gives structure to the data, and each leaf node contains one data point. To simplify integration with EPICS [3], a way to assign a PV name to each leaf is defined. For that purpose, attributes can be added to each node that add part of a PV name, or define units (for display purposes), or minimum and maximum values.

The database provides versioning of the data. It can contain several independent data sets, called *files*, and for each file, several *commits* can be stored in several *branches*. This structure is also shown in Fig. 1. The data are stored in such a way that any commit can be identified through just a single integer variable, the commit id. No data are ever overwritten, only updates creating new commits are possible.

One important decision taken during the design phase is that the access to the configuration storage has been separated from the hardware access. The IOC accessing the configuration database reacts to just one PV defining the commit id to load, and exports all PVs defined in the data set. On the hardware access side, the configuration data are taken from these PVs and applied to the hardware at the appropriate time, usually by means of a state machine.

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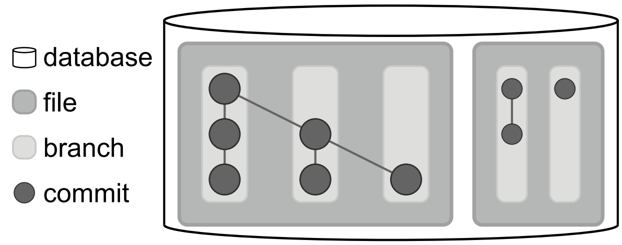

Figure 1: Contents of the Database. Several files with several branches and several commits per branch can be stored.

The overview of the proposed system is shown in Fig. 2: The editor is used to put the correct configuration into the database, from where it is retrieved by the configuration IOC. The IOC extracts the stored PV names and makes then available via the Channel Access protocol. State machines that control the configuration of the various subsystems read the data and apply them to the hardware.

Storage in the database and editing via the APIs are type safe. The supported data types are integer, floating point, string, and arbitrary-length binary. The data structures are compatible with the XML format, and this is the default format when importing from or exporting to a file.

DESCRIPTION OF THE SYSTEM

Graphical User Interface

The main interface to edit the configuration data is through an interface integrated into Control System Studio (CSS). In Fig. 3, the editor view available in the CSS environment is shown.

To help with the implementation of OPIs working with the configuration database, a Jython module is provided that can be used to access configuration database functionality from within OPI scripts. The OPIs can use a special data source, config://, to access the loaded configuration and its metadata. Together, this allows for device-specific configuration screens to be easily developed by means of the OPI editor.

It is also possible to compare the loaded configuration with the currently active values, and to selectively accept new values into the database.

Validation In order to prevent the operator from entering invalid data into the database, all data are validated before they are committed to the database. The idea is to detect obvious errors in the configuration way before it is activated in the system. The validation is run immediately before uploading to the database, and the results are reported to the user in the CSS GUI.

A generic framework to validate settings against fixed limits is available. As an example, typical limits could define

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INTERFACE BETWEEN EPICS AND ADO*

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Abstract

EPICS is widely used software infrastructure to control Particle Accelerators, its Channel Access (CA) network protocol for communication with Input/Output Controllers (IOCs) is easy to implement in hardware. Many vendors provide CA support for their devices. The control systems of the Collider-Accelerator Department (C-AD) at Brookhaven National Laboratory (BNL) is a complex system consisting of approximately 1.5 million [1] control points. The control of all devices is unified using an Accelerator Device Objects (ADO) software abstraction layer. In this paper we present software solutions for cross-communication between two different platforms. They were implemented for the integration of a NSLS II Power Supply Controller hardware into the RHIC Controls System.

INTRODUCTION

EPICS Software Infrastructure

EPICS is used in more than 100 of independent projects, number of controlled process variables (PVs) ranges from 1K to 300K.

The key features of the EPICS infrastructure:

- Client-server model: device is controlled by an Input/Output Control program (IOC), which provide support for 'records'. Records provide access and control to process variables.
- Client-server protocol: EPICS Channel Access protocol (CA).
- Transport layer: TCPIP.
- Name server: No central name server.
- Number of lines in the Base Code: 200K of C code.
- Source availability: Open source.

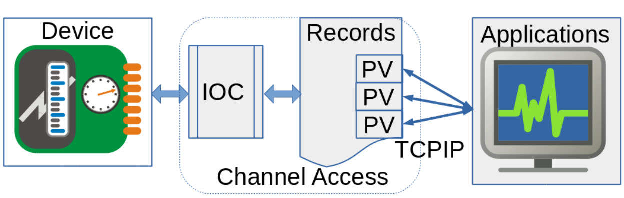

Figure 1: EPICS client-server model.

RHIC Controls Infrastructure

The RHIC control system provides the operational interface to the collider and injection beam lines. The equipment under control includes more than 350 VME crates, and hundreds of network-capable devices. The control of all devices is unified using Accelerator Device Objects (ADO) software abstraction layer

The key features of the RHIC Controls infrastructure:

- Client-server model: device is controlled by an ADO Manager program, which hosts the process variables.
- Client-server protocol: RPC.
- Transport layer: TCPIP.
- Name server: CNS, an RPC-based server program, connected to central Sybase database.
- Number of lines in the Base Code: pure Python implementation: 5K, (original C++ implementation: ~200K).
- Source availability: proprietary.

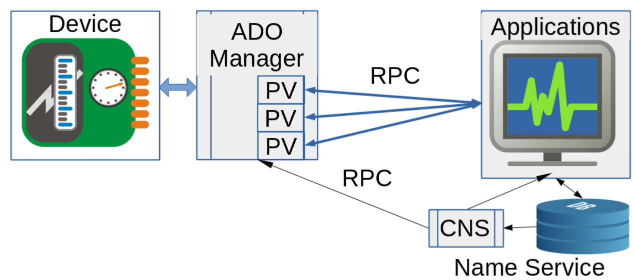

Figure 2: RHIC Controls client-server model.

CONTROL OF THE EPICS-MANAGED DEVICE IN RHIC ENVIRONMENT

The server for an EPICS-managed device should monitor and react on two sources of changes:

- monitor changes of the EPICS PVs (e.g using EPICS API ca_pend_event() loop) and change the corresponding ADO PV.
- monitor changes of the ADO PVs (e.g. using ADO API HandleNextEvent() loop) and change the corresponding EPICS PV.

The logically simplest approach is to build two separate applications: epics2ado (based on camonitor from EPICS API) and ado2epics (based on adoIf from ADO API) as illustrated on Fig. 3.

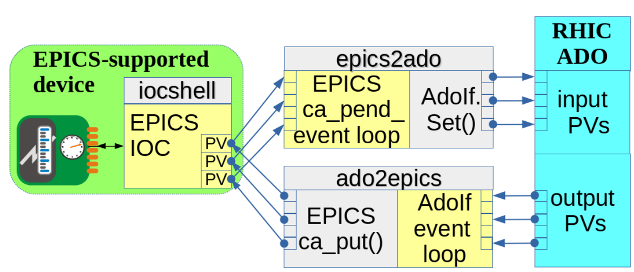

Figure 3: Two-way translation between EPICS and ADO.

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NEXT GENERATION CONTROL SYSTEM USING THE EtherCAT TECHNOLOGY

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Abstract

Toward the SPring-8 upgrade, which we call SPring-8-II, we have adopted EtherCAT with a master/slave topology as a network-based fieldbus. Since the cyclic data transfer time is less than 1 ms, EtherCAT can provide sufficient performance for a fast control and feedback system. Controllers and sensors are set near equipment, and input and output data are sent to/from an EtherCAT master via a LAN cable. This reduces the number of wires and the working time for wiring. In FY2016, we installed EtherCAT into three different equipment control systems. One was a prototype digital LLRF system in the high-power RF test stand at SPring-8. Another was the encoder readout for an undulator at SPring-8. The other was the control system for a kicker magnet power supply at SACLA. An XMC-typed EtherCAT master module was implemented into each of these systems and connected to multiple vendor slaves. In this paper, we report the results of an electrical noise immunity test on LAN cables, the status of the new control systems using EtherCAT technology, and the installation plan of the EtherCAT slaves under development.

INTRODUCTION

As an Ethernet-based open standard protocol, FL-net has been operating well for over 10 years at SPring-8 and SACLA. FL-net is a factory floor network protocol with a masterless topology [1]. Since the token cycle time of FL-net is between ~15 ms and ~180 ms, we are introducing FL-net into slow control such as facility control, the data acquisition of radiation monitors, and high-power supplies for the klystrons. Currently, an upgrade plan of SPring-8 is in progress [2]. High-speed bus access, the transfer of large amounts of data, and synchronization with a timing signal are required in the next-generation control system. As a network fieldbus, we adopted Ethernet for Control Automation Technology (EtherCAT) with a master/slave topology [3]. Since its cyclic data transfer time is less than 1 ms, EtherCAT is suitable for a fast control and feedback system. The introduction of EtherCAT is proceeding at semiconductor and automobile factories, and its market is large. There are many choices of commercial products based on EtherCAT and a stable supply of commercial products is attractive for long-term operation and maintenance. Additionally, it is relatively easy to develop a control unit supporting EtherCAT by using an EtherCAT slave protocol stack.

In this paper, we report the results of an electrical noise immunity test on LAN cables and the installation of the control systems using EtherCAT technology.

ELECTRICAL NOISE IMMUNITY OF LAN CABLES

Since EtherCAT slaves can be installed near control components such as motors and signal sources, EtherCAT can reduce wiring and working time, and it is cost effective. However, in accelerator and synchrotron radiation facilities, slaves may be installed in places with high electrical noise levels, so it is necessary to pay attention to the effect of electrical noise on LAN cables. Therefore, we conducted the electrical fast transient/burst immunity (FTB) test documented in IEC 61000 4-4 [4].

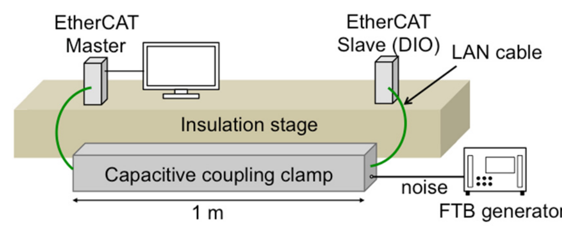

Figure 1: Configuration of the FTB test.

Test Method

We tested 1) CAT5e UTP, 2) CAT5e STP, 3) CAT7, 4) CAT5e using NoiseBEAT tape, which was developed by NTT AT [5] and was employed special magnetic alloy films to provide reliable EMI noise reduction. Figure 1 shows the configuration at the FTB test. A LAN cable was wired through a capacitive coupling clamp of 1 m length. Each LAN cable had a length of 10 m. An EtherCAT master (Beckhoff C6920-0040) [6] and a DIO slave (Hitachi Zosen ECAT-DIO 8) [7] were set on an insulation stage. An FTB generator outputted the test voltage with a pulse wave of 66 kHz or 30 kHz in a burst form with a cycle of 300 ms. The test voltage was varied in increments of 1 kV in the range from +/-0.5 kV to +/-4.5 kV. The test time was 60 s each test. To judge whether a LAN cable was being subjected to noise damage, a judgment program with the following sequence was run:

- The master sends a specified value of a digital output (DO) to the slave.

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MADOCA TO EPICS GATEWAY

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Abstract

MADOCA-to-EPICS gateway has been developed for easy and rapid integration of EPICS-ready devices into MADOCA, the control software framework for SPring-8 and SACLA. MADOCA uses equipment control software called equipment manager (EM) in the device control layer. The MADOCA-to-EPICS gateway is implemented as a general-purpose EM to handle EPICS IOCs. The gateway consists of EM functions that interact with IOCs using channel access (CA) protocol corresponding to EPICS commands such as caget, caput and camonitor. We can build the gateway for the target EPICS device by editing the EM configuration file, without any programming. We have applied the gateway to the Libera Brilliance+, installed in the SPring-8 storage ring, to be evaluated towards the SPring-8 upgrade project. In addition, it has been applied to the Libera Brilliance Single Pass and Spark installed in beam transport line, and the Libera Spark and Cavity installed in SACLA. The gateway is helpful in minimizing the installation time and effort, even for the different platform (CPU and OS) devices. We will report on the development and advantage as well as the performance improvement of the MADOCA-to-EPICS gateway.

INTRODUCTION

The MADOCA (Message And Database Oriented Control Architecture) [1] control framework was developed at SPring-8 and utilized in the control systems of SPring-8 and SACLA. MADOCA is a message-oriented control system based on a client-server model. It sends a text-based message to a remote VME or another front-end computer and the VME sends back the response as a message.

In the meantime, there is EPICS (Experimental Physics and Industrial Control System) [2] and TANGO [3], which are popular control systems for many accelerator facilities. There are commercially available devices compliant with these control systems. For example, Libera, the BPM signal processing system, has in-built EPICS and TANGO.

We have developed MADOCA-to-EPICS gateway for easy and rapid integration of EPICS-ready devices into MADOCA control system.

DESIGN POLICY

The design policy of MADOCA-to-EPICS gateway development is as following.

- Provide as a general-purpose EM functions.
- Build the gateway EM by editing the configuration file without any programming.

In order to realize this, we have developed based on the features of MADOCA and EPICS described below.

MADOCA is a message driven client-server model control framework covering layers from presentation to equipment control. In the equipment control layer, the equipment manager (EM) receives a command from the operating terminal, interprets it, associates with the physical devices, and sends a command to the target device via the device driver. Therefore, it accepts the response from the device, converts it to a logical value, and returns it to the operating terminal. In performing these control schemes, EM has three processing functions: a function to interpret a message, a function to control a device, and a function to abstract as a message. The received message (SVOC command), three processing functions, and the control target device are mapped in the EM configuration file.

EPICS employs a client-server model and a publish-subscribe model as a communication model. The EPICS input/output controller (IOC) runs on each device and communication is handled uniformly by a channel access (CA) protocol. There is a database of records on the IOC with each record representing a device or its control. Essentially, all controls can be realized with commands based on CA protocols such as caput which sets a value to a record and caget which returns a record status.

In order to integrate EPICS-ready devices into the MADOCA control system, we have developed a general-purpose EM function for processing based on EPICS CA protocol. This allows us to build the gateway EM by editing the EPICS record name in the EM configuration file, without any programming. The basic scheme of the MADOCA-to-EPICS gateway is shown in Figure 1.

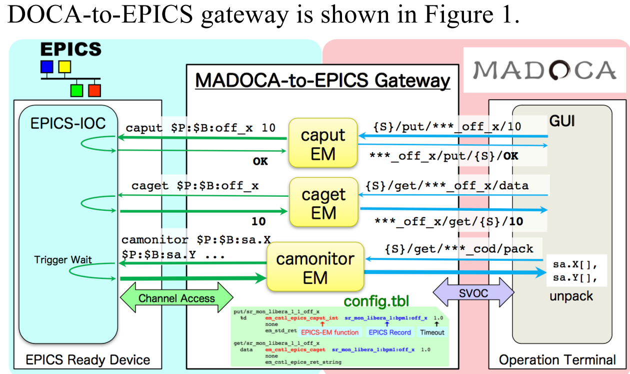

Figure 1: Scheme of MADOCA-to-EPICS gateway.

GATEWAY EM

In EPICS, all controls can be realized using the CA protocol-based commands (caget, caput, camonitor) to the EPICS process variable (PV) specified by the record name. The role of the command is shown below.

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TOWARDS A TIME-CONSTRAINED SERVICE-ORIENTED ARCHITECTURE FOR AUTOMATION AND CONTROL IN LARGE-SCALE DYNAMIC SYSTEMS

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Abstract

Rapidly changing demands for interoperability among heterogeneous systems leads to a paradigm shift from pre-defined control strategies to dynamic customization within many automation systems, e.g., large-scale scientific facilities. However, today's mass systems are of a very static nature. Fully changing the control process requires a high amount of expensive manual efforts and is quite error prone. Hence, flexibility will become a key factor in the future control systems. The adoption of web services and Service-Oriented Architecture (SOA) can provide the requested capability of flexibility. Since the adaptation of SOAs to automation systems has to face time-constrained requirements, particular attention should be paid to real-time web services for deterministic behaviour. This paper proposes a novel framework for the integration of a Time-Constrained SOA (TcSOA) into mass automation systems. Our design enables service encapsulation in filed level and evaluates how real time technologies can be synthesized with web services to enable deterministic performance.

INTRODUCTION

Today, the automation systems face challenges due to the changing demands on interoperability from their users. Formally, mass and standardized output was a key factor for the competitiveness. Nowadays and in the future the customization will become more and more important. Furthermore, the development cycles of these systems are about to become much shorter. This leads to a paradigm shift from mass production to mass customization within the dynamic system [1][2]. This means that the systems must be rapidly designed, able to convert quickly to the new models and able to integrate technology.

Currently, the engineering process for automation is characterized by high time-consuming manual configuration efforts. For example, in device-centric facilities for basic scientific research, all device properties and the data to be transferred must be defined by an automation engineer. Any modification of such a system requires an at least partial manual reconfiguration. Most of the time, the flexibility of current systems is limited to the pre-defined boundaries of the system. Therefore, the manual engineering is a major obstacle on the way to future fully automated systems.

Furthermore, the advance of engineering technologies relates closely to information technologies (ITs). Since design and operation of a dynamic system needs numerous types of decision-making at all of its hierarchy levels of automation, prompt and effective decisions not only depend on advanced reasoning techniques, but also on real-time data gathering and processing [3]. Every major development of automation has been supported by the advancement of IT. For example, the widely adoption of computer numerical control (CNC) made flexible manufacturing systems (FMSs) feasible; the technologies for distributed control systems (DCSs) made the interconnection of various parts in large automation systems practical. That is the reason why more and more cases in scientific scenarios rely on the professional provides of IT software solutions to replace or advance their conventional systems.

By today, the software infrastructure of big systems is often organized in vertical automation layers accordingly, shown as figure 1.

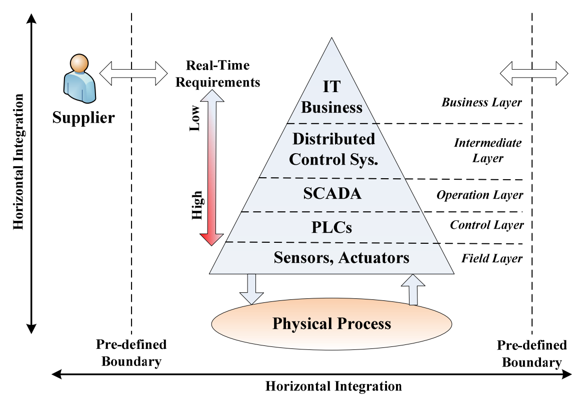

Figure 1: Automation Layers.

At the field layer, sensors and actuators provide interface to control physical processes. At the control layer, Programming Logic Controllers (PLCs) read from sensors, process them and generate new signals for the actuators. This process is repeated cyclically and autonomously on the basis of pre-defined control logic. At the operation layer, the data of the sub-system is gathered and visualized by industrial control software suite, like Supervisory Control and Data Acquisition (SCADA). And then, all the sub-systems are interconnected by distributed control systems based on Ethernet. This layer acts as a mediator between operation layer and business layer. It is in charge of collecting and integrating data from all operations for upper layer, and translating control orders into concrete control commands. Finally, the business layer contains software functionally for planning purpose. From the communication aspect, the layers differ in their requirements on real-time communication, especially for device-centric dynamic systems.

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PYTHON AND MATLAB INTERFACES TO RHIC CONTROLS DATA *

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Abstract

In keeping with a long tradition in the BNL Collider-Accelerator Department (C-AD) controls environment, we try to provide general and simple to use interfaces to the users of the controls. In the past, we have built command line tools, Java tools, and C++ tools that allow users to easily access live and historical controls data. With more demand for access through other interfaces, we recently built a set of Python and MATLAB modules to simplify access to control system data. This is possible, and made relatively easy, with the development of HTTP service interfaces to the controls. While this paper focuses on the Python and MATLAB tools built on top of the HTTP services, this work demonstrates clearly how the HTTP service paradigm frees the developer from having to work from any particular operating system or develop using any particular development tool.

INTRODUCTION

The C-AD controls system [1,2] was developed in the mid-1990's and built largely in C, C++, and Java (some legacy code in C with new code all in C++ and Java). The basic design is based on the Accelerator Device Object (ADO) model, which is similar to the TACO (predecessor to TANGO [4]) model. The ADO model, shown in Fig. 1, is a client-server model that uses TCP/IP as the communcation protocol and RPC at the server level.

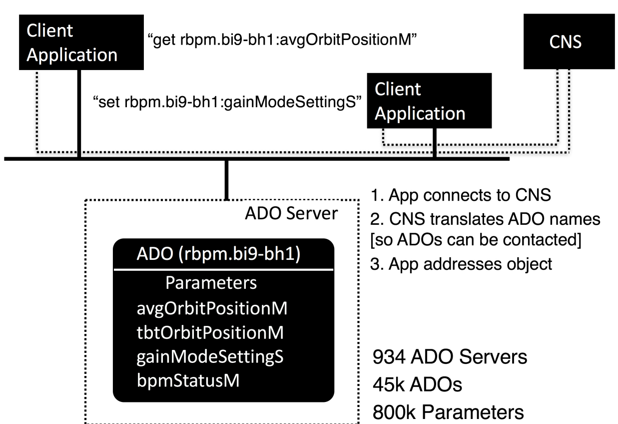

Figure 1: C-AD Controls ADO communication model.

In the ADO communications model, a client application just has to know the name of the ADO and device parameter in order to establish a connection to that parameter. Communication is done using *get* and *set* calls. Asynchronous requests can also be established. In the example shown in Fig. 1, two clients are trying to communicate with the same ADO, rbpm.bi9-bh1, but to different parameters. The ADO server handles the client requests as they are received. Since the communication is through TPC/IP, the client needs to establish a direct connection to the ADO server. We use a specialized Controls Name Server (CNS) to tranlate ADO names into host names and RPC program/version numbers, so those ADOs can be contacted.

RESTFUL SERVICES MODEL

A Representational State Transfer (REST) architectural style of communication utilizes the communication protocol at the internet level, to use textual resource representations and predefined stateless operations. HTTP is an application protocol and the next communication layer up from TCP/IP, a transport protocol, and provides a clean, standard, and well-defined protocol for this communication. The use of HTTP servers provides the ability to abstract away the control system and even the operating system dependencies from the client application [3]. The client can now be an iOS app, an Android app, a Python script, a MATLAB® script, or even just a simple web page built to interface to the HTTP server. In each case a client just has to know the HTTP specific protocol interface and the names of the control system ADO's and devices. Figure 2 shows the communications model for a Python application communicating to the controls through an HTTP Device server interface and through an HTTP Data server interface. The Device Server allows direct *set* and *get* communication to the ADO parameters while the Data Server provides access to logged data.

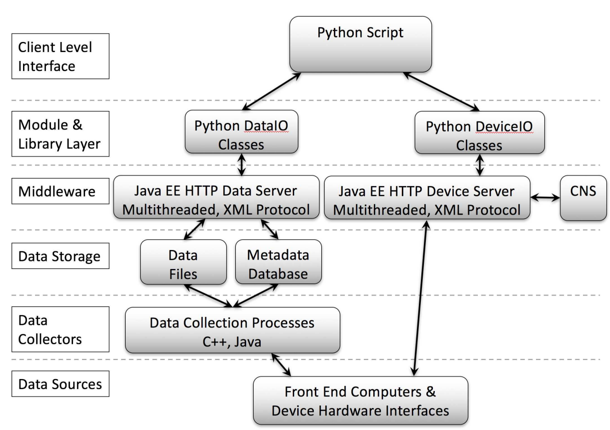

Figure 2: Example of HTTP communications model.

Data Server

In a REST communication model, the HTTP message includes a request (such as *GET*, and *PUT*) along with the meta

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JavaFX AND CS-STUDIO: BENEFITS AND DISADVANTAGES IN DEVELOPING THE NEXT GENERATION OF CONTROL SYSTEM SOFTWARE

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Abstract

The new developments inside the CS-Studio community [1–4] were made using the JavaFX platform [5–9] to overcome the limitations and difficulties of using Eclipse SWT. This article will explain the benefits and disadvantages of using the JavaFX technology inside Eclipse RCP, and try to foresee the path of the new generations of CS-Studio application.

INTRODUCTION

Control System Studio (CS-Studio, see [1,2]), is a multi-platform, Eclipse-based [10–12] desktop application, containing tools and features to monitor and operate large scale control systems, such as the ones in the accelerator community.

The first version of CS-Studio is dated back to 2006 [1]. Its implementation was based on the Eclipse Rich Client Platform (Eclipse RCP, see [11, 12]), and its user interface was realized using the Eclipse Standard Widget Toolkit (Eclipse SWT, see [12, 13]).

Since August 2012, when Oracle released version 2.2 of JavaFX (finally available for Windows, Max OS X, and Linux, see [5]), thanks to the availability of the `FXCanvas` class[1] [7,8,14] allowing JavaFX be embedded into an Eclipse SWT user interface, the CS-Studio community started to develop new tools and features using JavaFX instead of Eclipse SWT.

Currently, the following features are based on JavaFX (see Fig. 1):

- Data Browser 3;
- Display Builder (see [15, 16]);
- Fault tools;
- Logging Configuration;
- Probe;
- PV Tree;
- Save & Restore, and its Periodic Table.

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[1] Already available on JavaFX 2.0, only for the Window platform [5].

ECLIPSE RCP

Eclipse Rich Client Platform [11, 12] has served the CS-Studio community well for about a decade. While Eclipse RCP is stable, this also means it has not offered significant new features for the CS-Studio use cases in the last couple of years.

SWT [13] and RAP (Remote Application Platform, see [17]) developments have halted. e(fx)clipse (JavaFX Tooling and Runtime for Eclipse and OSGi, see [18]) has stalled, not progressing towards replacing SWT. E4 [12, 19] is an interesting concept at the lower API level, but the 'compatibility' layer remains the only practical API. The tycho-based build system [20] causes repeated issues with CS-Studio build setups.

Benefits

The following are recognized by the CS-Studio community to be the advantages of developing CS-Studio with the Eclipse RCP framework:

- OSGi [21] packaging, control of exported packages, dependencies;
- Extension points mechanism
  - for PV types, logbook support, archive data source, widgets,
  - for online help,
  - for preference UI;
- Cross platform (Max OS X, Linux, Windows);
- Configuration of site-specific products via plugins and features;
- OSGi console with 'telnet' access;
- Jetty [22] for services that have web interface;
- Hierarchical preferences;
- Workspace persists window layout and preference changes;
- Object contribution mechanism for context menu: Open apps on files, "PV Name" context menu;
- Support for CVS [23], Subversion (SVN, [24]), Git [25];

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CONTROLS CONFIGURATION DATABASE AT ESS

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Abstract

At the European Spallation Source (ESS), thousands of (physical and logical) devices will be in production and execute a wide range of functions to enable both the machine and end-station instruments to perform as expected from a controls point of view. Typical examples of such devices are racks, power supplies, motors, pumps, PLCs and IOCs. To properly manage the information of devices in an integrated fashion and at the same time allow external applications (consuming this information) to perform well, an application called Controls Configuration Database (CCDB) was developed at ESS. The present paper introduces this application, describes its features, architecture and technology stack, data concepts, interfaces, and ecosystem; finally, it enumerates development directions that could be pursued to further improve it.

INTRODUCTION

Many research facilities are routinely facing the challenge of managing huge amounts of heterogeneous controls-related information in a proper manner. Most have a panoply of databases to tackle this or, worse, a monolithic database composed of innumerous tables. Few facilities, however, have a truly centralized, flexible and coherent approach to manage such information which can ensure that 1) the development effort is kept at a reasonable level (by avoiding the proliferation of databases or a dense database which is difficult to maintain), 2) data duplication/inconsistency is mitigated and, most importantly, 3) users have access to a holistic view of the control system.

To overcome this challenge, the CCDB [1] was developed with the goal of enabling the collection, storage and distribution of controls configuration data needed to install, commission and operate the ESS control system from day one. Along with single sign-on capabilities shared with disparate ESS applications, a fine-grained user authorization mechanism, several ways to read/write data from/into, multiple views over the same information, the CCDB also has modelling capabilities: Users can define device types and associate properties to these, create devices (out of device types), and specify relationships between these. Additionally, users can represent the ESS control system in a hierarchical fashion through containers and slots (placeholders in the control system structure for devices). This modelling capability is actually the most prominent feature of this application as it enables it to cope with virtually any kind of controls scenario (that needs to be modelled/stored) but also lowers both its development effort and persistence layer complexity (i.e. database density). This feature considerably reduces the time users have to wait to represent/store devices as no software development is required.

Moreover, thanks to a well-defined programmatic interface, the CCDB supports external applications (e.g. IOC Factory) to perform their domain specific businesses adequately and share data in an efficient way.

DESCRIPTION

The origins of the CCDB can be traced back to a project called Proteus [2] developed at the Facility for Rare Isotope Beams (FRIB) with the main goal of managing controls configuration information. Due to this goal being similar to what ESS was pursuing in 2013, the initial code base of the CCDB actually sprung out of Proteus. A significant portion of this code base (and to a lesser extension the database schema) had to be re-written to cope with new (ESS) requirements though. Development of the CCDB started in early 2014 and went into production at the end of 2015. Since then, several versions have been deployed, with version 1.3 released in October 2017 being the latest. Table 1 summarizes key CCDB metrics.

Table 1: Metrics about the CCDB

Description	Value
Tables (persistence tier)	40
Constraints (persistence tier)	100
Indexes (persistence tier)	7
Lines of code (persistence tier)	0
Classes in Java (business tier)	388
Lines of code (business tier)	38,224
Web pages (presentation tier)	7
Dialogs (presentation tier)	21
Lines of code (presentation tier)	3,863

Nowadays, the CCDB is part of an international collaboration called DISCS [3]. This collaboration is composed of several research facilities (ESS being one of them) with the aim of developing databases, services and applications that any experimental physics facility can easily configure, use and extend for its commissioning, operation and maintenance. The CCDB is being developed as the configuration module within this collaboration, and is considered to be the most important module.

Features

Besides its major feature (modelling capabilities), the CCDB has other features or characteristics worth mentioning. These are:

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MALCOLM: A MIDDLELAYER FRAMEWORK FOR GENERIC CONTINUOUS SCANNING

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Abstract

Malcolm is a middlelayer framework that implements high level configure/run behaviour of control system components like those used in continuous scans. It was created as part of the Mapping project at Diamond Light Source to improve the performance of continuous scanning and make it easier to share code between beamlines. It takes the form of a Python framework which wraps up groups of EPICS PVs into modular "Blocks". A hierarchy of these can be created, with the Blocks at the top of the tree providing a higher level scanning interface to GDA, Diamond's Generic Data Acquisition software. The framework can be used as a library in continuous scanning scripts, or can act as a server via pluggable communications modules. It currently has server and client support for both pvData over pvAccess and JSON over websockets. When running as a webserver this allows a web GUI to be used to visualize the connections between these blocks (like the wiring of EPICS areaDetector plugins). This paper details the architecture and design of framework, and gives some examples of its use at Diamond.

INTRODUCTION

Diamond Light Source [1] is a third-generation 3 GeV synchrotron light source with 35 independent experimental stations attached to photon beamlines. A number of these beamlines use a technique called continuous scanning where motors are moved in a continuous trajectory while a detector takes a number of data frames synchronized with hardware trigger pulses as illustrated in Fig. 1. This technique increases the efficiency of an experiment by reducing the number of times a motor has to decelerate, settle and accelerate, effectively decreasing the scan dead-time.

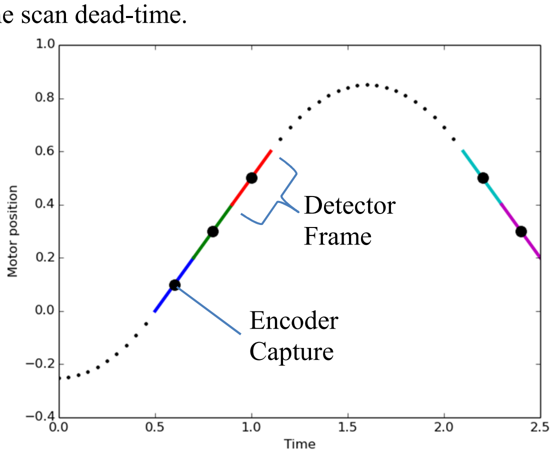

Figure 1: Detector frames synchronous with a motor undergoing a snake trajectory scan.

THE MAPPING PROJECT

Diamond has multiple beamlines capable of conducting mapping experiments where the sample is moved through the X-ray beam and a frame is sampled on one or more detectors at each point. In 2015, Diamond created the Mapping Project [2, 3] to enable all beamlines that conduct mapping to benefit from common features like live visualization and processing of data and optimisations like continuous scanning. A set of 5 beamlines with diverse techniques and detectors were selected to participate in the project to ensure that the stack of components being developed (as shown in Fig. 2) could be easily deployed on multiple beamlines and support a variety of experimental equipment and instrumentation.

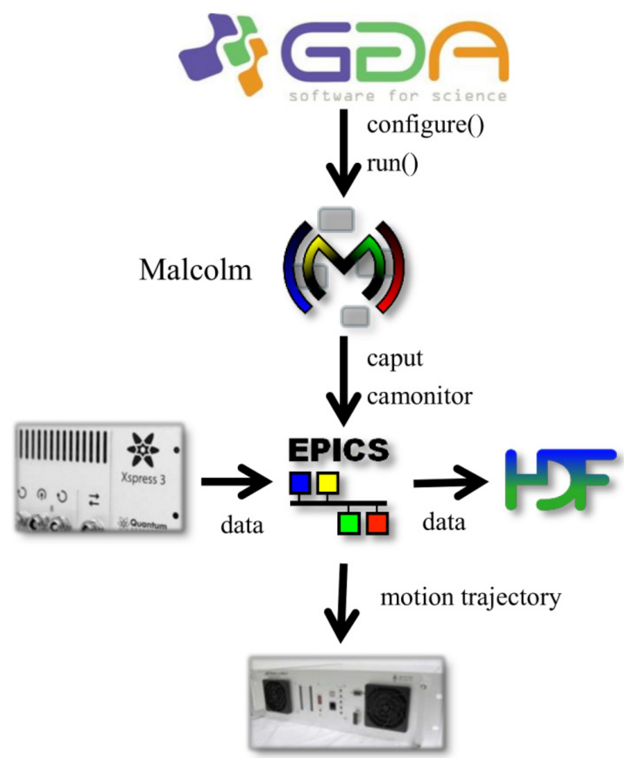

Figure 2: Mapping Project component stack.

New developments were made in trajectory scanning the Delta Tau Geobrick [4], writing multi-dimensional data using HDF5 SWMR [5], live processing and visualization of data in GDA [6] and DAWN [7], and the Malcolm [8] middlelayer that is the subject of this paper.

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SIP4C/C++ AT CERN – STATUS AND LESSONS LEARNED

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Abstract

After 4 years of promoting the Software Improvement Process for C/C++ (SIP4C/C++) initiative at CERN, we describe the current status for tools and procedures along with how they have been integrated into our environment. Based on feedback from four project teams, we present reasons for and against their adoption. Finally, we show how SIP4C/C++ has improved development and delivery processes as well as the first-line support of delivered products.

BACKGROUND

A C/C++ software improvement process (SIP4C/C++) has been promoted in the CERN Accelerator Controls group since 2011, addressing technical and cultural aspects of our software development work. A first paper was presented at ICALEPCS 2013 [1]. On the technical side, a number of off-the-shelf software products have been deployed and integrated, including Atlassian *Fisheye/Crucible* (code review), *Google test* and *Google mock* (unit test), *Valgrind* (memory debugging/profiling) and *SonarQube* (static code analysis). Likewise, certain in-house developments are now operational such as a generic Makefile, *Makefile.generic,* (compile/link/deploy), *CMX* (for publishing runtime process metrics) and *Manifest* (capturing library dependencies). In addition, SIP4C/C++ has influenced our culture by promoting integration of said products into our binaries and workflows.

Four projects have adopted SIP4C/C++ to various degrees:

CMW delivers C and C++ libraries providing transport facilities as extendible classes, letting the user create remotely accessible servers which expose data according to the device/property model employed in our controls system.

FESA a C++ framework based on CMW libraries, formalizing the creation of device/property-based servers.

SILECS resembles FESA, but focuses on letting users expose PLC data according to the device/property model.

TIMING provides and operates a number of executables used to sequence and synchronise CERN's accelerator complex, along with libraries for other developers to use.

OBJECTIVES

The objectives of the SIP4C/C++ initiative are: 1) agree on and establish best software quality practices, 2) choose tools for quality, and 3) integrate these tools into the software development process.

RESULTS

For each participating project, the SIP4C/C++ products and procedures mentioned above were evaluated in terms of uptake as either "Strong", "Medium" and "Weak". Reasons for and against adoption were collected along with suggestions for future improvements.

Common Build Tool

Status: The Makefile.generic is stable. Includes targets for compiling, linking, SVN commits with support for tags and branching, deploying, documentation, test execution and launch of the Valgrind memory debugger/profiler. Also, provides automatic generation of the Manifest (see below).

Uptake: Strong in all four projects, with all products managed using Makefile.generic

Pros: Essential for uniform approach to release management and testing, which in turn facilitates cross-project development teams. Once adopted, it greatly simplifies integration of new target platforms. It meets the requirements of many users and as it was implemented in-house, we can readily adapt it to future needs and new platforms.

Cons: Approaches the limits for what Make is intended for. Its complexity makes it hard to know what is possible and how to achieve it – in particular for inexperienced users. It was very time consuming to adopt and hence best suited for projects of a substantial size where the effort was found to be worthwhile. Projects risk losing time on refactoring if the Make system changes. Our implementation is non-standard and hence requires dedicated resources for evolution. The current solution depends on remote resources, i.e. network (NFS) access is required.

Future: Moving towards a higher-level service based on standard, open-source products (e.g. *cmake*) with support for dependency management would help decrease confusion and errors. There should be support for working offline, i.e. to download all resources once.

The Manifest, Dependency Capture

Status: Stable, with a few known issues, in particular problems in correctly navigating symbolic links. Dependency information is captured as XML at build-time, via Makefile.generic, and visualized as shown in Figure 1.

Uptake: Medium in FESA and TIMING, weak in CMW and SILECS. FESA uses the manifest ad hoc to manually spot end-user dependency conflicts, whereas TIMING parses the XML to automatically configure source directory paths for *gdb*. CMW saw little interest, finding the dependency information of committed Makefiles to be more reliable.

Pros: Provides useful information in case of certain unexplained run-time behaviours and it is effortless to use due to integration with Makefile.generic

Cons: The solution is non-standard. A system like *pkg-config* could be interesting, but would require a rewrite of Makefile.generic

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CBNG – THE NEW BUILD TOOL USED TO BUILD MILLIONS OF LINES OF JAVA CODE AT CERN

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Abstract

A large part of the CERN Accelerator Control System is written in Java by around 180 developers (software engineers, operators, physicists and hardware specialists). The codebase contains more than 10 million lines of code, which are packaged as 1000+ JARs and are deployed as 600+ different client/server applications. All this software are produced using CommonBuild Next Generation (CBNG), an enterprise build tool implemented on top of industry standards, which simplifies and standardizes the way our applications are built.

CBNG not only includes general build tool features (such as dependency management, code compilation, test execution and artifact uploading), but also provides traceability throughout the software life cycle and makes releases ready for deployment. The interface is kept as simple as possible: the users declare the dependencies and the deployment units of their projects in one file. This article describes the build process, as well as the design goals, the features, and the technology behind CBNG.

INTRODUCTION

The work on a Java-based Control System for the LHC was started in 1998 and the need for a unified build process emerged shortly. In 2002, an Ant-based [1] tool, CommonBuild was introduced for this purpose [2], which used an Apache JJAR [3]-based repository for dependency management. Over the years active development on these products have stopped as new competitors entered the market, first Maven [4] and then Gradle [5]. The latter tools provide an improved, de facto industry standard method for building Java programs and managing dependencies, which served as a motivation to look for a replacement.

Table 1: Evolution of Complexity of Java Software

	2005	2017
Products	130	1 000
Dependency levels	10	25
Developers	30	180

Nevertheless, over the last decade new requirements have emerged. The codebase and complexity of the control system has grown rapidly (see Table 1) and is now larger than 10 million lines of code, distributed among more than 1000 projects, written and maintained by 180 developers. Therefore, the CERN Controls Group decided to keep a centrally maintained, unified build process for Java instead of having all teams set up their own build procedures. Many big companies like LinkedIn [6] or Netflix [7] follow the same approach, whereby a centralised tooling team provides a modern build tool with company-specific extensions to all developers to unify the development process and culture.

We chose Gradle, an open-source build automation system as the basis to implement CBNG (CommonBuild Next Generation). CBNG helps developers to avoid duplicating the same build logic across several projects and save time by providing them a common continuous integration (CI)/continuous delivery (CD) *pipeline*. CBNG also provides a simplification layer over Gradle, *enabling physicists to focus on physics*. Our developers do not have to know anything about Gradle, by reading a few pages of documentation they are able to create their projects, do development and push to production. Nonetheless, professional software developers can still benefit from the advanced built-in Gradle features.

Finally, yet importantly, the centralised release management and the unified build pipeline of CBNG aids maintenance over time. For example, with CBNG it is considerably easier than with Gradle to explore what the relationship is across projects, detect which third-party libraries are used and which are not.

Our tooling team began to investigate modern build tools in 2011 and started the development of CBNG in 2013. In the beginning of 2017, the old build system was replaced by CBNG and by the summer all the 1000 projects were built by the new tool [8].

DEVELOPMENT WORKFLOW

The development workflow is illustrated in Fig. 1. The developer either creates a new project in their Eclipse IDE [9] or checks out an existing project from version control. To start, they call the `bob eclipse` command (`bob` is the command-line shortcut for CBNG) which reads the project descriptor (step 1), downloads the dependencies of the project from the internal Maven repository (in our case JFrog Artifactory [10]) and makes them available to the IDE (step 2).

During local development, the developer typically works inside the IDE. When they are ready to publish their library or application, they make sure all code is committed back to version control and then execute the `bob release` command (step 3). This command first asks the user for their credentials and then triggers the build process on the remote *Release Server*. This service downloads the source code and builds the project. If the build is successful, it uploads the produced artifacts to Artifactory.

If the developed project is an executable product (a server or a GUI application), then additional, fully automated steps take place (step 4). To begin with, all the files are copied

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EVALUATION OF MODEL BASED REAL TIME FEEDBACK CONTROL SYSTEM ON PLASMA DENSITY*

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Abstract

The KSTAR plasma control system has very powerful monolithic software architecture that has dedicated centralized system architecture. However, due to increasing of real time functionality on distributed local control system, we need a flexible high-performance software framework. A new real time core engine program inherited design philosophy from the Very Large Telescope (VLT) control software. A new Tool for Advanced Control (TAC) engine was based on C++ standard run on Linux. It is a multithreaded core engine program for execution of real time application. The elemental building blocks are chained together to form a control application. A control application dictated as a single xml file, and it is parsed when the core engine initializing. The core engine is realized inside EPICS IOC as a standard library together with KSTAR common framework library. The IOC is automatically linked with Pulse Automation System, and performs sequential plasma operation.

INTRODCUTION

Since the KSTAR facility has similar engineering characteristics to ITER, the KSTAR control team is carrying out an evaluation tasks for the ITER control system element technology for the past several years [1]. The results of the collaboration are also reflected in the upgrade of the KSTAR control system. An additional time synchronization and real time network which were derived from ITER have been adopted as a complementary network infrastructure [2]. The SDN is based on UDP/IPv4 multicast over 10Gb Ethernet. TCN is based on Precision time Protocol (PTP version 2, IEEE-1588-2008). Besides the basic network infrastructure, KSTAR adopted design philosophy of the ITER Real Time Framework (RTF) [3] for the next generation of plasma control system. As a result of solid collaboration, new real-time core programs have been implemented and are under constant development to increase functionality and reliability. The new application performs a real-time feedback control of the plasma density and performs gas puffing.

REAL TIME CORE PROGRAM

Real time core program inherit from the TAC [4]. The TAC-engine provides a mechanism for a user to specify the structure and behaviour of a digital control algorithm on a high abstraction level. It provides over 40 numbers of elemental processing blocks which have a user defined processing role. The engine is implemented using the standard C++ language and compiled into a static and a shared libraries to support portability for various applications, including EPICS. Fig. 1 shows fundamental libraries and basic structure.

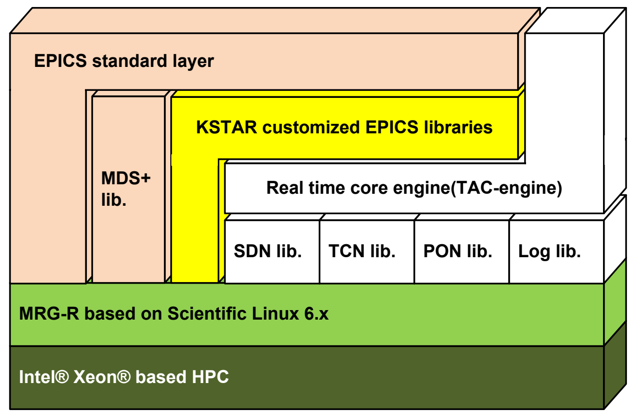

Figure 1: Software Components and architecture of EPICS IOC for real time processing.

An application designer links existing blocks for appropriate configuration. The IOC initiates the engine program according to the KSTAR sequential operation flow.

Applied Software Component

- KSTAR standard software framework library (sfwLib): Provides customized libraries, template, EPICS DB files and system environment files. It is similar to EPICS native ASYN library and supports common functions for DAQ and control systems [5].
- sdn-coreLib: base library to process SDN topics both subscribe and publish.
- TCN Lib: 3rd party deamon from ITER provides high precison time synchronization.
- PON Lib: provides EPICS CA function with external IOC.
- IOC Lib: provides PV connection inside IOC.
- Log Lib: propagates error and trace logging information to local file. The library can be safely used inside real-time portions of software.

APPLICATION CONFIGURATION FILE

The core program uses a single configuration file. The control application file describes all the libraries, threads, blocks, and link information for each function block used. The IOC indicates an appropriate filename, and the engine initializes the class instance with given configuration. The example of file is shown in Fig. 2. Fig. 3 depicts the basic software components inside the IOC and connections.

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NEW DEVELOPMENTS FOR THE TANGO ALARM SYSTEM

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Abstract

The TANGO Alarm System, based on an efficient event-driven, highly configurable rule-based engine named AlarmHandler, has undergone a deep refactoring. The dedicated MySQL database has been dropped; the TANGO database now stores all the configuration whereas the HDB++ historical database keeps all the alarms history. Correlating alarms with any other engineering data is now much simpler. A dynamic attribute is provided for each alarm rule; this allows to easily build a hierarchy of AlarmHandlers. The AlarmHandler manages Attribute quality in the alarm rules and provides possible exceptions resulting in alarm evaluation. Mathematical functions, such as sin, cos, pow, min, max and ternary conditionals are available in the alarm formulae. The TANGO AlarmHandler device server is now based on the IEC 62682 standard.

INTRODUCTION

An alarm system is a tool that allows to notify operators of abnormal process condition or equipment malfunctions. The alarm system plays a central role in increasing uptime and overall service quality in the control systems of the Elettra and FERMI accelerators. In particular, the alarm system allows operators to be early notified of possible major faults, and to take the necessary action to prevent them.

Building on the experience matured during several years of use, with thousands of alarms deployed, a number of improvements and new functionalities for the TANGO alarm system have been designed and implemented.

EVOLUTION OF THE TANGO ALARM SYSTEM

The first alarm system for TANGO has been developed at Elettra in 2004 [1]. The main requirements identified were:

- easily configurable at runtime
- support for complex alarm rules, with logical, binary, mathematical operators and functions
- support for alarm rules based on values gathered from multiple subsystems
- consistency of alarm states between multiple clients.

Named Alarm Collector, the TANGO device was designed to be completely asynchronous, exploiting the freshly added publish/subscribe support in TANGO. Every attribute involved in the formula is subscribed for the change event; when the Alarm Collector receives a new event, the evaluation of all the matching alarm formulae is triggered. The state of alarms was exposed to clients as an array of strings, containing all the necessary information: the actual condition of the alarm, the acknowledge flag, the timestamp, the severity, the group and the optional message associated to the alarm.

During 2008 the Alarm System undergo the first refactoring. GNU Flex and Bison, used as lexical scanner and parser, have been replaced with a novel parser developed with the Spirit Parser Framework [2], an object oriented recursive descendent parser generator implemented using template meta-programming techniques. As part of the Boost libraries, the Spirit Parser is written in C++, and use operator overloading to compose parser objects. The alarm parser has been implemented to build an Abstract Syntax Tree (AST) as the result of the parsing of the formula. Thus, each alarm rule is parsed only once at device initialization, and the evaluation is done using the AST, that results in better performance.

Furthermore, the capability to store the history of alarms, including the state and message, into a dedicated MySQL database has been added. The original schema included two tables: the '*description*' table, to store the configuration, and the '*alarms*' table, keeping track of the alarm history.

The possibility to execute a TANGO command as the alarm condition changes has been added. Two different commands can be configured, the first to be executed when the alarm condition changes from NORMAL to ACTIVE, the second when it changes from ACTIVE to NORMAL. The commands may have no input parameter or DevString input parameter. In the second case, the DevString is filled with the alarm name, group, message and the values that triggered the alarm condition using a 'key=value;' representation.

Also, the support to email notification triggered by alarm state change has been added. A new TANGO Device, named AlarmMail, has been developed in Python, providing mailing capabilities. This device provides a phonebook and a mailing list that can be associated to alarm groups. The commands SendAlarm and SendNormal, which accept a DevString argument, allow to send emails reporting an alarm or a normal notification. These commands can be configured as the actions to be triggered by the alarms to provide email notification.

DESIGN GUIDELINES

A number of requirements has been taken into account during the design phase of the deep refactoring of the alarm system:

- drop the dedicated MySQL database used to store the configuration and the history
- save the alarm configuration in the TANGO DB
- save the alarm history using HDB++ [3]
- use the state of an alarm in the formula of another alarm
- comply to the IEC 62682:2014 standard

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NEW DEVELOPMENTS FOR THE HDB++ TANGO ARCHIVING SYSTEM

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Abstract

TANGO HDB++ is a high performance event-driven archiving system which stores data with micro-second resolution timestamps, using archivers written in C++. HDB++ currently supports MySQL and Apache Cassandra back-ends but could be easily extended to support additional back-ends. Since the initial release many improvements and new features have been added to the HDB++. In addition to bug-fixes and optimizations, the support for context-based archiving allows to define an archiving strategy for each attribute, specifying when it has to be archived or not. Temporary archiving is supported by means of a time-to-live parameter, available on a per-attribute basis. The Cassandra back-end is using Cassandra TTL native feature underneath to implement the time-to-live. With dynamic loading of specific libraries switching back-ends can be done on-the-fly and is as simple as changing a property. Partition and maintenance scripts are now available for HDB++ and MySQL. The HDB++ tools, such as extraction libraries and GUIs, followed HDB++ evolution to help the user to take full advantage of the new features.

INTRODUCTION

The HDB++ TANGO archiving system [1, 2] is a tool that allows to store the attribute values in a TANGO based control system into an historical database, exploiting the publish/subscribe TANGO capabilities. The publish/subscribe paradigm is available in TANGO via the event subsystem. More in detail, the *archive* event is provided for archiving purposes and can be triggered on threshold comparison and/or periodic basis. The HDB++ architecture is fully event based; therefore, a part of HDB++ setup consists of conveniently configure TANGO devices to send events as required. The TANGO archiving system consists of two main components, namely the EventSubscriber TANGO device, or archiving engine, and the ConfigurationManager TANGO device, that simplifies archiving configuration and management. The HDB++ also provides the libraries to interface the supported back-ends, libraries for data extraction and some graphical user interfaces for configuration and data visualization. The typical HDB++ setup is shown in Fig. 1.

NEW FUNCTIONALITIES

In addition to bug-fixes and optimisations, a number of new functionalities and improvements have been developed for the HDB++ archiving system.

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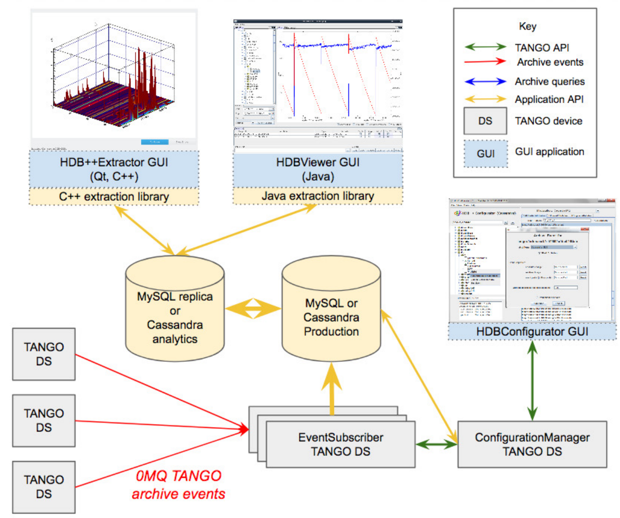

Figure 1: Typical HDB++ setup.

Context-based Archiving

The support for context-based archiving allows to define an archiving strategy for each attribute. A strategy is the list of contexts for which the attribute has to be archived. When an EventSubscriber is set to a context, only attributes that have this specific context in their strategy are archived, and all the remaining attributes are automatically stopped. The strategy configuration for each attribute is saved in an EventSubscriber property named *AttributeList*, using a "name=value" approach, where the name is "strategy" and the value is a list of context labels separated by "|". Some attribute configuration lines, taken from the *AttributeList* property, are shown in Table 1; it is worth noting the use of the Fully Qualified Device Name (FQDN) to identify each attribute, allowing an EventSubscriber to archive data coming from different TANGO facilities.

Table 1: AttributeList Property Configuration Excerpt

tango://srv-tango-srf.fcs.elettra.trieste.it:20000/eos/climate/ ↩
18b20.01/state; strategy=RUN|SHUTDOWN
tango://srv-tango-srf.fcs.elettra.trieste.it:20000/pil/laser/ ↩
evops.01/state; strategy=RUN

The list of the context labels can be defined as TANGO database free property, and/or as class property and/or as device property named *ContextsList*. Whenever defined, device property setting overrides class property which in turn overrides free property. The *ContextsList* property contains an array of strings, specifying available context names, with

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TANGO WEB ACCESS MODULES AND WEB CLIENTS FOR NICA CONTROL SYSTEM

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Abstract

NICA (Nuclotron-based Ion Collider Facility) is a new accelerator complex designed at the Joint Institute for Nuclear Research (Dubna, Russia) to study properties of dense baryonic matter. The report describes Tango-modules designed at JINR to provide web-access to Tango-based control system. RestDS is a lightweight Tango REST service, developed in C++ with Boost and OpenSSL libraries. It implements Tango REST API and Tango JINR REST API; WebSocketDS is a lightweight Tango WebSocket service, developed in C++ with WebSocket++, Boost and OpenSSL libraries. It implements Tango attributes reading and command executing through WebSockets. The report also gives examples of web client applications for NICA control system, using these services.

INTRODUCTION

The Nuclotron-based Ion Collider fAcility is a new accelerator complex being constructed at JINR. It is aimed to study the properties of nuclear matter in the region of the maximum baryonic density. It includes injection complex, new superconducting booster synchrotron, the existing superconducting heavy ion synchrotron Nuclotron, collider having two new superconducting rings and new beam transfer channels [1]. NICA accelerator complex general scheme is shown in Fig 1.

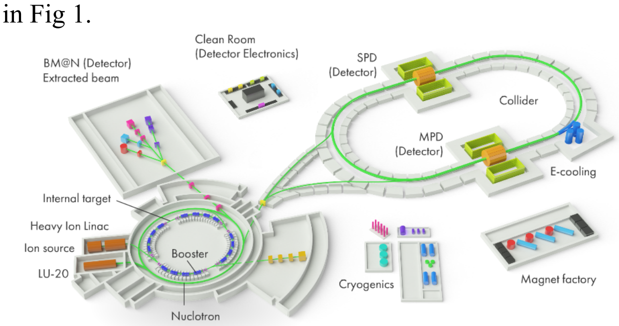

Figure 1: NICA accelerator complex general scheme [2].

NICA control system is based on Tango Controls framework - free open source device-oriented controls toolkit for controlling any kind of hardware or software and building SCADA systems [3]. The client applications are traditionally developed using LabView or Taurus frameworks.

In recent years, there has been a rapid development of web technologies. Now there is an opportunity to develop cross-platform, flexible, fast and convenient web applications. The idea to create web client applications for the control system seems to be promising. To achieve this goal universal tools for communication between Tango Controls and web clients are required. The most common data transmit technologies are WebSocket and REST.

WEBSOCKET

WebSocket is a computer communications protocol, providing full-duplex communication channels over a single TCP connection. It enables interaction between a browser and a web server with lower overheads, facilitating real-time data transfer from and to the server.

WebSocketDS [4] is lightweight tango module that is used to communicate tango devices to the outside world through the WebSocket. It was developed in C++ with Boost, OpenSSL and WebSocket++. Requests and responses are encoded in JSON.

WebSocketDS supports:

- Periodic attributes reading;
- Attributes reading on demand;
- Commands execution;
- Events subscription (change, periodic, archiving, user);

There are several modes of WebSocketDS operation. If the server mode is used, the server controls the information, being red from tango. The client mode means the user-defined data comes from server.

WebSocketDS is being operational in beam intensity measurement system at the Nuclotron, and also in injection complex diagnostic system. The WebSocketDS general operational diagram is shown in Fig 2.

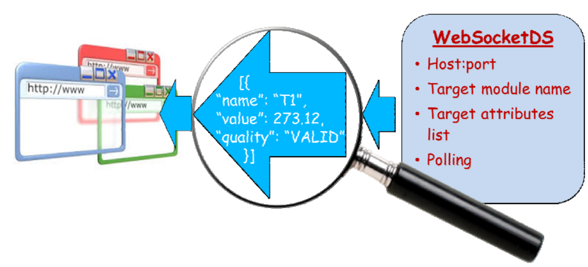

Figure 2: WebSocketDS general operational diagram.

REST

REpresentational State Transfer is set of architectural principles to design web services that focus on system's resources. Every resource is identified by its Unified Resource Locator (URL). URL is unique within controls system. REST-compliant Web services allow requesting systems to access and manipulate textual representations of Web resources using a uniform and predefined set of

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IMPROVING THROUGHPUT AND LATENCY OF D-Bus TO MEET THE REQUIREMENTS OF THE FAIR CONTROL SYSTEM

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Abstract

In developing the control system for the FAIR accelerator complex we encountered strict latency and throughput constraints on the timely supply of data to devices controlling ramped magnets. In addition, the timing hardware that interfaces to the White Rabbit timing network may be shared by multiple processes on a single front-end computer. This paper describes the interprocess communication and resource-sharing system, and the consequences of using the D-Bus message bus. Then our experience of improving latency and throughput performance to meet the realtime requirements of the control system is discussed. Work is also presented on prioritisation techniques to allow time-critical services to share the bus with other components.

INTRODUCTION

The White Rabbit based FAIR Timing System developed at GSI [1] provides FPGA-based Timing Receiver hardware for frontend computers. The SAFTlib project (Simplified API for Timing) was designed to share the resources of the Timing Receivers and provide a stable interface that abstracts software clients from the complexity of the timing system. The design goals are to:

- Share the Timing Receiver hardware resources
- Unify different underlying hardware.
- Prevent applications creating conflicting events
- Isolate applications from failures in other clients
- Monitor hardware status

Interprocess communication between clients and the SAFTlib process (saftd) is via the d-bus shared message bus.

This paper describes the hardware and software environment in which it is used and experiences in using SAFTlib in a production environment. The primary focus is on achieving the throughput and latency necessary to operate the FAIR accelerators whilst maintaining the flexibility and compatibility of the original SAFTlib design.

FAIR ACCELERATOR ENVIRONMENT

The FAIR project will include a complex of accelerators and a new control system is under development [2]. The CRYRING low-energy storage ring is being used to test and evaluate the control system before retrofitting the existing GSI infrastructure and equipping the new FAIR accelerators.

Timing Network

The FAIR timing system uses White Rabbit to distribute high precision timing events over a dedicated Ethernet-based network. The complexities of clock synchronization, signal latencies and network topology are abstracted from the users of the timing system. The high-level applications interact with the Data Master, which maintains a schedule of events and distributes them to Timing Receivers. Low-level applications interact with the Timing Receivers located close to the equipment. Equipment that controls a logically related set of accelerator components is collected into a Timing Group.

Frontend Controllers

The standard environment for the FAIR control system is the Scalable Control Unit [3]. It provides an Intel 64-bit CPU, Linux Operating System with realtime patches, an FPGA Timing Receiver connected via PCI-express and Wishbone. The timing software is also required to run on other systems with greater processing power for Beam Diagnostics, systems interfacing to hardware using a VME Bus, and systems with USB-connected Timing Receivers. The SAFTlib software aims to provide a standard interface across multiple platforms.

Timing Receivers

The Data Master sends event messages over the White Rabbit network shortly in advance of their planned execution time. The Timing Receiver hardware matches events against a set of conditions. The Event-Condition-Action (ECA) unit is responsible for generating actions from incoming Timing Events. For equipment with hard real-time requirements, hardware actions are used. These send signals over a variety of bus interfaces directly to equipment. An example is the trigger synchronization event that is used to start waveform generators. For events that can tolerate higher latency software actions can be used. For example, sequence start events signal that a device should be prepared for a new cycle and load data for a later hardware trigger, a gap event can signal that software has a period in which it may freely read the status of equipment.

Function Generators

Central to the performance investigation is the anticipated load from Function Generator units. These generate arbitrary waveforms from a set of polynomial coefficients and after D/A conversion control a variety of magnet power supplies. The polynomials describe the waveform in segments starting as 1ms in length. This

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TANGO BASED SOFTWARE OF CONTROL SYSTEM OF LIA-20

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Abstract

The linear induction accelerator LIA-20 for radiography is a pulsed machine designed to provide three consecutive electron bunches. Since every pulse is a distinctive experiment, it is of high importance to provide coherence of the facility state and the experimental data. This paper presents overall software architecture. Challenges and particular approaches to designing of a pulsed machine control system using Tango are discussed.

LIA-20 PROJECT

Linear Inductor Accelerator LIA-20 is designed to produce three electron bunches with energy up to 20 MeV, current up to 2 kA and lateral size after focusing on the target less than 1 mm. It is planned to provide three consecutive bunches, with one of them divided into 9 angles. The accelerator will be used for the flash X-Ray radiography.

LIA-20 consists of the injector, 30 “short” accelerating modules (SAM) and 12 “long” ones (LAM). Injector generates beam with the energy up to 2 MeV. SAM increases the energy by 0.33 MeV and LAM increases the energy by 0.66 MeV. The total length is about 75 meters. Control units are placed along the installation. All units are based on uniform VME crate and connected via Ethernet. Structure of the control system is described in detail in [1].

DATA RATES

All channels could be divided into following groups:

Fast. All measurements faster than 10 us: voltage on inductor, currents on lenses and beam position monitor.

Slow. This group includes measurements with duration up to several milliseconds (charging device, degaussing current).

Timing. These channels provide all devices with proper start pulse.

Interlock. These channels belong to subsystem that prohibit experiment in case of component malfunction or failure [2].

Technological controls. This group incorporates vacuum controls, optical system alignment, control of power supplies.

First four groups are bound to machine cycles, while the last one is continuous. Tables 1 present the summary of channels and data rates. Estimation provided for one-bunch cycle.

SOFTWARE OVERVIEW

Experience of LIA-2 [3] shows that use of widely-used control system software could reduce costs. Taking into account that LIA-20 is more sophisticated than LIA-2 it could be crucial.

After some studies it was decided to use TANGO controls. A lot of tools (like rapid UI prototyping, Archive service, macros) are available out-of-the-box or in the form external library.

User Software

User applications are created using Python language and PyQt/PyTango/Taurus libraries. There are two types of user application: “engineer” and “operator's”. The first one provides access to “raw” tango device. It is designed for developing and testing purposes. The second one is high-level application that interacts with multiple tango devices and hides implementation details. Examples of operator’s applications is shown in Figure 1.

Mimic Diagram prototype visualizes a summary of all subsystem's states. It is based on PyQt/QWebKit and SVG. The use of SVG allows to utilize ordinary vector editors like Inkscape to create and modify diagram.

Time Editor is a prototype of editing tool for timing diagrams [4]. It provides operator the ability to prepare, verify and apply timing diagrams. Current version directly applies values to the tango devices. Drawback of such approach is that it is quite difficult to track and revert changes. Management of changes is a common task and should be implemented as standalone service.

Table 1: Data Rates Estimation

Channel type	Number of channels		Data rate	
	whole system	**per VME crate**	**whole system**	**per VME crate**
Fast	594	22	5.7 MB/cycle	214 KB/cycle
Slow	1485	55	13.5 MB/cycle	0.5 MB/cycle
Timing	1485	55	13.5 KB/cycle	0.5 KB/cycle
Interlock	1485	55	13.5 KB/cycle	0.5 KB/cycle
Technological control	1000	~40	513 KB/min	19 KB/min
	6000	~280	19.3 MB/cycle + 540 KB/min	3.5 MB/cycle + 19.5 KB/min

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CONTAINERIZED CONTROL STRUCTURE FOR ACCELERATORS

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Abstract

Nowadays, modern accelerators are starting to use virtualization to implement their control systems. Following this idea, one of the possibilities is to use containers. Containers are highly scalable, easy to produce/reproduce, easy to share, resilient, elastic and low cost in terms of computational resources. All of those are characteristics that fit with the necessities of a well defined and versatile control system. In this paper, a control structure based on this paradigm is discussed. Firstly, the technologies available for this task are briefly compared, starting from containerizing tools and following with the container orchestration technologies. As a result, Kubernetes and Docker are selected. Then, the basis of Kubernetes/Docker and how it fits into the control of an accelerator is stated. Following the control applications suitable to be containerized are analyzed: electronic log systems, archiving engines, middleware servers, etc. Finally, a particular structure for an accelerator based on EPICS as middleware is sketched.

INTRODUCTION

Virtualization technology[1] has became a standard in many fields related to the IT. Especially, at DevOps and Cloud services. This standardization and the benefits it provides has cause its adoption in other areas. In the large facilities field, there are being efforts on this direction. As an example Virtual Machines (VMs) are used at [1–3] for software standardization and maintaining. At [4–6] the authors add High Availability (HA) and resources optimization to the control system using also VMs. In conclusion, the use of virtualization provides benefits to the control system architecture. We can state that a good control system architecture for a large facility should be maintainable, robust, easy to scale and efficient:

- Maintainable. A good architecture should be easy to describe and deploy automatically. It needs to be based on a limited number of standards and reliable technologies. Those technologies should be proven and tested, supported and maintained by a vendor or a community or both, being positive if they are easy to share. Moreover, the system must be prepared to fit new technological challenges.
- Robust. The control system must have an agile and secure response to fault events, including fault tolerance early error detection and fast recovery.
- Easy to scale. Adding new elements and plant changes to accomplish control system upgrades.
- Efficient. Use the resources efficiently and maintain low energy consumption.

Additionally, taking into account the very particular necessities for large scientific facilities, the use of open source technologies is very valuable.

Virtualization with VMs cover almost all of these characteristics, facilitating the maintenance of large control systems. However, as reported in [4, 6], they need a long period for recovery from serious faults as machine crash. Also, they do not use the machines resources in the most efficient way, because they need to implement an Hypervisor for every VM.

On the other hand, Container based virtualization covers the control system requirements, using the resources in a more efficient way. Moreover, the use of containers in combination with a container orchestration tool can overcome also the slow fault recovery. This work discusses the application of containerized solutions in accelerators, analyzing the existing solutions and a possible valid architecture.

It is worth stating that low level control system does not fit with the mainstream containerization philosophy. It is more focused on Cloud and microservices. However, there are efforts focused on that, as in [7].

CONTAINERIZATION

Containerization (or operating system-level virtualization) is a method of virtualization that enables a layer of isolation creating different user-spaces instances in the same kernel.

There are different container technologies: Docker, LXC, OpenVZ, BSD Jails, Solaris Zones, Turbo, etc[2]. Most of the large scientific facilities (LHC, ITER, SNS, CHSNS, KEK,...) relay on Linux as their main Operating System, so we will focus the discussion on Linux based containers.

In Linux, containerization is based on the creation of user-spaces instances, at the kernel level. It is done via two kernel components: *namespaces* and *cgroups*. Namespaces divide the operating system into virtual segments. While cgroups can apply constraints, or limitations, to system resources [8].

Among the containers based on Linux, the most popular are: Docker, Flockport (LXC) and Rocket (rkt).

In [9] the authors compare mainly Docker and LXC stating that Docker is better at computation time, memory throughput and network I/O performance. While LXC is better at Disk I/O performance.

Both of them report no over-heads on memory utilization or CPU, whilst I/O and operating system interactions incurred some ones. That means, as expected, that containers are a good lightweight option for virtualization.

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[1] Note that the scope of this paper evolves very rapidly, so a lot of information is not yet available through peer reviewed papers. Consequently, some of the references and the information is taken from specialized webpages.

[2] https://en.wikipedia.org/wiki/Operating-system-level_virtualization

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DEVELOPMENT OF NICA CONTROL SYSTEM: ACCESS CONTROL AND LOGGING

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Abstract

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex being constructed at the Joint Institute for Nuclear Research (Dubna, Russia). It will provide heavy ion colliding experiments to study properties of dense baryonic matter. The TANGO based control system of the NICA complex is under development now. The report describes design of the role-based authorization and logging system. It allows limiting access to any Tango device command or attribute according to a user roles and location. The system also restricts access to the Tango database and records details of its modifications. The authorization is performed on the Tango server side thus complementing the native TANGO client-side access control. First tests of the system were performed during the latest Nuclotron run.

INTRODUCTION

NICA accelerating complex is currently under construction in Joint Institute for Nuclear Research, Dubna, Russia. The complex will consists of heavy-ion and polarized particles sources, RFQ injector, heavy- and light-ion linear accelerators, superconducting booster synchrotron, Nuclotron and two superconducting collider rings [1]. The first stage of the accelerator complex will start its operation in the end of 2018 year in start-up configuration which includes full injection complex, Booster synchrotron, upgraded Nuclotron synchrotron and BM@N detector. The final configuration of the NICA complex including NICA collider and MPD detector will start the operation in 2023 providing design luminosity of $1.0\cdot10^{27}$ cm^{-2}s^{-1} in $^{197}Au^{79+}$ collisions.

The TANGO controls [2] based control system is being developed at JINR [3]. The control system of the NICA complex aims at accomplishing few main tasks:

- Management of large amount of equipment which is distributed on the accelerator complex area.
- Realization of different regimes of the accelerator complex working cycle – colliding or fixed target experiments, various ion types and energy.
- Strict synchronization of accelerators in the chain.
- Comprehensive beam diagnostics during the entire cycle.
- Providing protection and safety measures.

ACCESS CONTROL SYSTEM

One of the most important aspects of the control system operation is restriction of access to the control system components. It is necessary to allow access to control system software and hardware only for certain users and give them corresponding rights to perform specific tasks. Other users have to be provided with status information without ability to control the equipment.

The access restrictions can be implemented either on network level by using private networks and certain firewall configuration or on the software level. The most effective method is to combine network and software restrictions.

The software checks in TANGO control system can be implemented by:

1. Checking access control in client applications. The operator user interface can enforce an additional authentication for performing some critical operations and perform logging of the operator actions. However, this type of access control cannot prevent usage of the other client applications such as standard TANGO client ‘jive’.
2. Using native TANGO access control. It works on the client side and can restrict access to TANGO devices to certain system accounts on certain IP addresses. However, usage of system accounts limits the flexibility of the system. Also, the native TANGO access control cannot be used for the authorization of Web clients because all the requests originate from one or few REST TANGO devices running on the fixed IP addresses [4].

An additional access control system is being developed at JINR to overcome limitations of the existing solutions for a TANGO based control system. The idea is to give a TANGO device ability to check the client’s permission to execute device’s commands or access attributes. We would like to have a central database of users, their permissions and global access logs. It’s necessary to provide a simple way to implement authorization on the TANGO device side without modification of TANGO libraries. Also, the system has to implement a way to check permissions of the Web applications which communicate with TANGO control system via REST TANGO devices.

Authorization Algorithm

The proposed operation algorithm of the authorization system is shown in Fig.1. Here, a TANGO client tries to execute a command on a TANGO device. The operation of the access control system is provided by two additional TANGO devices: the authorization TANGO device and the authorization manager TANGO device.

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A WEB-BASED REPORT TOOL FOR TANGO CONTROL SYSTEMS VIA WEBSOCKETS

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Abstract

Beamlines at Synchrotron Light sources operate 24 hours/day requiring Beamline scientists to have tools to monitor the current state of the Beamline without interfering with the measurements being carried out.

The previous web report system developed at ALBA was based on cron tasks querying the Tango Control system and generating html files. The new system integrates all those automatic tasks in a Tornado Tango Device letting the users create their own reports without requiring the intervention of the software support groups.

This device runs a Tornado [1] web server providing an Html5 [2] web interface to create, customize and visualize its reports in real time (via WebSockets [3]). Originally designed for the vacuum engineers to monitor the vacuum, is actually used by the scientists and engineers involved in the experiment and the different on-call services to remotely check the beamline overall status.

REPORTS TO BE UPDATED

A report is an informational task made with the specific intention of relaying information or recounting certain events in a widely presentable and scrutinized form. Scientists and the different sections involved in a Beamline operation need the control system to provide the necessary tools to generate accurate reports with the status of the Beamlines. Moreover, these reports need to be generated constantly without interfering with the experiments that are being carried out. From the different items available to control and monitor a Beamline, the scientist or the report receiver is who decides which ones provide relevant information to be included in the report. There are already tools to create reports in file format or emails, but for those signals that need to be continuously monitored they are not efficient.

Within ALBA computing section we have improved the way to create automatic reports using a new web-based report tool. It is integrated in the Tango system through a new device server, the Tornado DS, which acts as a gateway between all the devices in the database and the report tool. The control system engineers have just to install and run the device server and then the scientist or other report client can easily create their own html reports. Reports are refreshed automatically and periodically. They can contain strings, numbers, curves or trends, which are automatically displayed according to the data type selected to be displayed.

HOW IT WORKS

The Tango Device Server inherits from Dynamic DS, so it contains all its properties, attributes and functions from its parent class, like the dynamic creation of attributes. This feature allows the creation of new attributes dynamically with formulas that may or may not depend on the values of other attributes available in other device servers within the same database. These dynamic attributes can be included manually using Tango tools or easily added from the HTML form provided with the Tornado DS server.

When the Tornado DS starts, an independent thread is responsible to periodically collect not only the values for the dynamic attributes, but also their label, quality or unit. The collected data is sent to the available clients in JSON [4] format to refresh its contents on the HTML page. The result is the default page provided with the Tornado DS shown in Figure 1.

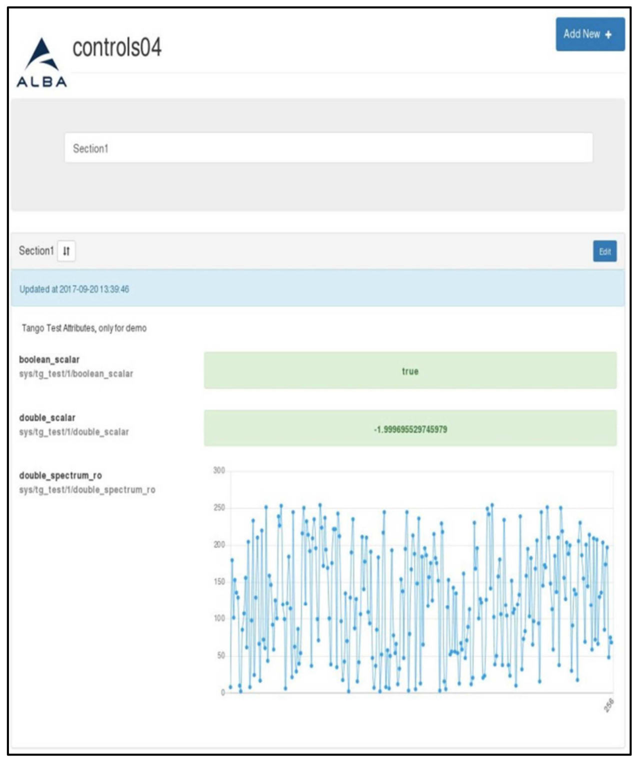

Figure 1: Default Tornado DS index page.

The default web page provided is divided by sections. All defined sections are available in the same page, and if needed, the can be hidden individually. Each section has a name, description and a set of attributes that are periodically refreshed. These attributes are shown with its label, unit and value, but also with a different background colour depending on the attribute quality. New sections can be added, removed or edited easily from the main page as shown in Figure 2: Edit, add or

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CUMBIA: A NEW LIBRARY FOR MULTI-THREADED APPLICATION DESIGN AND IMPLEMENTATION

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Abstract

Cumbia is a new library that offers a carefree approach to multi-threaded application design and implementation. Written from scratch, it can be seen as the evolution of the *QTango* library [1], because it offers a more flexible and object oriented multi-threaded programming style. Less concern about locking techniques and synchronization, and well defined design patterns stand for more focus on the work to be performed inside *cumbia activities* and reliable and reusable software as a result. The user writes *activities* and decides when their instances are started and to which thread they belong. A token is used to register an *activity*, and activities with the same token are run in the same thread. Computed results can be forwarded to the main execution thread, where a GUI can be updated. In conjunction with the *cumbia-tango* module, this framework serves the developer willing to connect an application to the TANGO control system. The integration is possible both on the client and the server side. An example of a TANGO device using *cumbia* to do work in background has already been developed, as well as simple *QT* [2] graphical clients relying on the framework.

COMPONENTS

Cumbia Modules

Cumbia is a set of distinct modules; from lower to higher level:

- *cumbia*: defines the *Activities*, the multi thread implementation and the format of the data exchanged between them;
- *cumbia-tango*: integrates *cumbia* with the TANGO control system framework, providing specialised *Activities* to read, write attributes and impart commands;
- *cumbia-epics*: integrates *cumbia* with the EPICS control system framework. Currently, only variable monitoring is implemented;
- *cumbia-qtcontrols*: offers a set of *QT* control widgets to build graphical user interfaces. Inspired by the *QTango*'s *qtcontrols* components, they have been enhanced and sometimes rewritten to look more stylish and friendly. The module is aware of the *cumbia* data structures though not linked to any specific engine such as *cumbia-tango* or *cumbia-epics*.
- *qumbia-tango-controls*: written in *QT*, is the layer that sticks *cumbia-tango* together with *cumbia-qtcontrols*;
- *qumbia-epics-controls*: written in *QT*, the component pairs *cumbia-epics* to *cumbia-qtcontrols*.
- *qumbia-apps*: a set of applications written in QT that provide elementary tools to read and write values to the TANGO and EPICS control systems.

Combining together the modules allows to instantiate a control system engine and build command line or *QT* graphical user interfaces effortlessly. Engines can coexist within the same application to seamlessly control devices belonging to separate control systems. Figure 1 shows how modules are interrelated.

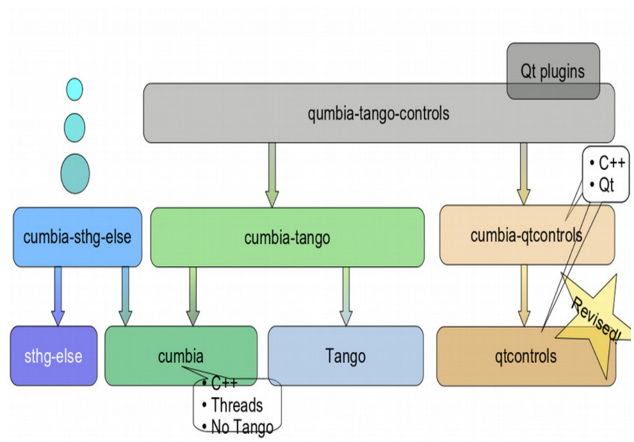

Figure 1: Relationships amongst *cumbia* modules.

CUMBIA

Cumbia is the name of the lower layer of the collection, as well as the name of a single object every application must hold in order to use its *services*.
In asynchronous environments, *threads* have always posed some kind of challenge for the programmer. Shared data, message exchange, proper termination are some aspects that cannot be overlooked. The *Android AsyncTask* [3] offers a simple approach to writing code that is executed in a separate thread. The API provides a method that is called in the secondary thread context and a couple of functions to post results on the main one.

Activities

Cumbia *CuActivity*'s purpose is to replicate the carefree approach supplied by the *AsyncTask*. In this respect, a *CuActivity* is an interface to allow subclasses to do work within three specific methods: *init*, *execute* and *onExit*. Therein, the code is run in a separate thread. The *publishProgress* and *publishResult* methods hand data to the main thread. To accomplish all this, an *event loop* must be running. By an initial parametrization, either a custom one (such as *QT*'s, used in *qumbia-qtcontrols*) or the builtin *cumbia CuEventLoop* can be installed. New activities must be registered in the *CuActivityManager* service, and unregistered when they are no longer needed. In this way, a *token* can be used to group several activities by a smaller number of threads. In other words, activities with the same token run in the same thread. Thread

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STATUS OF THE DEVELOPMENT OF THE EXPERIMENT DATA ACQUISITION PIPELINE FOR THE EUROPEAN SPALLATION SOURCE*

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Abstract

The European Spallation Source will produce more data than existing neutron facilities, due to higher accelerator power and to the fact that all data will be collected in event mode with no hardware veto. Detector data will be acquired and aggregated with metadata coming from sources such as sample environment, choppers and motion control. To aggregate data we will use Apache Kafka with FlatBuffers serialisation. A common schema repository defines the formats to be used by the data producers and consumers. The main consumers we are prototyping are a file writer for NeXus files and live reduction and visualisation via Mantid. A Jenkins-based setup using virtual machines is being used for integration tests, and physical servers are available in an integration laboratory alongside real hardware. We present the current status of the data acquisition pipeline and results from the testing and integration work going on at the ESS Data Management and Software Centre in collaboration with in-kind and BrightnESS partners.

INTRODUCTION

The European Spallation Source (ESS) is a spallation neutron source currently being built in Lund, Sweden. It will operate as a user facility offering a high brightness neutron beam in long pulses that can be tailored for adjusting resolution and bandwidth [1].

Located in Copenhagen, Denmark, the ESS Data Management and Software Centre (DMSC) is developing software for the experiment data acquisition pipeline in collaboration with the Science and Technology Facilities Council (STFC), as an in-kind partner, and Paul Scherrer Institut (PSI) and Elettra as part of the BrightnESS project [2]. This pipeline will transport and transform data from sources in the instrument, including neutron detectors and EPICS servers, to software performing tasks such as live experiment feedback and file writing. In the following sections, we discuss the architecture and components of the data acquisition pipeline, their current status and the tests being used to evaluate them, and present the conclusions and plans for future work.

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Event Mode Acquisition

Instrument data at ESS will be acquired mainly in event mode, i.e., each neutron that is detected generates a pair of pixel identifier (ID) and timestamp values, where the ID corresponds to the location of the neutron in the detector. In this approach, in contrast with acquisition in histograms, the list of individual events is stored for subsequent experiment steps, such as data reduction and analysis; this allows the user to create histograms using different criteria, if desired. In addition, there will be no hardware veto for automatically stopping acquisition in case of chopper phase errors. Accelerator pulse information and the chopper top dead centre (TDC) signals will be acquired and attached to the datasets, allowing filtering to happen during the data reduction step.

Due to the high brightness beam and event mode acquisition, experiments at ESS will generate large volumes of data. Table 1 shows anticipated neutron event rates for some ESS instruments [3]. The proposed architecture for the data acquisition pipeline addresses these requirements with parallelisation and a clustered approach to data aggregation.

Table 1: Anticipated Neutron and Detector Rates for Some Early ESS Instruments

Instrument	Rate on Sample [n/s]	Rate on Detector [Hz]	Data Rate [MB/s]
BEER	10^9	2×10^5	1.6
C-SPEC	10^8	2×10^5	1.6
DREAMS	3.4×10^8	10^7	80
ESTIA		10^8	800
FREIA	5×10^8	1.2×10^7	96
HEIMDAL	2×10^9	8×10^6	64
LOKI	$\leq 10^9/\text{cm}^2$	4×10^7	320
SKADI	$\leq 10^9/\text{cm}^2$	4×10^7	320
T-REX	10^8	2×10^5	1.6

THE DATA ACQUISITION PIPELINE

ESS instruments will use an aggregator-based data acquisition pipeline. Apache Kafka was chosen as the central technology for aggregation and streaming, using Google FlatBuffers for serialisation. In this architecture, producers and consumers of data are decoupled and exchange data through the aggregator. Figure 1 shows an overview of the

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ABSTRACTED HARDWARE AND MIDDLEWARE ACCESS IN CONTROL APPLICATIONS

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R. Steinbrück, M. Kuntzsch, HZDR, Dresden-Rossendorf, Germany
P. Prędki, Rapid Development, Łódź, Poland
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Abstract

Hardware access often brings implementation details into a control application, which are subsequently published to the control system. Experience at DESY has shown that it is beneficial for the software quality to use a high level of abstraction from the beginning of a project. Some hardware registers for instance can immediately be treated as process variables if an appropriate library is taking care of most of the error handling. Other parts of the hardware need an additional layer to match the abstraction level of the application. Like this development cycles can be shortened and the code is easier to read and maintain because the logic focuses on what is done, not how it is done.

We present the abstraction concept we are using, which is not only unifying the access to hardware but also how process variables are published via the control system middleware.

INTRODUCTION

With the advent of the MicroTCA.4 standard it was possible to combine powerful, FPGA based computations with precise analogue electronics on comparatively large rear transition modules. [1] This allowed to implement a compact, fully digital control of the low level radio frequency signals (LLRF) at the FLASH accelerator. [2] The new, modular hardware platform had the need for a user space library to access the individual boards in the crate. Starting with PCI Express, which is used in MicroTCA.4, the DeviceAccess library became the basis of the *MicroTCA.4 User tool kit (MTCA4U)*. With its modern C++ interface, which abstracts the details of hardware access, the library was soon extended to Ethernet-based protocols and outgrew the original scope of only being used in MicroTCA crates. Consequently the software suite was renamed to *ChimeraTK (Control system and Hardware Interface with Mapped and Extensible Register-based device Abstraction Tool Kit)*.

The digital LLRF at FLASH was very successful and other facilities also started to use MicroTCA based systems for the accelerator controls. This brought the challenge that the complex device server has to be supported for multiple control system and middleware frameworks. The ControlSystemAdapter was introduced to decouple the application logic from the specifics of a particular control system and improve code reusability and maintainability.

Although starting as two separate libraries, the abstraction concepts for the DeviceAccess library and the ControlSystemAdapter were very similar. In the past year, their interfaces were unified and a new library called ApplicationCore was created. It is the consistent continuation of the abstraction process and facilitates the creation of device server applications in a control system independent way.

THE DeviceAccess LIBRARY

One of the main concepts of the DeviceAccess interface is the introduction of so called register accessors. These objects behave like a scalar integer or floating point variable in the user code, or an iterable one or two dimensional container of these data types, with additional functions to read from and write to the device. The accessor automatically allocates a data buffer of the correct size, does necessary data type conversions and takes care of implementation details like handshakes with the hardware.

An important abstraction step is the identification of registers by name. When creating the register accessor, the application is using a functional name instead of the numerical address in the I/O memory. This allows to not only access numerically addressed registers, but also process variables on another device servers, like a *DOOCS property* or an *EPICS channel*. Numerically addressed device backends require a name mapping table, which can also contain additional information like conversion parameters from a fixed point data format used on the hardware to floating point data types used on the CPU running the device server. For the firmware used at DESY this mapping is automatically generated. Register names can have a tree structure by separating hierarchy levels with a slash ('/'). Like this registers can be grouped into directories like in a (UNIX) file system. Firmware can now be implemented in a modular way with each functional block providing registers in a directory, and placing the same module twice does not cause naming conflicts, while the software accessing each block still finds all the register it needs in one directory. The `Device` interface provides a catalogue which lists all registers it can access.

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MANAGEMENT SOFTWARE AND DATA EXCHANGE PROTOCOL FOR THE INFN-LNS ACCELERATORS BEAMLINES

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Abstract

This paper describes the design and the development of an innovative management software for the accelerators beamlines at INFN-LNS. The Graphical User Interface, the data exchange protocol, the software functionality and the hardware will be illustrated. Compared to traditional platforms for the accelerators console, at INFN-LNS we have developed a new concept of control system and data acquisition framework, based on a data structures server which so far has never been used for supervisory control. We have chosen Redis as a highly scalable data store, shared by multiple and different processes. With such system it is possible to communicate cross-platform, cross-server or cross-application in a very simple way, using very lightweight libraries. A complex and highly ergonomic Graphic User Interface allows to control all the parameters with a user-friendly interactive approach, ensuring high functionality so that the beam operator can visually work in a realistic environment. All the information related to the beamline elements involved in the beam transport, can be stored in a centralized database, with suitable criteria to have a historical database.

INTRODUCTION

In a complex and heterogeneous environment, like the LNS beamlines, is very important to have a clear and powerful synoptic which helps the operators in their work of beam transportation.

For this purpose, we developed a complex and highly ergonomic Graphical User Interface, that allows to control all the parameters adopting a user-friendly interactive approach, so that the beam operator can visually navigate through a pseudo-realistic beamline reproduction. The modular approach of this platform allows to build and modify all the beamlines, just adding/removing all the elements, that can be managed individually.

The users that transport the beam can therefore set and read all the setting parameters, thanks to a continuous communication with the field level. The data communication has been realized following a new concept of control system and data acquisition framework, based on a data structures server which so far had never been used for supervisory control.

The beamline consists of different devices from different vendors and for this reason a standard protocol for data exchange has been developed.

We have chosen Redis [1] as a highly scalable data store, shared by multiple and different processes and applications. This system easily allows cross-platform, cross-server and cross-application communication, using extremely lightweight libraries.

We decided to call our system E.T.N.A., acronym of Enhanced Transport Network for Accelerators.

SYSTEM ARCHITECTURE

The system architecture is composed by three level, as shown on Figure 1. The field level is composed by all sensors, PLCs and field machines of the beamlines. The user interfaces aim to provide control and monitoring of the beamline to operators. In the middle of this architecture we have the core of our system, the REDIS online DB, used for data exchange from both field level and the GUIs.

The middle tier also hosts a MySQL server for static data storage and we have a certain degree of fault-taulerance by using Linux-HA and DRBD. Linux-HA is a clustering solution that provides reliability, availability and serviceability. In our architecture we have two identical servers, a master and a slave, which ensure that the services running on one of them can be automatically moved and restarted in the backup's node.

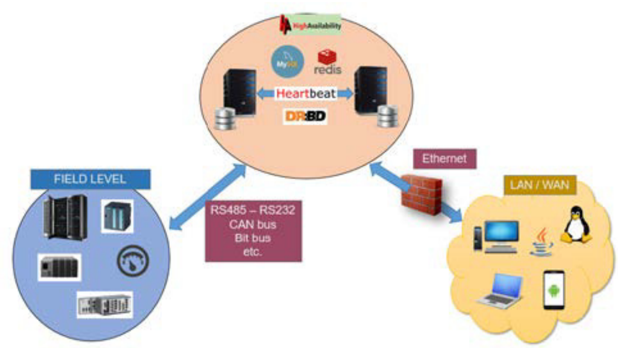

Figure 1: System architecture.

Cluster infrastructure services are implemented via Heartbeat. This daemon allows clients to know about the presence or disappearance of peer processes on other machines and to easily exchange messages with them. The Heartbeat daemon must be combined with a cluster resource manager, which has the task of starting and stopping the services that cluster will make highly available. We used Pacemaker that is the preferred cluster resource manager for clusters based on Heartbeat.

THE CONSOLE GUI

The local console GUI, queries the in-memory database through a polling procedure and gets the data coming

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DEVELOPMENT OF POST-MORTEM VIEWER FOR THE TAIWAN PHOTON SOURCE

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Abstract

The Taiwan Photon Source (TPS) is a 3-GeV third-generation synchrotron light source located in Hsinchu, Taiwan. The post-mortem (PM) system is act as an important tool to diagnostic the cause of trip events caused by beam loss. A MATLAB-based and web-based viewer were developed to plot and view the each event to understand the cause and effect of the event. The post-mortem viewer architecture and implementation were presented in this report.

INTRODUCTION

The TPS is available for user service. During the operation, inevitably there will be unexpected beam trips due to subsystem failure or other abnormal circumstances. Some of the subsystem interlocks, like the BPM orbit (position and angle), vacuum, front-end and beam line interlocks need to shut down the RF system for machine protection. It is possible to find out the reason for such an event by using the beam trip post-mortem (PM) system. The PM system can record the relevant signals from the subsystem when a beam trip occurs. It also can automatically generate beam trip reports and perform a simple analysis of the recorded signals to give possible event identification. So far, typical beam trip events include RF trips, sub-system interlock trips, and spontaneous kicker firings. Several trip scenarios can be found in reference [1]. A MATLAB-based and web-based viewer were developed to plot and view the each event to understand the cause and effect of the event. The MATLAB-based viewer has the full functionality to display the data. The web-based viewer allowing for a quick review of the trip event through the web browser. The post-mortem viewer architecture, plans and implementation were presented in this report

SYSTEM DESCRIPTION

The architecture of the TPS PM system is shown in Fig. 1. The system includes the beam trip detector, EPICS embedded standalone data recorders, data storage server and viewer. The main system features are the following: generate a trigger signal to data recorders when the stored beam current is lost abnormally; record relevant signals to server when a beam trip occurs; view the report from the GUI tool or web browser to analyze each event for cause and effect. The data storage server is used to store PM data and generate report, and provides FTP and HTTP services for PM Viewer and web page access. The report generator process is used to create an html file format report and writes the event description to the database for web page access. The flow char of the save program is shown in Fig. 2. A complete overview can be found in reference [2].

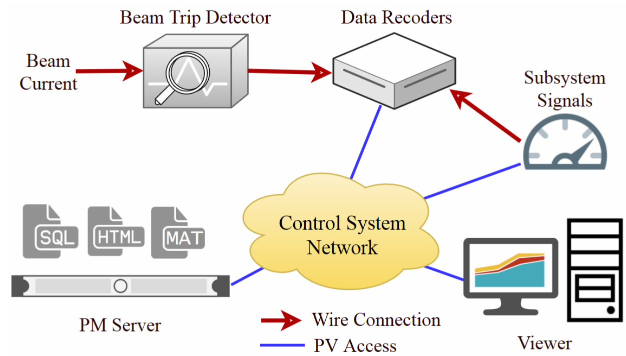

Figure 1: Schematic layout of the TPS PM system.

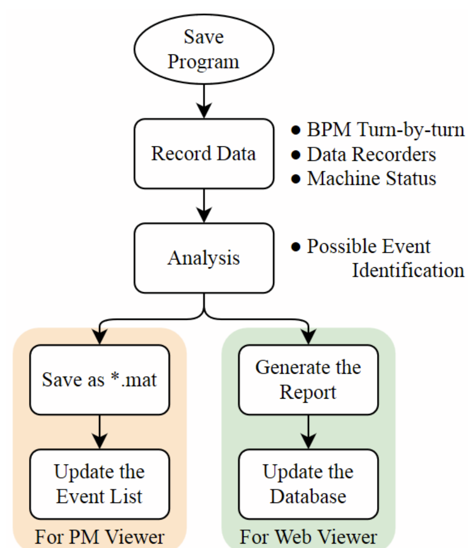

Figure 2: Flow char of the save program.

POST-MORTEM VIEWER GUI

PM Viewer

The PM Viewer GUI is designed to list and plot beam trip events and the graphic user interface is developed with the Matlab's GUI-building tool (Graphical User Interface Development Environment, GUIDE) as shown in Fig. 3. It can list the beam trip event with a simple note and provide a signal list check box to select for display the desired data, which can be downloaded from the server using the FTP protocol. The flow char of the plot function is shown in Fig. 4. Figure 5 shows that the vacuum interlock is active during 400 mA operation. The RF system is shut down within a few milliseconds. Finally, the BPM position interlock is active. Some kickers were unexpectedly fired without system trigger signal, causing an instant loss of the electron beam, as shown in Fig. 6. A customized toolbar can provide simple data adjustment functions as shown in Fig. 7.

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WEB EXTENSIBLE DISPLAY MANAGER*

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Abstract

Jefferson Lab's Web Extensible Display Manager (WEDM) allows staff to access EDM control system screens from a web browser in remote offices and from mobile devices. Native browser technologies are leveraged to avoid installing and managing software on remote clients such as browser plugins, tunnel applications, or an EDM environment. Since standard network ports are used firewall exceptions are minimized. To avoid security concerns from remote users modifying a control system, WEDM exposes read-only access and basic web authentication can be used to further restrict access. Updates of monitored EPICS channels are delivered via a Web Socket using a web gateway. The software translates EDM description files (denoted with the *edl* suffix) to HTML with Scalable Vector Graphics (SVG) following the EDM's *edl* file vector drawing rules to create faithful screen renderings. The WEDM server parses *edl* files and creates the HTML equivalent in real-time allowing existing screens to work without modification. Alternatively, the familiar drag and drop EDM screen creation tool can be used to create optimized screens sized specifically for smart phones and then rendered by WEDM.

INTRODUCTION

WEDM employs native web technologies including Web Sockets, HTML 5 and SVG to deliver faithful renderings of control system EDM screens for remote users who can view them using nothing more than a web browser. The ease at which screens can be viewed facilitates on call troubleshooting and off-site monitoring of control systems. Figure 1 illustrates an EDM controls screen rendered in a browser via WEDM.

The initial goals for the deployment of WEDM include (1) enable improved response times of the accelerator support personnel (reduce the Mean Time To Repair, MTTR, improve system availability), (2) reduce the number of staff granted accounts on control system workstations, and (3) reduce the number of special-purpose EPICS kiosks in use.

Improved Response Time

With WEDM available, a support personnel alerted to a problem need no longer have access to a full-blown PC with network access dependent upon 2-factor hardware authentication in order to view screens. As long as cellular service or Wi-Fi is available, identical menus and screens as available to the control room operator are accessible through any web browser. Even without the ability to make changes directly, they can provide diagnosis and guidance or even walk the operator through making changes to specific settings.

Fewer Control System Computer Accounts

Prior to WEDM, it was necessary to grant users full accounts on control system workstations in order to run EDM and view screens. A significant number of these users have no need to update settings and can now access their screens via the web simply using their standard JLab username and password. For example, the facilities management department is switching from expensive proprietary monitoring software to EPICS for monitoring their gas, water, and electricity meters. These users will rely on WEDM to view the outputs of their meters.

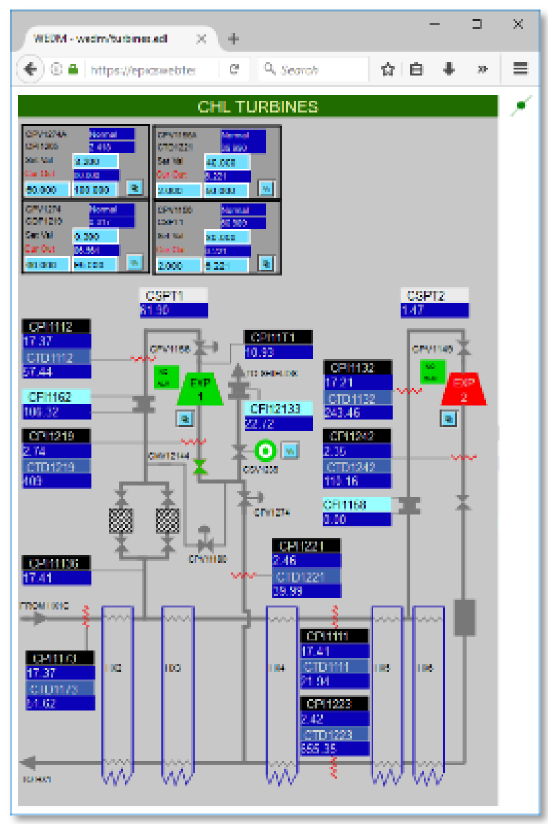

Figure 1: An EDM screen rendered in WEDM.

Reduce Reliance on EPICS Kiosks

A number of EPICS "kiosks" exist at Jefferson Lab. These include a dedicated xterm that allows security guards to monitor special alarm screens at times of year when the control room is not staffed, as well as a number of xterms on roll-around carts in service buildings and tunnels. It is envisioned that over time the number of these

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AN INTERACTIVE WORKFLOW TO MANAGE TOMOGRAPHY EXPERIMENTS AT ESRF

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Abstract

At the ESRF the activity of several beamlines is based upon tomography X-ray imaging in various fields such as Paleontology, Medical Imaging and Materials Science. The instrument control and data processing systems are cloned on all the relevant beamlines, however the steps of the processing pipeline from the data acquisition to their full exploitation in high quality publications are based upon a heterogeneous stack scenario comprised of e.g. SPEC, Python, Octave, PyHST2 and MATLAB modules. The need has clearly appeared to logically sequence the operations performed by these different actors as user-friendly workflows. At the ESRF we selected a generic workflow tool, Orange, originally developed at the University of Ljubljana and designed for data mining in collaboration with the open source community. The graphical interface enables the easy inclusion/exclusion of functionalities represented by individual boxes. Each box can be managed by simple Python code generating graphical interfaces via the PyQt5 library and is defined by a set of inputs and outputs which can be linked together to produce consistent data processing workflows.

Figure 1: TOMWER logo.

INTRODUCTION

Tomography experiments require a set of treatments during acquisition to control the images and to prepare the post-processing. Those treatments are time consuming if repeated frequently.

The goal of TOMWER (see Fig. 1) is to offer a tool able to automate a part of the acquisition and reconstruction processes on ESRF Tomography beamlines. TOMWER stands for "TOMography Workflow EsRf".

One of the objectives is also to divide these treatments into common atomic processes. Processes can be associated together to create a workflow defining a complex treatment.

Due to the complexity of the treatment and the long history to develop the routines, the software have been developed in a large variety of languages such as Octave, MATLAB, Python, etc. Due to lack of resources it is not possible to envisage rewriting all these codes. On top of this many users/developers at the ESRF do not have knowledge of all these languages, most have knowledge about Python programming. This is why it has been decide to use Python as the glue language.

To let users define their own workflows we chose the Orange [1] canvas. The user-friendly interface for defining workflow was the first reason of this choice. Moreover Orange offers some key functionality like help, checks on input and output types for each connection and the packaging.

Despite the fact that we decided to create an Orange3 add-on for TOMWER, each process is accessible without the Graphical User Interface.

In order to fit some of our needs we had to fork the Orange3 original project. Only small modifications have been made, especially to allow cycling inside a workflow. We hope to move those modifications into the Orange3 core project to facilitate maintenance in the future.

The fork of the original Orange3 project can be found in [2].

The TOMWER project is distributed under the MIT license. Orange3 follows the GNU General Public License v3.

The TOMWER add-on and the library are also strongly based into the silx toolkit [3]. This library offers a set of tools to simplify development of data analysis applications. This work particularly benefits from the I/O functionalities and the visualization widgets.

DESIGN

Architecture

The two main packages of the TOMWER project are:

- The 'core' package which groups core functionalities and has no dependency on Orange3.
- The 'widgets' package where classes inheriting from 'OWWidget' (Orange3 widget) are stored.

As we have a graphical user interface and as some treatment can be time consuming we decided to design the application to be multithreaded.

The application for tomography manages data buffering and synchronization in order to speed up treatment.

Process Definition

Each step of the workflow corresponds to a single atomic data treatment and is graphically represented by an orange3 box. This treatment is also characterized by input(s) and output(s). When the orange3 box receives an input/signal it executes the tool action and can emits one or more output/signal. This is the Orange3 design.

The list of inputs and outputs is defined in Table 1.

Signals between tools are designed by Qt signals. Connection between two tools is technically a Qt signal (output emitted) and a Qt slot (input 'received') connected together.

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INSPECTOR, A ZERO CODE IDE FOR CONTROL SYSTEMS USER INTERFACE DEVELOPMENT

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Abstract

Developing operational User Interfaces (UI) can be challenging, especially during machine upgrade or commissioning where many changes can suddenly be required. An agile Integrated Development Environment (IDE) with enhanced refactoring capabilities can ease the development process.

Inspector is an intuitive UI oriented IDE allowing for development of control interfaces and data processing. It features a state of the art visual interface composer fitted with an ample set of graphical components offering rich customization. It also integrates a scripting environment for soft real time data processing and UI scripting for complex interfaces.

Furthermore, Inspector supports many data sources. Alongside the short application development time, it means Inspector can be used in early stages of device engineering or it can be used on top of a full control system stack to create elaborate high level control UIs.

Inspector is now a mission critical tool at CERN providing agile features for creating and maintaining control system interfaces. It is intensively used by experts, machine operators and performs seamlessly from small test benches to complex instruments such as LHC or LINAC4.

INTRODUCTION

In a constantly evolving research environment, changes in software may be indispensable for the control of new machines. Software can become outdated with the introduction of new technologies or advancements that facilitate usage and provide improved features.

Complex systems in accelerators require intricate software that requires proper maintenance and updates. Furthermore, software in accelerators are mostly developed in the scope of a Team or Department for a specific apparatus using local knowhow. Developing this kind of software may require users to participate in the software development in conjunction with the developers. Users may lack the availability or skills to profoundly help the development of software, potentially leading to poorly developed applications or applications that do not fulfil the needs of stakeholders.

Therefore, and with the increasing number of unique software applications, the combined time and cost of maintaining and developing software is becoming too high. UI software requires large amounts of graphical user interface (GUI) related code, increasing the development cost and restricting the skills necessary to create adequate user control interfaces.

Inspector proposes a separation between the UI and the software technology, essentially allowing the creation of zero code applications in order to diminish the cost of developing and maintaining such applications.

ZERO CODE CONCEPT

Following the *What You See Is What You Get* (WYSIWYG) approach, Inspector introduces a visual IDE for the development of UI control applications. It applies the concept of abstracting the application from the underlying technology. It requires no code in the creation of applications. This approach means that Inspector allows the creation of UI control applications simply by using visual tools. As such, users can perform changes to Inspector-created applications or even create full applications without the involvement of developers and without coding skills.

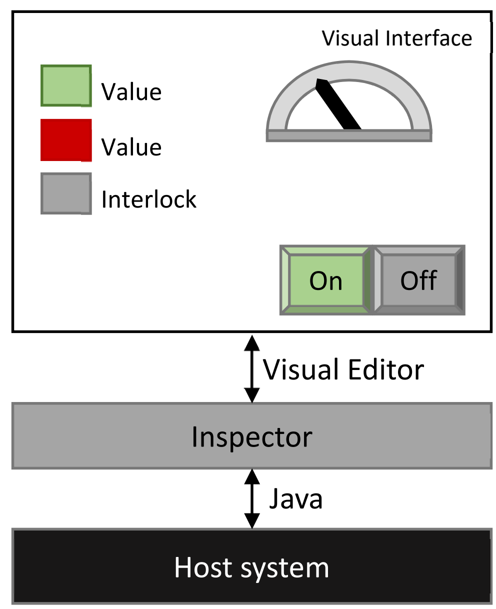

Figure 1: Integration between interface and system.

The creation of Inspector applications allows users to concentrate their efforts on the data presentation, rather than on implementation details. Inspector takes responsibility of making the applications portable, within the production environment. It also provides graphical tools for the creation of the user interfaces, along with accurate UI elements to present many types of data. As illustrated in Fig. 1, Inspector acts as an abstraction layer between the visual interfaces of control applications and the rest of the system, including any frameworks used.

Applications created with Inspector are independent of the base technology, meaning that any maintenance in regards to technology or frameworks is not handled by the user/developer but solely by Inspector. Any changes must

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JAVAFX CHARTS: IMPLEMENTATION OF MISSING FEATURES

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Abstract

JavaFX, the GUI toolkit included in the standard JDK, provides charting components with commonly used chart types, a simple API and wide customization possibilities via CSS. Nevertheless, while the offered functionality is easy to use and of high quality, it lacks a number of features that are crucial for scientific or controls GUIs. Examples are the possibility to zoom and pan the chart content, superposition of different plot types, data annotations, decorations or a logarithmic axis. The standard charts also show performance limitations when exposed to large data sets or high update rates.

The article will describe how we have implemented the missing features and overcome the performance problems.

JAVAFX CHARTING PACKAGE

JavaFX is a software platform enabling creation of rich client applications. It includes a charting package with Pie Chart and a set of most commonly used XY charts such as Area Chart, Bar Chart, Line Chart or Scatter Chart. Each chart is represented by a class and can be styled using Cascading Style Sheets (CSS) and dedicated style classes [1], in a similar way as all the other JavaFX components.

Although the JavaFX charting package allows developers to create sophisticated and well-looking charts that are sufficient for typical business applications, it misses a number of built-in features that are essential for scientific tools used for data visualisation and analysis.

Missing Features

One missing piece of functionality is an easy, graphical way of zooming, i.e. by drawing a bounding box with mouse cursor. For charts containing a significant number of points, it is usually a *must have* feature that users just expect to be there.

Also, JavaFX does not provide an easy way for developers to add custom graphical elements on top of their charts. Examples are data point annotations, lines and rectangles defining limits, text labels or other decorations that help in interpretation and enrich the displayed data.

Other missing features that are commonly used in the controls domain include logarithmic scales, the possibility of mixing different plot types on a single chart or a heatmap chart used to display particle beam images.

Most of the aforementioned features are present in the list of possible enhancements for OpenJFX [2] but up to and including Java 10 there are no plans of the JavaFX team to actually implement them.

CERN CHART EXTENSIONS

Motivation

Lacking the required functionality, we faced a choice between either implementing it ourselves or using a 3rd party library that would support it.

As of today, the only suitable open source library is *JFreeChart* [3] in combination with *FXGraphics2D* [4]. The rich set of functionality offered by *JFreeChart* comes with a relatively steep learning curve for its API. Most of our non-professional software developers (like physicists or operators) preferred to use the standard JavaFX charting package and simpler APIs that they already knew. We wanted to avoid a hybrid approach, with JavaFX charting used for some applications and *JFreeChart* for others, as it would make long-term support and maintenance of these applications more difficult and expensive. Since the estimated development effort was not very high, we decided to implement it, with an idea of making it open sourced and available for the JavaFX community.

XYChartPane

The central class of the package is *XYChartPane*. In several aspects, it is similar to the standard JavaFX *StackPane*, which lays out its children in a back-to-front stack, but is specialized to lay out instances of *XYChart* and to manage nodes belonging to custom chart plugins (see next section for details).

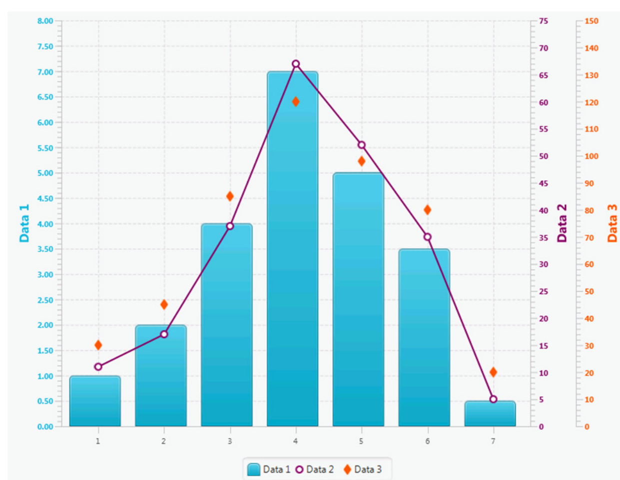

Figure 1: XYChartPane with different chart types.

The main (base) chart must be specified at the construction of *XYChartPane* but the additional charts, drawn on top of each other (see Fig. 1), can be added and removed at any moment via exposed observable list of overlay charts.

All the overlay charts use the X-axis of the base chart. They may also share the common Y-axis of the base chart

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ENHANCING THE MxCuBE USER INTERFACE BY A FINITE STATE MACHINE (FSM) MODEL

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Abstract

The acquisition of X-ray diffraction data from macromolecular crystals is a major activity at many synchrotrons and requires user interfaces that provide robust and easy-to-use control of the experimental setup. Building on the modular design of the MxCuBE beamline user interface, we have implemented a finite state machine model that allows to describe and monitor the interaction of the user with the beamline in a typical experiment. Using a finite state machine, the path of user interaction can be rationalized and error conditions and recovery procedures can be systematically dealt with.

INTRODUCTION

EMBL Hamburg operates two beamlines, P13 and P14, for macromolecular X-ray crystallography (MX) on the PETRA III synchrotron at DESY (Hamburg, Germany). On both beamlines, MxCuBE [1] is used as the user interface. While in MX, a large fraction of data collections are considered as 'measurements' and are often conducted by non-experts, still many data collections can be considered as 'experiments' in which a fine control of data collection parameters is required to obtain usable data. Both aspects require the user interface to be robust and easy-to-use for measurements while providing flexibility and deeper control for experiments. To make the control of the beamlines more robust and intuitive from the user perspective, we have embarked on describing the interaction of the user with the beamline as a finite state machine (FSM). An FSM is a mathematical model of a closed or open loop discrete-event system with defined states [2]. FSM-graphs are widely used to define, analyse and control the functioning of system. Applications include software engineering and experimental control systems. For example, state graphs are used in Large Hadron Collider experiments at CERN [3, 4] and in data acquisition system at the European X-ray free-electron laser: Karabo SCADA framework [5]. For the case of controlling an experiment/measurement on an MX beamline, the modularity and clean separation between low-level hardware access and the graphical interface within MxCuBE allows implementing an FSM model into the main experimental cycle. Important features of using an FSM are the ability to have an overview of all relevant beamline components, to keep track of user actions, and to guide users and/or beamline staff in case of failure or alarm.

USE CASE

A highly-simplified typical user interaction with a macromolecular crystallography (MX) beamline for the collection of diffraction data includes mounting the sample onto a sample positioning device (goniometer), centering of the sample with respect to the X-ray beam, setting of the data collection parameters, triggering of the data collection, execution of the data collection which consists of rotating the sample in the X-ray beam, and finally unmounting of the sample. The MxCuBE graphical user interface (GUI) for MX beamlines contains numerous widgets to control the settings of the beamline hardware including X-ray energy, beam attenuation factors, size and shape of the X-ray beam, distance between the sample and X-ray detector, and others (Fig. 1). To facilitate sample centering, the user interface offers a life view of the sample and various means to position and orient the sample. The data collection parameters are set by entering numerical values for controlling sample rotation speeds, exposure times etc. The many different ways of collecting data on a given crystals and the interdependencies between different - often technically high-end and thus not ultimately stable - components of the beamline result in a highly complex system for which stable operation is not trivial to achieve. An important factor in this context is also the fact that many users of MX beamlines are inexperienced posing high requirements in terms of making the operation robust and supporting recovery from errors.

FINITE STATE MACHINE

In the case of FSM, a system can be in exactly one finite state. It can move to another state in response to defined external inputs (stimuli). An FSM is defined as a set of states and transitions, an initial state, and conditions for transitions. For a typical user interaction with the experimental GUI during an MX data collection, it is possible to indicate several common steps (transitions in the FSM graph):

1. Sample mounting on the sample positioning device (goniometer).
2. Sample centring.
3. Entry and validation of data collection parameters.
4. Execution of data collection.
5. Sample dismounting.
6. Returning to step 1.

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SOLARIS DIGITAL USER OFFICE

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Abstract

User Office is needed in any research facility providing services for users. Nowadays each facility uses tools for management of users. Digital User Office is a tool developed with collaboration with ACK Cyofnet AGH, Krakow, Poland. The project was aimed at building system with use of modern technologies, flexible enough to accommodate easily changes requires by rapid development of SOLARIS (new national synchrotron radiation center in Poland). The main features and plans for development will be presented.

SOLARIS DIGITAL USER OFFICE (DUO)

Each facility adopted or developed own system supporting process of users and proposal management. In general user office is a central contact point for users [1]. They can manage their accounts, submit proposals, submit publications and experimental reports. The digital user office allows to prepare statistical information or list of research scientific domains.

The user office typically covers:

- calls for proposals
- management of mailing lists/newsletters
- handling of proposals and experimental reports
- badge requests (access to facility, dosimeters)
- managing publications database

While waiting for first users the concept of SOLARIS DUO was developed. Having in mind that system will evolve with growth of synchrotron and that technology of web portals changes rapidly, the idea to develop Digital User Office from scratch was agreed on. It has given opportunity to tailor solution to SOLARIS needs. The work was done to overview existing synchrotrons in other countries to find best solutions and adapt them to SOLARIS DUO vision at that time.

Registration

Typically user starts with very simple registration process by filling in only basic contact information. Simplified registration form can be seen on Fig.1. After confirmation of user e-mail address one can log into one's DUO account.

The basic dashboard allows to manage user account information and prepare draft proposals. Proposals cannot be submitted until user adds one's affiliation. Affiliation is a link between user and his/hers home institution. It is allowed to have multiple affiliation and specify proposals in context of given affiliation.

The user of the DUO system can have multiple roles. The basic one is a Light User – for whom only basic information about account is registered. Such user can prepare and save draft of proposal. After adding affiliation user can submit proposal when there is Open Call.

In the context of proposal lifecycle there is Main Proposer, Co-proposers role that are recognized for responsible scientist leading the research. When proposal is accepted the Experimentalists role can be granted to persons that come to SOLARIS facility.

The second group of roles are these prepared for staff required for proposal evaluation:

- Radiation Manger
- Safety Manager
- Beamline Manager
- Reviewer

The last one: the User Office Manager is for administration of User Office and overview the whole process.

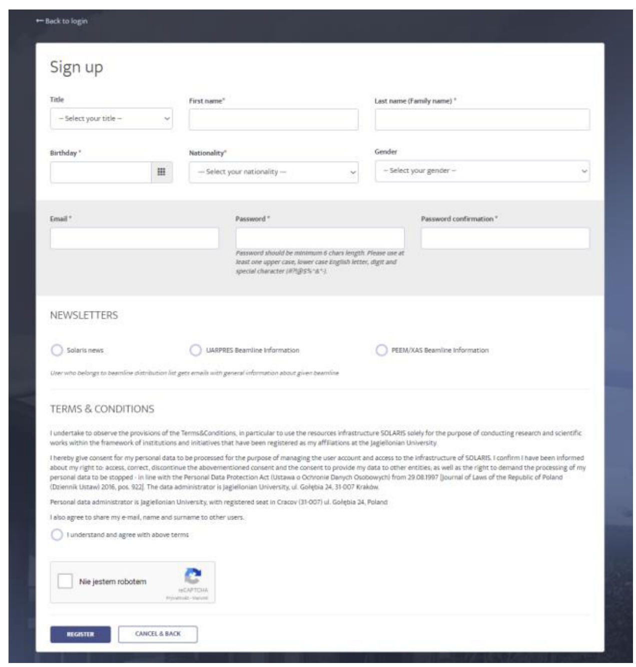

Figure 1: Snapshot of registration form.

Proposal

Preparation of proposal is split into 4 steps.

In first step user gathers general information about proposal (title, keywords, list of proposer and co-proposers, indicates affiliation of the proposal, scientific discipline, chosen beamline for the experiment and number of shifts).

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AUTOMATING OPERATION STATISTICS AT PETRA-3

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Abstract

The quoted machine availability of a particle accelerator over some time range is usually hand-generated by a machine coordinator, who pores over archived operations parameters and logbook entries for the time period in question. When the machine is deemed unavailable for operations, 'blame' is typically assigned to one or more machine sub-systems. With a 'perfect' representation of all possible machine states and all possible fatal alarms it is possible to calculate machine availability and assign blame automatically and thereby remove any bias and uncertainty that might creep in when a human is involved. Any system which attempts to do this must nevertheless recognize the de-facto impossibility of achieving perfection and allow for 'corrections' by a machine coordinator. Such a system for automated availability statistics was recently presented [1] and we now report on results and improvements following a half year in operation at PETRA-3 and its accelerator chain.

INTRODUCTION

A particle accelerator facility has an operations schedule (potentially 24/7) where the facility is obligated to supply users or experiments with beam. Any unanticipated deviation from this operations schedule is regarded as non-availability. Quite naturally, machine coordinators strive to present a perfect score of 100% availability at the weekly operations meeting. Traditionally a machine coordinator will scour the machine data, spreadsheets, logbook entries, etc. to obtain the *official* availability of the facility over the period in question.

We are motivated to generate this availability number automatically for several reasons. First and foremost, we can remove the human element entirely if the official availability is generated entirely automatically. Secondly, we can free up a significant amount of time spent by the coordinator calculating such a number by hand. Finally, we can monitor the availability on-line during operations.

Furthermore, the information at our fingertips will also allow us to automatically calculate the meantime between failures (MTBF) for any chosen time range.

Finally, the online information goes a long way in helping those parties responsible for a particular subsystem to identify and repair operations issues in the context of the *whole machine*.

REQUIRED SERVICES

Automatically calculating machine availability over a selected time range requires three central services. There must be a machine state server which correctly defines all possible declared states of a facility. There must be a central alarm system with a clear definition of what constitutes a fatal alarm. There must also be an archive system which keeps a history of the state and fatal-alarm information. The criteria which identify which states designate official operations (as opposed to, say, machine studies) should also be in place. For example, a fatal alarm of the RF system during *machine studies* does not constitute a failure of the accelerator facility, which tacitly suggests that the circumstances under which a fatal alarm does in fact lead to a failure of the facility must be established. Only then can we calculate a meaningful value for the meantime between failures.

Machine State Server and Periphery

The possible states of an accelerator facility are defined by the machine coordinators and the facility itself will be in *some* state at any given time. Theoretically the choice might be as simple as *running* or *not running*, but is generally more complicated. The state of a machine will be declared to the state server and the machine will be assumed to be in that state until another state declaration is made. The set of all possible machine states is completely configurable.

An additional declared state *problems* is used to identify real failures of the machine. Thus, there must be some service which officially declares this state.

In practice, the actual declaration of a machine state is governed by the following schema:

- The de-facto state is entered into a calendar well in advance (i.e. *machine studies*, *test run*, *user run*, *maintenance*, etc.)
- The real state is declared by the afore-mentioned service, which also makes use of a set of predefined rules. These rules make use of the de-facto state as well as the current machine conditions (e.g. *preparing*, *out-of-specs*, *problems*, etc.)
- The operators can manually intervene and set the declared state to whatever is deemed appropriate.

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ADAPTATIONS TO CS-STUDIO FOR USE AT DIAMOND LIGHT SOURCE

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Abstract

Control System Studio [1] (CS-Studio) is one of the most widely-used display managers for EPICS. It is based on the Eclipse Rich Client Platform (Eclipse RCP), allowing for coherent integration of interfaces for different systems with common graphical elements and preferences. However, this user interface presents a different way of working to those from the previous generation of EPICS tools such as Extensible Display Manager [2] (EDM) and Striptool. At Diamond Light Source, EDM has been used since commissioning in two different ways: for machine operations and for beamline controls. Both uses of EDM will eventually be replaced with CS-Studio and significant effort has been put into this transition. Two kinds of change proved necessary: adaptations to CS-Studio itself, and changes to the typical user workflows. This paper presents both types of changes that were needed to make CS-Studio a productive tool at Diamond.

INTRODUCTION

Since commissioning in 2007, Diamond Light Source (DLS) has used the display manager EDM for all graphical interfaces to the EPICS control system, for controlling both the accelerators and the photon beamlines. EDM has performed well, but now relies on libraries that are becoming obsolete, and is supported by only one developer. CS-Studio is one of the most widely-used replacements for EDM. It is written in Java and based on Eclipse RCP, and so it runs on Windows, MacOS and Linux, but this also means that it has a very different user interface to EDM. Making the transition between the two applications presented a number of challenges.

MODIFICATIONS TO THE CS-STUDIO PRODUCT

Since CS-Studio is an open-source collaboration, users are free to modify the code for their own purposes. DLS has decided that the benefits of working with the CS-Studio collaboration to maintain a single code-base outweigh the freedom to fork the code and make any convenient changes. Working with the collaboration, a number of changes to the CS-Studio application have been made that helped ease the transition from EDM to CS-Studio.

Automatic Conversion

Many thousands of EDM displays are in use at DLS. To reproduce this behaviour in CS-Studio, it is essential that those displays can be automatically converted into equivalent screens, since it would not be feasible to recreate all of these screens from scratch. EDM defines its displays in a custom file format that describes the layout of a number of types of widgets and the properties of each widget. CS-Studio's display tool BOY uses an XML-based format that describes layouts in a similar way, with a range of widgets that are similar but not identical. At the time that DLS began to move to CS-Studio, a tool existed to make a widget-for-widget conversion between the two formats. We have put a significant amount of effort into improving the quality of conversion, including creating new widgets to allow more accurate reproduction of the same behaviour. The converted screens are in most cases difficult to distinguish from the originals rendered by EDM, and other members of the community will benefit from the improved conversion capability.

Standalone Windows

Figure 1: An EDM screen (left) and the same screen converted for CS-Studio (right).

EDM operates using many individual windows, and the DLS operators have defined a way of working that lays out many such windows across multiple Linux virtual desktops, in a classic control-system-style interface. CS-Studio, because of its use of the Eclipse toolkit, shows its content inside one or more large windows known as workbench windows, with a tabbed interface allowing rearrangement of a number of views inside those windows. Because the control

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VACUUM CONTROL SYSTEM OF SSC-LINAC

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Abstract

SSC-Linac is a linear accelerator injector of SSC in HIRFL. The vacuum control system is based on EPICS which is a real-time distributed control software. The Labview real-time VIs and EPICS VIs were used to design Input/Output Controller(IOC). The different kinds of CRIO modules were adopt in device layer, which can monitor the serial port data from vacuum gauges and contol vacuum valves. The whole control system can acquire vacuum data, control vacuum devices remotely, make the pressure value of the vacuum gauge and vacuum valve interlocked. It also keeps the equipment work stable and the beam has a high quality.

INTRODUCTION

EPICS is a set of Open Source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as a particle accelerators, telescopes and other large scientific experiments [1]. The OPI(Operator Interface) is based on CSS(Control System Studio). NI cRIO-9022 is used to design the EPICS IOC in this project.

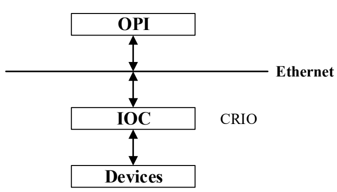

Figure 1: The structure of vacuum control system.

SOFTWARE

The design includes three sections, which are to receive pressure data from vacuum gauge, to control vacuum valves to be in or to be out, to get the status of vacuum valves. We use FPGA mode to design the program with Labview, because FPGA mode is more stable and faster than SCAN mode [2]. We need an external power supply which has 5V voltage to control vacuum valves. NI provides EPICS modules to write and read data with PVs, The modules support five kinds of data, such as ai, ao, bi, bo and waveform, if you want to define a new type of record, it is forbidden.

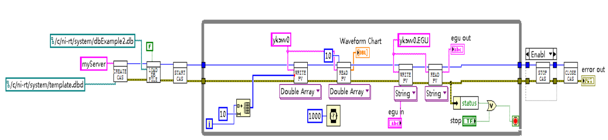

Figure 2: An example of the program.

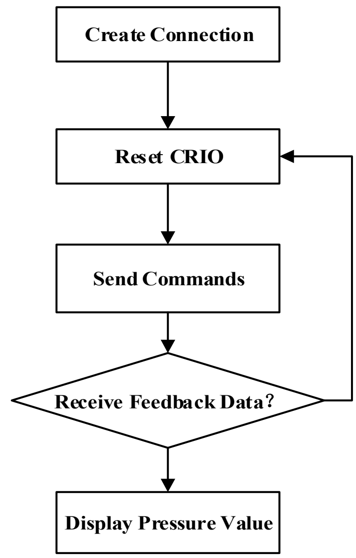

Figure 3: The flow diagram of the design.

Engineering view of this project is shown bellow:

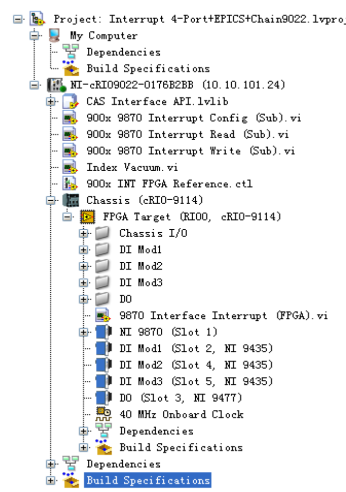

Figure 4: Engineering view.

The project has to set auto running when cRIO is powered on. Users can do it in "Build Specifications" step by step.

HARDWARE

The interface of vacuum gauge is RS232, DB9, so we use NI-9870 serial module to receive pressure data from vacuum gauges. We use NI-9477 which is a digital output module to control vacuum valves and use NI- 9435 which is a digital input module to get valve status. NI-9870 module can provide 4 serial ports which can link to 4 vacuum gauges. The hardware is shown in figure 4 bellow.

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LIMA: LIBRARY FOR IMAGE ACQUISITION A WORLDWIDE PROJECT FOR 2D DETECTOR CONTROL

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Abstract

The LIMA project started in 2009. The goal was to provide a software library for the unified control of 2D detectors. LIMA is a collaborative project involving synchrotrons, research facilities and industrial companies. LIMA supports most detectors used for X-ray detection or other scientific applications. Live display is supported via a video interface and most of the native video camera image formats are supported. LIMA provides a plug-in architecture for on-line processing which allows image pre-treatment before saving e.g. noise reduction algorithm or automatic X-ray beam attenuation during continuous scans. The library supports many file formats including EDF, CBF, FITS, HDF5 and TIFF. To cope with increasing detector acquisition speed, the latest LIMA release includes multi-threaded, parallelized image saving with data compression (gzip or lz4). For even higher throughput a new design, based on a distributed multi-computer architecture, of the LIMA framework is envisaged. The paper will describe the LIMA roadmap for the coming years.

INTRODUCTION

LIMA was born to address the problem of controlling 2D detector in the context of beamline (BL) control systems [1]. An important number of detectors need to be integrated in order to operate BL experiments and different approaches had been followed in the past in order to optimise efforts in this (never-ending) integration process. Based on the accumulated experience at the ESRF, LIMA has been built on top of the following paradigms:

- Clear separation between image generation and image processing
- Use of events and threads in order to better use system resources
- Control-system agnostic library that can be included in different kinds of applications
- High-performance code in C++, which can be bound to other high-level languages

Structure

The implementation of these concepts was made using the plugin philosophy, shown in Figure 1. A LIMA core library contains the code for image processing and a camera plugin is in charge of generating the images. The visible part of the library core is the Control Layer, exporting to the user the generic configuration and control of the image acquisition and processing. The camera plugin, also referred to as the Hardware Layer, registers to the Control Layer through a well-defined *hardware interface,* which contains different functional, independent blocks called *capabilities*. The *capabilities* control generic functionality that can be present in 2D detectors, covering different domains like image manipulation, external synchronisation, video streaming, among others. Three capabilities are mandatory for all plugins: generic detector information, frame synchronisation and image buffer control. Others, like pixel binning, region-of-interest (RoI) selection and shutter control are optional.

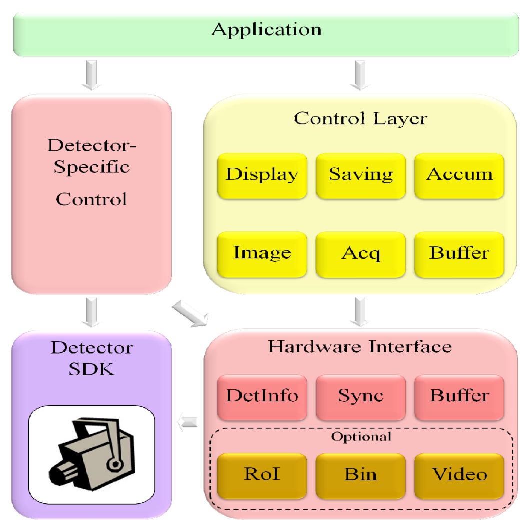

Figure 1: general LIMA layout.

Once the capabilities are discovered and configured, the control layer can start an acquisition of a sequence of frames. It is the responsibility of the plugin to inject each new acquired frame, which enters into the processing chain.

Processlib

A helper library *Processlib* was developed to implement the frame processing chain. It allows defining a sequence of tasks to be executed to each acquired frame. Tasks can run sequentially or in parallel, depending if they modify the source image or not. They are executed by a pool of threads, which is dimensioned depending on the number of available CPU cores. Operations on different frames can be parallelised, allowing data acquisitions to run faster than a traditional single-CPU

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ESPRESSO INSTRUMENT CONTROL ELECTRONICS AND SOFTWARE: FINAL PHASES BEFORE THE INSTALLATION IN CHILE

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Abstract

ESPRESSO, the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations, is undergoing the final testing phases before being shipped to Chile and installed in the Combined Coudé Laboratory (CCL) at the European Organisation for Astronomical Research in the Southern Hemisphere - Very Large Telescope site (ESO-VLT).

The integration of the instrument took place at the Astronomical Observatory of Geneva. It included the full tests of the Instrument Control Electronics (ICE) and Control Software, designed and developed at the INAF - Astronomical Observatory of Trieste.

ESPRESSO is the first ESO-VLT permanent instrument whose electronics is based on Beckhoff PLCs. Two PLC CPUs shares all the workload of the ESPRESSO functions and communicates through the OPC-UA protocol with the VLT instrument control software.

In this phase all the devices and subsystems of ESPRESSO are installed, connected together and verified, mimicking the final working conditions in Chile.

This paper will summarize the features of the ESPRESSO control system, the tests performed during the integration in Europe and the main performances obtained before the integration of the whole instrument "on sky" in South America.

INTRODUCTION

ESPRESSO is the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations of ESO that is now being installed at the Very Large Telescope site in Chile [1]. ESPRESSO aims to detect rocky exoplanets using the radial velocity method, and to search for variation of fundamental physical constants through cosmic time. To reach this goal the spectral resolution is expected to be up to 200,000.

ESPRESSO can operate with up to 4 VLT UTs (Unit Telescopes), through dedicated Front End Units (FEU).

Most of the moving parts and sensors of ESPRESSO are controlled by the Instrument Control Electronics and Software [2] [3]. All these devices are controlled by two Beckhoff PLC CPUs placed in the Instrument Main Cabinet (IMC). The CPU belongs to the CX2030 series, and supports EtherCAT fieldbus. In each CPU the OPC-UA server is installed to allow the communication with the higher level software. Several further electronics subracks, containing Beckhoff decentralized modules, are EtherCAT-linked to the two PLC CPUs in the IMC, following the daisy chain reported in Figure 1. The yellow boxes in Figure 1 represent the CPUs in the main cabinet.

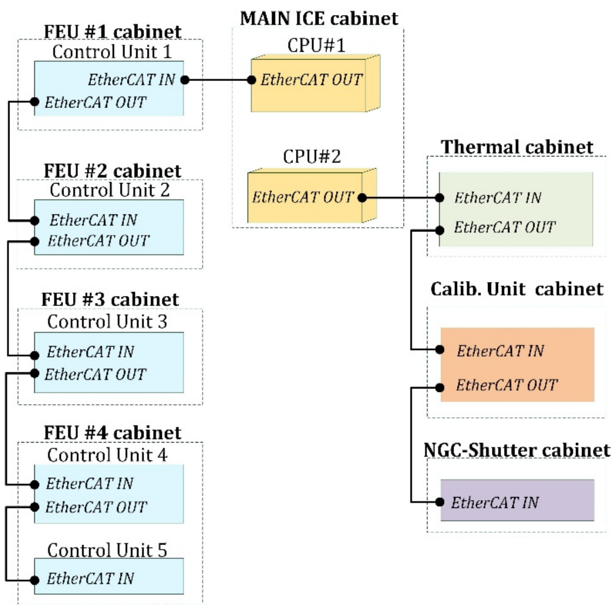

Figure 1: Beckhoff control system daisy chain.

The first CPU controls all the moving parts and sensors of the FEU, driving the Beckhoff modules placed in each FEU 1m high cabinet. These four cabinets are positioned near the FEU arm to control, as shown in Figure 2.

The second CPU controls all the functions of the other subsystems: Lakeshore temperature controllers placed in the Thermal Cabinet, motors, lamps and sensors placed in the Calibration Unit cabinet and drives the three shutters through the NGC-Shutter interface cabinet.

Figure 3 shows the 2m high cabinets: Thermal Control System cabinet (on the left), Instrument Main Cabinet (center) and Calibration Unit cabinet (on the right side). The Thermal and Calibration cabinets have been built respectively in collaboration with the Genèva Astronomical Observatory and the Bern University.

The CPU are programmed using TwinCAT 3 development software, in Structured Text, language supported by the IEC 61131-3 standard.

The ESPRESSO Control Software architecture is compliant with the ESO/VLT standards and is based on the VLT Control Software [4].

In June 2017 the PAE (Preliminary Acceptance Europe) took place at the Geneva Observatory, where the instrument has been accepted by ESO. ESPRESSO ICE and ICS

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THE DESIGN OF CSNS INSTRUMENT CONTROL

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Abstract

To meet the increasing demand from user community, China is now building a world-class spallation neutron source, called CSNS(China Spallation Neutron Source). It can provide users a neutron scattering platform with high flux, wide wavelength range and high efficiency. CSNS construction is will completed in this year. There are three neutron instruments in CSNS, which are GPPD, SANS and RM. CSNS Experimental Control System is in charge of the operation of NS target and instruments.

The instrument control system of CSNS is based on EPICS and White Rabbit network, offering device operation, timing synchronization, synchronization of DAQ and physical software, metadata collection and generation of experiment summary. This paper will introduce the structure of instrument control.

INTRODUCTION

Neutron scattering becomes a more and more important method probe the structure of the microscopic world. In physics, chemistry, biology, life science, material science, new energy, as well as in other applications, Neutron scattering is the widely used as a complementary way to X-ray in advance research.

To meet the increasing demand from user community, China is now building a world-class spallation neutron source, called CSNS (China Spallation Neutron Source) [1]. It can provide users a neutron scattering platform with high flux, wide wavelength range and high efficiency. CSNS construction will be completed this year, and got first neutron in August, 2017.

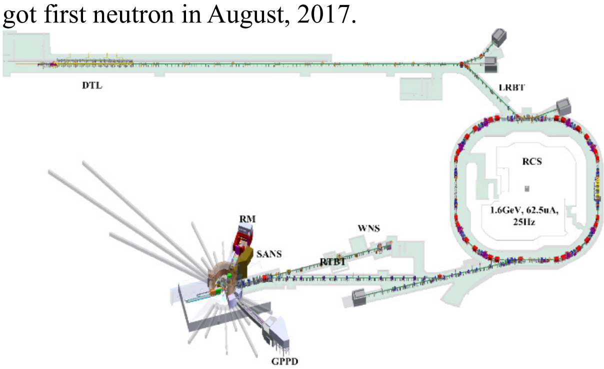

Figure 1: The Layout of CSNS.

* Work supported by China Spallation Neutron Source, the science and technology project of Guangdong province under grand No. 2016B090918131 and 2017B090901007.
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The experimental control system of CSNS is in charge of target and instrument control [2]. The task of instrument control includes:

1. Provide local control to instrument device.
2. Ingrate all devices belonged to the instrument into one system, including sample environment, slit， chopper, etc.
3. Provide facility information, mainly on accelerator information.
4. Provide the trigger signal (T0) when proton hit the target and time synchronization for device to get timestamp.
5. Interact with security systems, including neutron shutter and personal safety protection system.
6. According to experiment requirement, coordinate all system, mainly focus on DAQ and physical software.
7. Record status information of device, producing experiment summary file for offline.
8. Provide remote monitor and optional remote control for whole neutron instrument.
9. Provide statistics of instrument operation.

CSNS instrument control is based on EPICS control system [3], integrating commercial hardware, Labview and other components. Some customized hardware are made for T0 fanout and time synchronization.

THE STRUCTURE OF INSTRUMENT CONTROL

Figure 2 shows the structure of instrument control. An instrument control is divided device control layer and global control layer. Device control layer mainly focus on local control of the device, providing standard EPICS CA interface and expert HMI. As a special case, detector, electronics and DAQ software can be viewed as one devices. DAQ software provide a standard interface to online analysis and also provide an online monitor interface to detector and electronics experts.

Global control layer mainly focus on integrating all device, providing global information and execute the procedure of experiment.

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CONTROL AND DATA ACQUISITION USING TANGO AND SARDANA AT THE NANOMAX BEAMLINE AT MAX IV

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Abstract

The MAX IV synchrotron radiation facility in Lund, Sweden, received its first external commissioning users in November 2016 at the Nanomax hard X-ray beamline. All components of the beamline, including the motorisation, vacuum and diagnostic elements, were integrated into the TANGO-based control system, which through the SARDANA layer also managed the collection of diffraction and fluorescence data from one- and two-dimensional detector channels. Hardware-synchronised continuous scanning ("fly-scanning") of the sample, mounted on a piezo stage, was achieved using a system built around a standard pulse generator and acquisition board controlled by a dedicated TANGO device. SARDANA macros were used to configure and execute the continuous scanning, and position data from the piezo controller were buffered in synchronization with triggers sent to the detectors, with all data subsequently written to HDF5 files. After successful initial operation, the system is currently being revised and expanded for the users expected in 2018.

INTRODUCTION

The first two beamlines on the 3 GeV storage ring at the MAX IV laboratory opened for external users in autumn 2016. The hard X-ray nanoprobe beamline, Nanomax, is designed to take full advantage of the low emittance of the storage ring and the resulting coherence properties of the X-ray beam. Nanomax will eventually provide two experimental stations; a Fresnel Zone Plate (FZP) station to reach the smallest focal spot down to 10 nm, and a second using Kirkpatrick-Baez (KB) mirrors offering greater flexibility and various scattering geometries at the expense of a larger beam size. The final end-stations are under construction, but users have already been received to perform diffraction and fluorescence experiments using non-final sample stages and detectors.

Following the MAX IV standard, the control system is based on TANGO [1]. Where possible, equipment is interfaced to TANGO via TCP/IP and for the client layer physicists can interact with TANGO via its Python binding or through SARDANA [2], which brings a macro server and standardised Graphical User Interfaces based on TAURUS [3]. From a control system point of view, the beamline upstream of the end-stations is fully commissioned, as described in the first section of this report. The end-stations are being integrated into TANGO as they are developed. The second section of the report describes the equipment controlled in the current developmental end-station and the hardware-synchronised continuous scanning system that was provided for the first users.

BEAMLINE CONTROL

An overview of the beamline is shown in Fig. 1. Its long length, approximately 100 m, results from the goal of achieving the small 10 nm spot size. The control system was installed for the commissioning of the optics section during 2015 and 2016. At MAX IV the TANGO control systems run on virtual machines (VMs), unless local computers are required in conjunction with physical hardware. As for the other beamlines, several VMs are used at Nanomax, separating the TANGO and archiving databases from multiple equipment controllers. In the control room several physical client computers are used to run TAURUS GUIs and the SPOCK SARDANA client; most of the user control is done via the latter. A single synoptic GUI shows all optical, vacuum and diagnostic elements of the beamline; a screenshot of this is shown in Fig. 2 and the technology behind this device has been described in [4]. The main aspects of the beamline that have already been commissioned are briefly described below.

Motorisation of optics. There are approximately 30 motorised axes for the control of the monochromator, mirrors, slits and various diagnostic equipment. The standard motion control system at MAX IV, the IcePAP [5], has been employed throughout. All axes are exposed as motors in SARDANA and configured in the appropriate physical units. Pseudo-motors allow the operators to steer the monochromator in terms of photon energy and Bragg angle.

Vacuum PLC system. The vacuum system comprises many valves, over 20 ion-pumps and over 50 temperature sensors, controlled and read out by an Allen Bradley PLC. The PLC tags are exposed as attributes of a single TANGO device that communicates with the PLC over Ethernet. This device acts as a server for a suite of higher level TANGO devices that represent the individual pieces of equipment. The higher level devices all inherit from a single "facade" type device which has been developed based on reactive programming principles and is described in detail elsewhere [6]. The PLC implements the machine and personal safety systems and the alarms are reported using PyALARM and the PANIC GUI [7].

Diagnostic cameras. Several Basler cameras are used for the beam diagnostics. These are integrated to TANGO using their Lima [8] drivers. A dedicated TAURUS GUI was developed for viewing the live image.

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SOFTWARE APPLICATIONS FOR BEAM TRACEABILITY AND MACHINE DOCUMENTATION AT ISOLDE

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Abstract

The ISOLDE facility at CERN requires a wide variety of software applications to ensure maximum productivity. It will be further enforced by two new applications; Automatic Save After set uP (ASAP) and Fast Beam Investigation (FBI). ASAP saves crucial time for the engineers in charge (EIC) during the physics campaign. It automatizes and standardizes a repetitive process. For each new set up, the EIC is required to document the settings of all important elements, before delivering beam to the users. FBI will be serving two different needs. First, it will be used as a beam traceability tool. The settings of every element of ISOLDE that could obstruct, stop or affect the beam will be tracked by the application. This will allow to understand better the presence of radioactive contaminants after each experiment at critical points in the facility. The second functionality will allow real time monitoring of the machine status during a physics run. FBI will be the most efficient way to visualize the status of the machine and find the reason that prevents the beam from the experimental station. Finally, an application has been developed to automatize with flexibility a sequence of pre-defined assignments, such as performing a measurement and setting a value to a device.

INTRODUCTION

ISOLDE is one of the leading research facilities in the field of nuclear physics. The latest addition, HIE-ISOLDE [1] increased the demand for beam time to conduct experiments. In such a demanding environment time is crucial. Even a few minutes gained from a repetitive task can account for hours gained within a year. These hours could be allocated in any other more productive manner. The three applications presented in this paper were conceived mainly with this achievement in mind. How to gain time and be more efficient. ASAP reduces the time the EIC is required to perform the task mentioned above, that takes place a minimum of once a week. FBI will contribute in efficiently resolving issues that hinder the users from receiving beam. In conclusion, the principle and the assignment possibilities of the Automation application are described.

AUTOMATIC SAVE AFTER SET-UP (ASAP)

The EIC is responsible to perform the beam set-up to a pre-defined destination. The specifications from the physics proposal needs to be fulfilled, meaning that the beam properties and transmission should be adequate to deliver the expected amount of beam to the users. Depending on the final destination this setting up procedure can require from a few hours to a few days. The longest duration concerns a beam reaching an experiment after HIE-ISOLDE which is the latest addition to the ISOLDE facility. In its current phase, ASAP does not include that area so details will not be mentioned here.

Tools used by the EIC While Setting up the Accelerators

Once the EIC verifies that the target used to generate the Radioactive Ion Beams (RIBs), is in good condition to provide beam, the set up can begin. After the beam is extracted from the target, it is guided through the beam line using different kinds of elements (separator dipoles, electrostatic quadrapoles and benders, beam steerers). A mass separation takes place either using the general purpose separator General Purpose Separator (GPS) or the High Resolution Separator (HRS). The beam, after this point consists mainly of the desired mass. It continues downstream, going through more elements, until it reaches the experimental station. The EIC controls all these devices via the equipment array application [2]. A series of beam diagnostics equipment provides critical information about the characteristics of the beam. The intensity is measured by a Faraday Cup (FC), vertical and horizontal position by Wire Grid (WG) and Wire Scanner (WS). The EIC needs to verify optimal transmission with the help of the FC, WS and WG while using the equipment array application to steer the beam accordingly. Once the EIC concludes the beam set up, the state of the machine needs to be logged. The reasons behind this are: a) to ensure that one can restore the facility to this approved state in the case of an unexpected event (e.g. power cut). b) Having stored the current state of the machine allows more easily discovering possible drifts in parts of the machine which would lead in loss in transmission efficiency. Every event that takes place in the facility is being described and logged in an application called logbook [3].

Traditional Process of Saving a Set-Up

The process of saving the state of the machine comprises of the following steps. a) From the equipment array application the EIC needs to save the file which includes all devices and their current values that results in an acceptable beam set-up. A descriptive name should be given to facilitate the identification of the specific situation for which the set-up took place (e.g. 170824_1137_GPS_SEP_13C16O.csv). The name typically includes a time stamp (‘YYMMDD_HHMM’), the part of the machine which represents a group of devices that are included in the file and the isotope used for the set

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SOFTWARE APPLICATIONS USED AT THE REX/HIE-ISOLDE LINAC

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Abstract

The HIE-ISOLDE Linac (High Intensity and Energy) [1] is a recent upgrade to the ISOLDE facility of CERN, increasing the maximum beam energy and providing means to explore more scientific opportunities. The main software tools required to set up the new superconducting post-accelerator and to characterise the beam provided to the experimental stations will be presented in this paper. Emphasis will be given to the suite of applications to control all beam instrumentation equipment which are more complex compared to the ones in the low energy part of ISOLDE. A variety of devices are used (Faraday cups, collimators, scanning slits, striping foils and Silicon detectors). Each serves its own purpose and provides different information concerning the beam characteristics. Every group of devices required a specific approach to be programmed.

INTRODUCTION

ISOLDE is one of the leading research facilities in the field of nuclear physics. Radioactive Ion Beams (RIBs) are produced when 1.4 GeV protons impact in a target.

The RIB of interest is extracted and transported to different experimental stations either directly or after being accelerated in the post-accelerator. In the latter, RIBs are transported to the REX-TRAP [2], charge-bred in the REX-EBIS [3] and accelerated to 2.85 MeV/u in the REX normal conducting section of the linac before being accelerated further (9.3 MeV/u for beams with A/q = 4.5 and to 14.3 MeV/u for A/q = 2.5) in the HIE-ISOLDE superconducting section of the linac. Software applications used for HIE-ISOLDE can be divided into two categories, Beam Set-Up related and Machine related. The first category contains the applications that enable the Engineers In Charge (EIC) to set up the desired beam regardless if it is stable (e.g. 39K) or radioactive beam (e.g. 76Zn). The second is for the applications that provide information about the status of critical systems. All applications in the second category are in PVSS.

One is the vacuum application [4]. With this the pressure for each sector of the machine is monitored and it allows opening or closing the vacuum sector valves in the beamline. The second application is used to monitor the status (i.e. temperatures, flows, LHe levels etc) of the cryoplant, the cryoline and the cryomodules. The Warm magnet Interlock Control system (WIC) is used to monitor the temperature of the normal conducting magnets.

In this paper more detail will be given on the first category.

BEAM SET-UP RELATED APPLICATIONS

This category includes the large majority of the applications used. The ones that will be described in this paper are: Equipment Array, EBIS Slow Extraction, HIE Beam Diagnostics (HIE-BD), HIE Silicon Detector (HIE-SD), HIE Energy Measurement, HIE Phasing, HIE Count Rate.

Equipment Array Application

Different types of equipment, such as electrostatic or magnetic elements, normal or super conducting cavities are used in the ISOLDE beam lines. They are all available to the EIC to set up the beam to its final destination. The Equipment array application is based on comma separated values (csv) files. They consist of 4 columns; name of device, buffer value, requested (CCV) value and Acquisition (AQN) value. On the loaded file the EIC can change the value of each device. Once the set-up is finalised a separate file can be saved. One can also scale the buffer values either by mass to charge ratio or by energy per nucleon. As an example, eight equipment arrays are typically used to characterize a set-up to deliver beam to the experimental station at the end of the first HEBT line.

Figure 1: The Beam Diagnostics application main panel.

Beam Diagnostics Application

For phase 2A of the project, In the HIE-ISOLDE section of the linac and the High Energy Beam Transfer lines (HEBTs) there are 18 diagnostic boxes [5] housing 70 devices. Those are divided into 18 Faraday cups (FC), 18 scanning slits (SL), 18 collimator slits (CS), 5 stripping foils (SF) and 5 Silicon detectors (SD). In the applications main panel (see Fig.1) every row represents a diagnostic box and every column is a different type of device. Every

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UNICOS FRAMEWORK AND EPICS: A POSSIBLE INTEGRATION

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Abstract

UNICOS (UNified Industrial Control System) is a CERN-made framework to develop industrial control applications. It follows a methodology based on ISA-88 and provides components in two layers of a control system: control and supervision. The control logic is running in the first layer, in a PLC (Programmable Logic Controller), and, in the second layer, a SCADA (Supervisory Control and Data Acquisition) system is used to interface with the operators and numerous other features (e.g. alarms, archiving, etc.). UNICOS supports SIEMENS WinCC OA as the SCADA system. In this paper, we propose to use EPICS (Experimental Physics and Industrial Control System) [1] as the supervision component of the UNICOS framework. The use case is the control system of a CO_2 cooling plant developed at CERN following the UNICOS methodology, which had to be integrated in a control system based on EPICS. The paper describes the methods and actions taken to make this integration feasible, including automatic EPICS database generation, PLC communications, visualization widgets, faceplates and synoptics and their integration into CSS [2] and EPICS, as well as the integration with the BEAST alarm system.

INTRODUCTION

UNICOS (UNified Industrial Control System) is a CERN-made framework to develop industrial control applications. The package Continuous Process Control (CPC) provides a specific environment for process control applications. It deals with the two upper layers of a classical control system: Supervision and Control. UNICOS proposes a method to design and develop the control application, which will run in commercial off-the-shelf products, e.g. Supervisory Control and Data Acquisition systems (SCADA) and Programmable Logic Controllers (PLC). The framework employs terminology and models of the ISA-88 standard for batch control systems that is also widely employed in continuous process control.

UNICOS-CPC is based on a well-defined set of standard device types covering most of the physical equipment (e.g. motors, valves, sensors, etc.) and the needs of a continuous process in terms of control; also it enforces the structure and provides a method for programming the process control logic.

The goal of UNICOS-CPC is to standardize the development of control applications at CERN by

- emphasizing good practices for both, design and operation, of the continuous process control applications

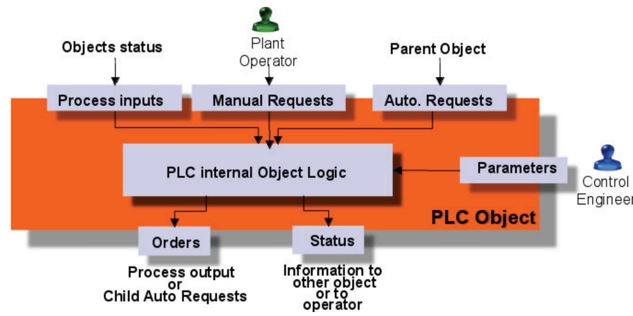

Figure 1: UNICOS object model.

- reducing the cost of automating continuous processes (e.g. cooling, HVAC, etc.) and
- optimizing life-cycle engineering efforts (e.g. using automatic code generation tools).

At CERN, UNICOS is used with WinCC OA as the supervision layer. This paper describes the effort to replace WinCC OA with an EPICS-based system, also employing Control System Studio (CSS) as the operator interface, the BEAST alarm system, and the Archiver Appliance to record PV history.

UNICOS CONCEPTS

UNICOS is an object oriented framework consisting of a package of programming tools facilitating control system development. It includes the baseline library (with a modular PID algorithm), the code generator with synoptic rules checker significantly reducing time of program development by a priory error identification, the skeleton templates, and examples of objects lists. The object definitions provided by UNICOS are split into:

- I/O Objects: Values to and from the hardware. E.g. Digital Input, Digital Output, Analog Input
- Field Objects: Physical equipment. E.g. OnOff, Analog, AnaDig, Controller, etc..
- Control Objects: Logic processing. E.g. PCO, Analog Alarm, Digital Alarm.

A typical UNICOS object model is presented in Fig. 1.

The UNICOS engineering life cycle presented in Fig. 2 is based on two initial documents: the functional analysis that is a Word document and an Excel XML specification file containing all object definitions, parametrization and hierarchy. The specification file is the primary input to the automatic code generation tool. This generation tool is equipped with a set of framework templates and user dependent logic templates to provide structured importation files for both PLC and SCADA, guaranteeing correct mapping between them.

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THE CONTROL SYSTEM OF THE CERN PLATFORM FOR THE TEST OF THE HIGH LUMINOSITY LHC SUPERCONDUCTING MAGNETS

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Abstract

A new generation of superconducting magnets is being developed, in the framework of the HL-LHC upgrade project. Several laboratories in Europe, USA, Japan and Russia collaborate on this project. One of the tasks assigned to CERN is to conduct the optimization tests and later the series tests, for the MQXFS and MQXF-A/B magnets. A new dedicated test bench has been built at the CERN superconducting magnet test facility (SM18), where these magnets will be evaluated under their operational conditions in the LHC tunnel. To fulfill the test conditions on these high performance magnets, a new high frequency data acquisition system (DAQ) has been designed, associated to a new software used to control two 15 kA power converters. This article presents all the technical aspects of these two major components of the test platform, from the PXIe hardware selection of the DAQ system to the operational applications deployment. The commissioning phase and results of the first measurement campaign are also reported.

INTRODUCTION

In the view to extend the discovery potential of the LHC accelerator, it is foreseen to increase its luminosity by a factor of ten beyond its initial design. To conduct this challenging project, from the preliminary studies up to the installation in the tunnel, expected for 2024/2025, a strong collaboration has been established worldwide. The involved laboratories and industrial partners from Europe, USA, Japan and Russia are joining their efforts through the High Luminosity Large Hadron Collider project (HL-LHC [1]).

This major upgrade leads, among other technological challenge, to the replacement of the Inner-Triplet, Nb-Ti made quadrupole magnets, by a new generation of high field magnets, based on Nb_3Sn conductor. In this framework, CERN has been charged to conduct the optimization tests on the MQXFS [2] (short coil prototypes, see Fig. 1) and later the series test for twenty MQXF.

At CERN, all the superconducting magnet evaluation tests are done in a dedicated test facility, named SM18. However, despite the fact that this facility is well equipped, with state of the art measurement technologies and more than fifteen dedicated cryostats (heavily used during the LHC magnets test campaign), none of them was fitted for these new demanding and upper sized magnets.

In this context, the construction of a new dedicated test area has been initiated in 2015, allowing the presence of a 800 mm large and 11 m long vertical cryostat and a high current power supply (up to 30 kA) and its associated protection circuit. These components are intended to test the magnets at the nominal temperature of 1.9 K with a peak field of 11.4 T at the conductor level.

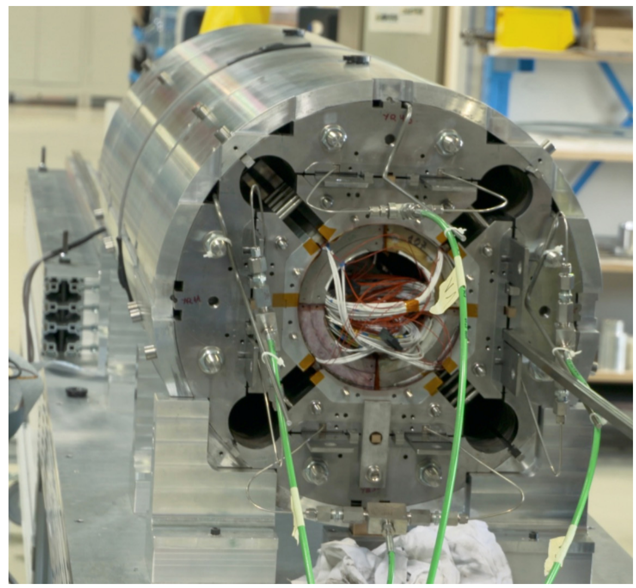

Figure 1: The assembly of the first model of the MQXFS quadrupole magnet.

Thus, in parallel with the assembly and installation of all the mechanical, electrical and cryogenic elements of this test bench (defined as Cluster D), a new data acquisition and power supplies control systems were designed and developed.

THE NEW DATA ACQUISITION SYSTEM

The aim of the DAQ is to record some signals from the magnet under test, mainly coil and quench heater voltages with the current in the circuit. The theoretical design of the DAQ system has been mainly guided by the fact that it was firstly dedicated to a magnet R&D research program. By experience we knew that in this type of project the measurement systems must be oversized in term of channels and treatment capabilities compared to one dedicated to a series measurement. The prototype magnets are much more instrumented, while hosting a big number of voltage taps (vtaps), strain gauges and quench heaters than in the final version of the production magnet. The second main point of the design was related to the high frequency reading ability, up to 200 kHz in our case. This is needed for the general magnet quench analysis but also for the flux jump analysis [3]. This very short instability, a typical behaviour of the Nb_3Sn magnet based conductor needs to be carefully studied during the prototype evaluation.

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AUTOMATION SOLUTIONS AND PROTOTYPES FOR THE X-RAY TOMOGRAPHY BEAMLINE OF SIRIUS, THE NEW BRAZILIAN SYNCHROTRON LIGHT SOURCE

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Abstract

Brazil is building Sirius, the new Brazilian synchrotron light source which will be the largest scientific infrastructure ever built in Brazil and one of the world's first 4th generation light laboratory. Mogno, the future X-ray nano and microtomography beamline is being designed to execute and process experiments in only few seconds. For this reason, prototypes and automated systems have being tested and implemented in the current Brazilian Synchrotron Light Laboratory (LNLS) imaging beamline (IMX). An industrial robot was installed to allow fast sample exchange through an easy-to-use graphical user interface. Also, scripts using Python and Experimental Physics and Industrial Control System (EPICS) were implemented for automatic sample alignment, measurement and reconstruction. In addition, a flow cell for study dynamics and behaviour of fluids at the rock pore scale in time resolved experiments (4D tomography) is being projected.

MOGNO BEAMLINE

MOGNO is designed to be a micro and nano imaging beamline focused towards multi-scale analysis of the internal 3D structures of different materials and objects. The beamline will be primarily devoted and specialized in zoom-tomography where a specimen can be studied at low and high-resolution. In parallel, MOGNO will be also dedicated to enable powerful 3D imaging competences which can be extended to 4D (time-resolved) imaging through in-situ experiments. This feature will allow the researchers to observe and quantify material responses during mechanical, thermal or chemical loadings.

It will work in medium (30 keV) and high (90 keV) energies. The beamline has two main scientific drivers: Multi-scale imaging of rocks under reservoir conditions and Imaging of biological samples and tumors, however Mogno will potentially cover many different areas, such as material science, bioengineering, clay science, civil engineering, paper and wood research, chemistry and earth/planetary science, food science, paleontology, archeology and cultural heritage.

PROTOTYPES UNDER TESTING

MOGNO Beamline will have a high flux and energy, which will make possible to perform very fast measurements. Because of this, an automatic measurement system is fundamental to use all the available beamtime. As already mentioned, the fast acquisition will also allow to perform time resolved X-ray tomography (4D tomography). Two prototypes are being tested at LNLS for future application at MOGNO. An automatic measuring system and a rotational flow cell.

AUTOMATIC MEASUREMENT SYSTEM

The IMX is a microtomography beamline that has maximum sample size of 7 mm and highest resolution of 1 μm. The pink beam energy ranges from 4 to 25keV.

For hard samples (like rocks, ceramics), the acquisition time is relatively long (some seconds per projection) and, for tomography, it's necessary to take several projections (we normally do something around 1000), making it time-consuming. When the experiment is done with lighter samples (eg. biological samples), this time reduces to less than one second, what already justifies an automated exchange system. At MOGNO, the whole measurement will take only few seconds, making an automatic system not only interesting, but necessary. Another important fact is that users bring many samples (few dozens), and stay at the beamline for a short period (2 - 3 days), so, to make the most of it, continuous measurements (i.e. 24h a day) are necessary. Manually exchanging samples make obligatory the presence of one person at the beamline. With an automated system, users can organise a queue of experiments and let the system run autonomously.

This system can be separated into main parts: sample exchange robot, process control system, automatic alignment system, graphical user interface for measurements preparation, and safety system to prevent accidents

Sample Exchange Robot

The robot installed at IMX is a Mitsubishi RV-2F-D1 (controller CR-750D). Its main parameters are:

Table 1: Robot Main Parameters [1]

Degrees of freedom	6
Max velocity (mm/s)	4950
Max load (kg)	2.0
Position repeatability (mm)	±0.02

For the robotic hand set, we use a pneumatic gripper (MHZ2-10D) and two Hall effect sensors (D-M9B), to monitor the tool open/close state, both from SMC, and a solenoid valve proper to work with the robot (see figure 1).

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AUTOMATIC ANGULAR ALIGNMENT OF LHC COLLIMATORS

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Abstract

The Large Hadron Collider (LHC) is equipped with a complex collimation system to protect sensitive equipment from unavoidable beam losses. Collimators are positioned close to the beam using an alignment procedure. Until now they have always been aligned assuming no tilt between the collimator and the beam, however, tank misalignments or beam envelope angles at large-divergence locations could introduce a tilt limiting the collimation performance. This paper describes three different algorithms to automatically align a chosen collimator at various angles. The implementation was tested with and without beam at the SPS and the LHC. No human intervention was required and the three algorithms converged to the same optimal tilt angle.

INTRODUCTION

The CERN Large Hadron Collider (LHC) is the largest particle accelerator in the world, built to accelerate and collide two counter-rotating beams, each having a nominal energy of 7 TeV, with a design luminosity of $10^{34} cm^{-2} s^{-1}$ at a bunch collision rate of 40 MHz [1]. The LHC is susceptible to beam losses from normal and abnormal conditions [2,3] and must therefore be protected from any damage which may be caused by such beam losses [4].

The collimation system handles such beam losses and achieves a cleaning efficiency of 99.998% of all halo particles [4]. They are arranged in the form of a hierarchy with primary collimators (TCP) closer to the beam intercepting primary halo particles; secondary collimators (TCSG) retracted from the primary ones cleaning secondary particles; and tertiary collimators (TCT) with more retraction cleaning the remaining showers. In order to preserve this cleaning hierarchy the collimators need to be aligned with a precision of a few microns. The collimators are positioned in three planes; horizontal, vertical and skew, and are mainly concentrated in two dedicated cleaning insertions, IR3 (Insertion Region 3) and IR7 [4].

The current operational settings for the betatron cleaning hierarchy envisage a 1.5 σ retraction margin between the primary and the secondary collimators of the betatron cleaning insertion, which correspond to less than 300 μm. In order to push the performance of the LHC, tighter collimator settings with smaller retractions are foreseen, in order to achieve a lower β^* (related to the colliding beam size) and improved halo cleaning [5].

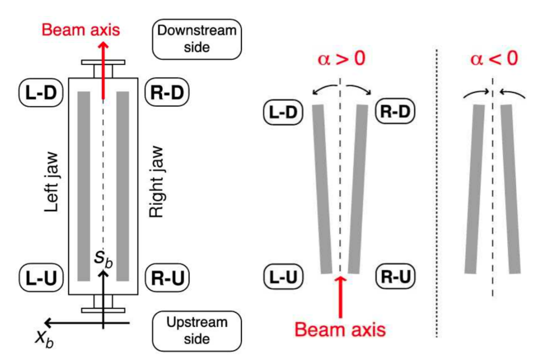
So far, collimators were aligned and operated with parallel jaws (zero tilt angle). Recent beam tests indicated that this approach will not be adequate to operate the system with retractions at 1.5 σ [6], therefore collimators need to be aligned at an appropriate tilt angle. At present, determining the best angle for a collimator would require one to manually apply an angular alignment method which is repeated for each LHC collimator. This motivated the development of an automatic software for efficiently performing angular alignments.

Over the years different elements have a tendency to move slowly due to ground motion. Having an angular alignment procedure that could be run at regular intervals (eg. on a yearly basis during the commissioning), would be useful to identify these issues early on. In addition, automating this would allow for exploring alignments at a larger angular range, and the different methods will be available for use on request. This was automated by aligning collimators using an established beam-based technique at different angles and the methods were tested without beam using a dedicated test-stand and then with beam in the Super Proton Synchrotron (SPS) and the LHC.

BACKGROUND

Collimator Coordinate System

In the LHC, ring-cleaning collimators are made of two jaws inside a vacuum tank and their coordinate system is displayed in Fig. 1a. Each jaw can be moved individually using dedicated stepping motors in the jaw corners with two degrees of freedom at either extremity, allowing collimators to be positioned at different angles, as displayed in Fig. 1b. The maximum and minimum possible angles are 1900 μrad and -1900 μrad respectively [8]. The jaw corners are known as left-up (LU) and right-up (RU) when they are upstream of the beam and left-down (LD) and right-down (RD) when they are downstream of the beam (or at the end of the beam).



(a) Jaw coordinate system (b) Jaw angular tilt convention

Figure 1: (a) The collimator coordinate system and (b) the jaw tilt angular convention as viewed from above, from [7].

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CONTROL IN EPICS FOR CONDITIONING TEST STANDS FOR ESS

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Abstract

CEA Irfu Saclay is involved as partner in the ESS accelerator construction through different work-packages: controls for several RF test stands, for cryomodule demonstrators, for the RFQ coupler test and for the conditioning around 120 couplers and the tests of 8 cryomodules. Due to the high number of components it is really crucial to automatize the conditioning. This paper describes how the control of these test stands was done using the ESS EPICS Environment and homemade EPICS modules. These custom modules were designed to be as generic as possible for reuse in future similar platforms and developments. They rely on the IOxOS FMC ADC3111 acquisition card, Beckhoff EtherCAT modules and the MRF timing system.

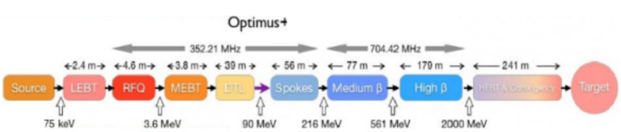

Figure 1: ESS acceleration stages.

INTRODUCTION

The European Spallation Source ESS is a large European research infrastructure under construction in Lund, Sweden. It will be composed among others of an RFQ and a total of 30 elliptical cryomodules (see Fig. 1). These will be integrated in the next 3 years with a delivery rate of one cryomodule per month. An international collaboration has been established to develop and construct the 30 elliptical cryomodules. CEA Saclay and IPN Orsay are collaborating to design, build and test a first Medium beta Elliptical Cavities Cryomodule Demonstrator (M-ECCTD). A second demonstrator with high beta cavities (H-ECCTD) is being developed by CEA before starting the cryomodules production. CEA will provide many other components, such as the power couplers and their RF processing, it will also provide the power couplers of the RFQ and their processing.

The control for all these activities has been developed in EPICS, based on the ESS EPICS Environment (EEE) [1] developed by the ESS control team at Lund (ICS). This environment integrates the use of versioned EPICS modules and allows genericity. Moreover, it provides EPICS drivers and modules for multiple hardware. Due to the numerous components to condition and several similar test stands, it appeared that an EPICS module platform with a certain level of genericity would be useful. This paper describes the use of the EEE environment and generic tools that have been developed here at CEA for these test stands.

DESCRIPTION

Hardware Solution

An IOxOS solution with the VME64X CPU card IFC1210 coupled with the ADC3111 FMC card [2] for the fast acquisition (see Fig. 2), an MRF solution with the VME EVG 230 card coupled with the VME EVR 230RF card for timing [3]., and Beckhoff EtherCAT modules [4] for the slow acquisition have been chosen. All the drivers for this hardware were developed by ICS.

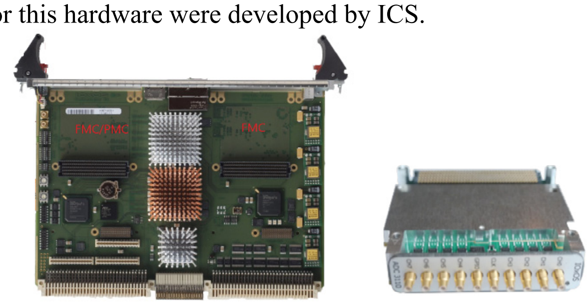

Figure 2: IOxOS cards (IFC1210 and ADC3111).

- The ADC3111 is an FMC mezzanine acquisition board which allows to acquire up to 8 channels at a sampling rate of up to 250 MHz.
- The VME64X CPU IFC1210 is a single board computer on which a real-time Linux kernel runs and allows to plug 2 FMC cards or 1 FMC and 1 PMC as shown in Fig. 3.

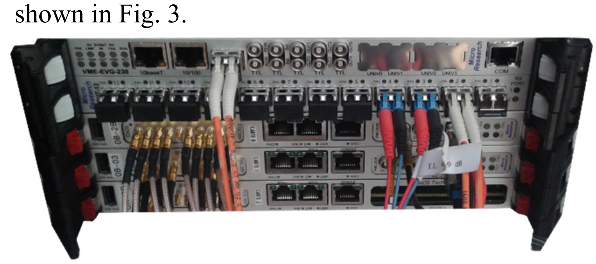

Figure 3: Example of VME rack used.

- MRF Timing system consists of an Event Generator (EVG) which converts timing events and signals to an optical signal distributed through Fan-Out Units to an array of Event Receivers (EVRs) (see Fig. 4). The EVRs decode the optical signal and produce hardware and software output signals based on the timing events received [3].

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UPGRADE OF THE ISIS MUON FRONT END MAGNETS: OLD AND NEW INSTRUMENT CONTROL SYSTEMS WORKING IN HARMONY

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Abstract

When the European Muon beamlines at the ISIS pulsed neutron and muon source [1] upgraded their front end magnets, it was desired that these new magnets should be controllable remotely. This work was undertaken by the team responsible for instrument control, who are in the process of a phased upgrade of instrument control software from a locally developed system (SECI) to an EPICS [2] based one (IBEX [3,4]). To increase the complexity of the task, parts of the front end needed to be controlled only by an individual instrument beamline, whilst some values needed to be tuned to the best compromise available for all three beamlines. Furthermore, the muon instruments were not ready for an upgrade to a full IBEX system at that time. By combining SECI, IBEX and the Mantid [5] data reduction package the required control and tuning has been achieved. This paper will give details of the challenges, the topology of the solution, how the current mixed system is performing, and what will be changed when the muon instruments are converted to IBEX.

BACKGROUND

The Muon beamlines at ISIS have been taking data for the last 30 years. During that time a number of upgrades have been made to the instrument [6]. In 2014 it was proposed to further develop the primary beamline, also known as the front end, in order to improve the performance of the beamlines and to replace aging components [7].

As well as these hardware changes it was decided to provide remote control capabilities for the beamline, which could allow tuning to be undertaken from a computer in a fraction of the time it takes to set the values by hand. There would also be a significant increase in the efficiency made by comparing the received rate of muons across all three instruments for different tunings. This comparison would need to be undertaken using the detector data from each of the three instruments, MuSR [8], EMu [9] and HiFi [10], which meant that this control was treated as beamline rather than accelerator control, and so the work was undertaken by the instrument computing controls team.

This team was in the process of developing IBEX, a new control system based on EPICS. The inherently distributed nature of EPICS meant that IBEX was the obvious choice for supplying this functionality. These muon instruments were not scheduled for conversion to IBEX at this time, and as such work needed to be undertaken to combine the new IBEX system and the existing SECI system which is heavily reliant on LabVIEW [11].

CHALLENGES

As well as the obvious challenge of combining of two control systems, there were a few other factors to consider.

The beamline consists of magnets controlled by 25 power supply units (PSUs), from 2 different manufacturers, using 4 different models and using various communication protocols and command sets.

Within those PSUs some were to be controlled for tuning across all three beamlines, whereas others belong to a single beamline. Some are to be settable only at the start of an ISIS cycle, others can be altered during the cycle.

At ISIS, the standard approach to any device, or item of sample environment equipment is to take the values currently set in the device as the preferred value when a software connection is made. However, there was a requirement with these PSUs to ensure that they start up with a set of known values, which meant taking the value stored in the computer as the preferred value.

There was also motion control to integrate into this front end, via a controller which is already shared between the three instruments.

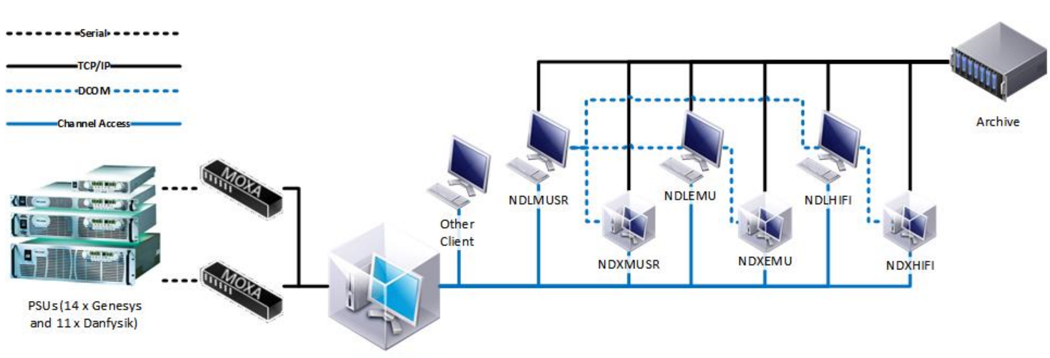

Figure 1: Hardware and computer overview of the muon front end system.

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Tm SERVICES: AN ARCHITECTURE FOR MONITORING AND CONTROLLING THE SQUARE KILOMETRE ARRAY (SKA) TELESCOPE MANAGER (Tm)*

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Abstract

The SKA project is an international effort (10 member and 10 associated countries with the involvement of 100 companies and research institutions) to build the world's largest radio telescope. The SKA Telescope Manager (TM) is the core package of the SKA Telescope aimed at scheduling observations, controlling their execution, monitoring the telescope and so on. To do that, TM directly interfaces with the Local Monitoring and Control systems (LMCs) of the other SKA Elements (e.g. Dishes), exchanging commands and data with them by using the TANGO controls framework.

TM in turn needs to be monitored and controlled, in order its continuous and proper operation is ensured. This higher responsibility together with others like collecting and displaying logging data to operators, performing lifecycle management of TM applications, directly deal - when possible - with management of TM faults (which also includes a direct handling of TM status and performance data) and interfacing with the virtualization platform compose the TM Services (SER) package that is discussed and presented in the present paper.

PRINCIPLE OF WORK

The principle that drove the development of the present architecture is to study the best practises and known architectures that could solve the problems highlighted by the TM and SER requirements and reuse those concepts whenever possible. This means that only if there are no proven solutions then a new concept or pattern would be developed.

RESPONSIBILITIES

From the requirements analysis (done with the help of the entire TM in the numerous discussion held) it has been extracted the main system's functions that are described in the use cases document.

They can be summarized in the following list:

- TM generic monitoring and fault management in order to detect internal failure and gather TM performance;
- TM lifecycle management in order to manage the versions of the TM and the TM applications which includes: configuration of TM software applications, starting, stopping and restarting of TM software applications, update and downgrade of TM software applications;
- TM Logging, which includes the control of the destination of log messages, the transformation of the message (if required) and the query GUI;
- Controlling of the virtualization system, according to the interface provided by the LINFRA (local infrastructure) team ("Instituto de Telecomunicações", Portugal, Lisbon).

Another important function of the system is the aggregation of the TM health status and the TM State (of the various TM applications) and reporting it to the Operator. This function can be considered an application of the current architecture.

CONTEXT

The TM Services take place in the middle between the domain logic and the infrastructure. In particular, the Figure 1 explains the above concept with a layered structure:

- Domain/Business Layer: functional monitoring and controlling of business logic performed by each application [1, 2];
- Services Layer: Monitors and controls processes on a generic level (not functionality) like web services, database servers, custom applications [3];
- Infrastructure Layer: Monitors and controls virtualisation, servers, OS, network, storage.

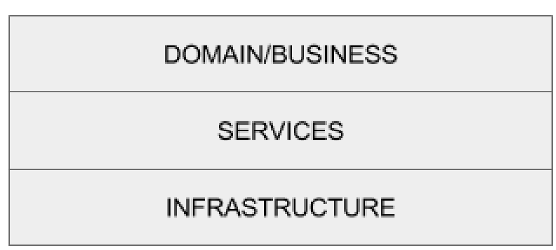

Figure 1: TM SER context.

ENTITY DECOMPOSITION

The entity managed by the TM SER package can be summarized in Figure 2. In particular the central block of the diagram is the **Entity**, that is the main data wherewith every TM Services application refer to. It can be

- a monitored process, that is an OS process that needs to be monitored and controlled or

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EVOLVING A LABVIEW END-STATION SOFTWARE TO A TANGO-BASED SOLUTION AT THE TWINMIC ELETTRA BEAMLINE

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Abstract

Developing and deploying software systems for data acquisition and experiment control in a beamline laboratory can be a very challenging task. In certain cases there is the need to replace and modernize an existing system in order to accommodate substantial beamline upgrades. DonkiOrchestra is a TANGO-based framework for data acquisition and experiment control developed at Elettra Sincrotrone Trieste. The framework is based on an advanced software trigger-driven paradigm developed in-house. DonkiOrchestra is meant to be general and flexible enough to be adapted to the development needs of different laboratories and their data acquisition requirements. This presentation outlines the upgrade of the LabVIEW-based TwinMic beamline control system which hosts a unique soft X-ray transmission and emission microscope. Other than the technical demanding tasks of interfacing and controlling old and new instrumentation with DonkiOrchestra, this presentation discusses the various challenges of upgrading the software in a working synchrotron beamline.

INTRODUCTION

The 2.4/2.0 GeV Italian third-generation synchrotron Elettra operates for users since 1994, 24 hours/day, seven days a week delivering more than 5000 hours/year of synchrotron light from IR to soft x-rays to 28 experimental stations. A substantial facility upgrade, named Elettra 2.0, is currently planned [1]. Every year scientists and engineers from more than 50 different countries compete by submitting proposals to access and perform scientific experiments on these stations. Synchrotron beamlines consist of a complex network of devices, such as sensors, detectors, motors, but also computational resources. The setup is not static and the data acquisition systems are constantly challenged by continues changes and upgrades, so a constant evolution of software technologies is necessary. Within the facility's organisation, the *Software for Experiments* team and the *Scientific Computing* team manage a set of core services spanning from beamline control and data acquisition systems to algorithms for data analysis. These are often deployed in Cloud computing system and advanced storage resources. Moreover a set of web based services for e-Science and Scientific Business management act as the backbone for a complete ICT service.

The present paper reports on the upgrade of the control and acquisition system of the TwinMic beamline, a soft X-ray transmission microscope working in the 400-2200 eV energy range that combines full-field imaging and scanning X-ray microscopy in a single instrument. The extreme versatility of the Twinmic beamline allows it to be utilised for a wide range of scientific experiments and applications; however the existing LabVIEW-based control system is not flexible enough to easily integrate new instrumentation or introduce custom experimental strategies. The age of the existing control system is another good reason for planning its upgrade: it is in use since 2007 when the beamline was opened to the users and is still deployed on an outdated Windows platform. Besides this, the lack of documentation and its monolithic architecture are two serious issues for the maintainability and the upgrades of the code. With the arrival of new instrumentation, like a new advanced sample stage, we took the chance of developing a new data acquisition and control system more flexible, more reliable and fully supported by the IT group. Next sections provide the reader with a technical overview of the upgraded control and acquisition system, that takes advantage of the flexibility and efficiency of DonkiOrchestra, an experiment oriented scheduler designed and developed for the Elettra and Fermi end-stations.

TWINMIC BEAMLINE

The TwinMic beamline at Elettra synchrotron light source hosts the European twin X-ray microscopy station [2], a unique instrument that integrates the advantages of the two typical X-ray microscopy configurations: the transmission X-ray microscopy (TXM) and the scanning transmission X-ray microscopy (STXM). The TwinMic beamline was built in 2006 and the microscope end-station was installed one year later. In the last 10 years the initial setup has been upgraded with the addition of a Low-energy X-ray fluorescence system (LEXRF), and with the availability of some coherent diffractive imaging modalities such as ptychography. The particular Twinmic experimental setup covers a wide range of applications in diverse research fields such as biology, biochemistry, medicine, pharmacology, environment, geochemistry, food, agriculture and materials science.

STXM Operation Mode

In STXM mode, a Zone Plate (ZP) focuses the incoming photon beam, and the specimen is raster-scanned across the microprobe as shown in Figure 1. An order-sorting aperture (OSA) is placed downstream of the

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MEDICIS HIGH LEVEL CONTROL APPLICATION

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Abstract

CERN MEDICIS is a research facility that will produce radioisotopes for medical research using the primary proton beam at ISOLDE and ISOLDE-like targets. It will start operating later in 2017. In this framework, the high-level application for the new MEDICIS beam line is responsible for the control of various equipment, such as power supplies, faraday cups and scanners, as well as the monitoring of environmental parameters such as the vacuum level. It is characterized by a single user-friendly interface to facilitate the operators' tasks.

In this paper, we provide arguments for the chosen solution and give the latest update on the status of the high-level application.

INTRODUCTION

CERN-MEDICIS [1] is a facility to produce radioactive isotopes for medical research. Radioactive isotopes are produced in a dedicated ISOLDE-like target placed between the ISOLDE primary target and the proton beam dump: protons non-interacting in the primary target have the chance to interact in the second one. Once irradiated, the target is removed by a robot and placed in the MEDICIS laboratory, where isotopes are extracted by diffusion in a high-voltage front-end and selected by a mass spectrometer before delivery to the medical research centre.

APPLICATION REQUIREMENTS

As any other beam lines at CERN, MEDICIS (Figure 1) one is equipped with several beam instruments.

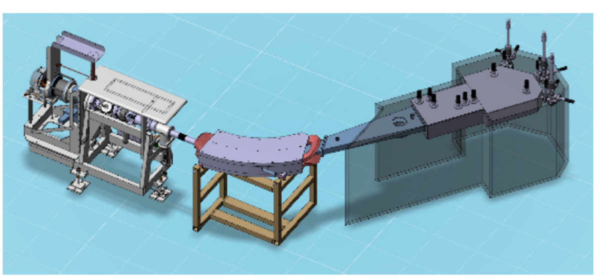

Figure 1: MEDICIS beam line.

Each instrument is provided by a CERN equipment group together with a specific expert user interface. A unified graphical user interface, to control or monitor all the hardware is required to simplify the facility operation and to reduce to a minimum the necessity of continuous monitoring of experts.

Since the MEDICIS facility is composed of a very heterogeneous set of hardware, one of the key point to be taken into account for the general control application is the flexibility: the software architecture should allow the integration in the Graphical User Interface (GUI) of any new devices in an easy way without re-programming the software.

In the following, the overview of the devices to be controlled/monitored is given to focus later on the software architecture chosen to ensure the requested flexibility.

The MEDICIS application represents a use case of an architecture that could totally generic and followed in the future developments of GUI for physics experiments.

HARDWARE

The main hardware to control and monitor are the power supplies, faraday cup, wire scanner vacuum and collection chamber. These devices will be shortly introduced below.

Power Supplies

Several types of power supplies (Figure 2) and converters are installed in the MEDICIS facility depending if there are aiming at beam steering, magnet powering for the beam line spectrometer or target warming for the front end.

A CERN protocol, CMW [2] is used as communication layer between the hardware and the user interface. The CERN power converter team is providing communication layers linked to the equipment [3].

Figure 2: Example of power supply installation.

Faraday Cup

A Faraday cup [4] is a conductive cup designed to intercept charged particles in vacuum. The resulting current can be measured and used to determine the number of ions or electrons hitting the cup.

The CERN beam instrumentation group handles the hardware and low-level control including safety. The CMW is also used to communicate with the higher control level.

Wire Scanner

A wire scanner [5] is installed in a diagnostic box just after the output of the separator magnet. This device is measuring the transverse beam density profile in a particle accelerator by means of a thin moving wire. As the wire passes through the beam the interaction generates a cascade of secondary particles. These are intercepted by a scintillator, coupled with a photomultiplier, which measures the intensity of the light produced. Alternatively, if a conducting wire material is used, the secondary emission electrons created can also be used to measure the beam

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A BUNCH-SYNCHRONIZED DATA ACQUISITION SYSTEM FOR THE EUROPEAN XFEL ACCELERATOR

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Abstract

The linear, super-conducting accelerator at the new European XFEL facility will be able to produce up to 2700 electron bunches for each shot at a repetition rate of 10 Hz. The bunch repetition rate might vary initially between 100 kHz and 4.5 MHz to accommodate the various needs of experiments at three different SASE beam lines. A solution, which is able to provide bunch-resolved data of multiple data sources together in one place for each shot, has been implemented at the European XFEL as an integral part of the accelerator control system. This will serve as a framework for high-level control applications, including online monitoring and slow feedback services. A similar system has been successfully run at the FLASH facility at DESY for more than a decade now. This paper presents design, implementation and first experiences from commissioning the XFEL control system data acquisition.

INTRODUCTION

The idea of a shot-synchronized bunch-resolved data acquisition originates at DESY in the project for the superconducting TESLA test facility (TTF) and its successor, the Free-Electron Laser in Hamburg (FLASH). With TTF as a prototype for a superconducting linear accelerator and FLASH being the first free–electron laser linear accelerator it became imminent to record the data from beam diagnostics and RF devices for analysis purposes.

Since this type of linear accelerator is operated in a pulsed mode, it is desirable to collect the data at its pulse or shot repetition rate. This enables bunch-resolved studies of individual shot data. If all the data of interest for a given shot is made available in a single data structure, analysis will be quite simplified. Since this task is very similar compared to how high-energy physics experiments structure their data and perform subsequent processing and analysis on it, some of their concepts have been re-used to design an accelerator data acquisition type.

One of the conceptual key elements is the event record. It combines all data required for an analysis from various triggered data sources together in one data structure and stamps it with a unique event identification number. This event number is essentially the shot or pulse number of the linear accelerator RF pulse. The shot number attached to the data allows for an easy synchronization after acquisition and does not require the classic approach of retrieving parameters individually and then subsequently synchronize it via timestamps to make correlations e.g.

With the upcoming European XFEL project and its similarity to its smaller colleague FLASH, such a shot-synchronized and bunch-resolved data acquisition was chosen to be a central part of the accelerator control system. Running this kind of acquisition system for more than a decade at the FLASH facility provided a great deal of experience for designing and creating the new acquisition.

The following sections will briefly illustrate the design of the data acquisition system and its parts, present the implementation at the European XFEL linear accelerator control system and show some statistics of current operation.

DESIGN AND LAYOUT

The overall layout of the data acquisition as used for the European XFEL accelerator control system is shown in Fig. 1. It is based on the DOOCS control system framework [1].

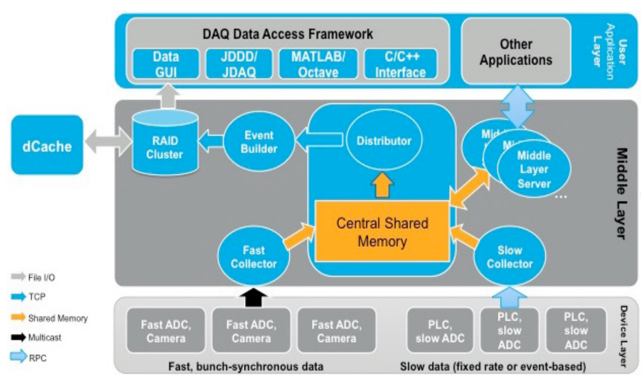

Figure 1: Schematic layout of a single data acquisition instance as used for acquiring shot-synchronized data from MicroTCA systems at the European XFEL linear accelerator control system.

On the device layer MicroTCA-based ADC modules, camera devices as well as PLC and other embedded devices are sending data to collector processes. A fast collector acquires data at the bunch repetition rate from triggered devices and a slow collector polling the data at rates of about 1 Hz from other hardware. The data has been stamped on the front-ends with a unique shot number provided by the timing system. Both collector processes are feeding the received data into a buffer manager using shared memory for storing the data. The distributor process functions as buffer manager and is in charge of managing the shared memory structure. Middle layer processes can connect to the buffer manager and read and/or

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XLive: DATA ACQUISITION AND VISUALIZATION AT THE NSLS-II ISS BEAMLINE

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Abstract

Asynchronous data acquisition at the Inner-Shell Spectroscopy beamline at NSLS-II is performed using custom FPGA based I/O devices ("pizza-boxes"), which store and timestamp data using GPS based clock [1]. During motor scans, incremental encoder signals corresponding to motion as well as analog detector signals are stored using EPICS IOCs. As each input creates a file with different timestamps, the data is first interpolated onto a common time grid. The energy scans are performed by a direct-drive monochromator, controlled with a Power PMAC controller [2]. The motion is programmed to follow the trajectory with speed profiles corresponding to desired data density. The "pizza-boxes" that read analog signals are typically set to oversample the data stream, digitally improving the ADC resolution. Then the data is binned onto a energy grid with data spacing driven by desired point spacing. In order to organize everything in an easy-to-use platform, we developed XLive, a Python based GUI application. It can be used from the pre-experiment preparation to the data visualization and exporting, including beamline tuning and data acquisition.

INTRODUCTION

The NSLS-II ISS Beamline data acquisition system consists of fly-scanning an energy range by moving the monochromator while collecting data from multiple detectors. Encoders and analog signals are sampled using custom FPGA based I/O devices ("pizza-boxes") – that are also able to trigger detectors and read external triggers using TTL inputs and outputs. The minimum acquisition time for analog inputs is 1 µs. Typically the acquisition time used is around 1 ms (after hardware averaging).

Fast and asynchronous data collection allows the beamline to get to the next level of complexity for spectroscopy measurements: n-dimensional data sets. The system is able to handle multiple detectors at the same time, moving users from 2D data sets (energy and intensity) to more complex data sets (e.g. energy, intensity, sample temperature, electric charge in the sample).

The main goal of XLive, a Python based GUI application, is to handle everything needed by the beamline from the pre-experiment preparation to data acquisition, visualization and processing within a reasonable time, being as simple as possible for users and as flexible as possible to be eventually exported to other NSLS-II spectroscopy beamlines.

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DATA ACQUISITION OVERVIEW

The data acquisition system (Figure 1) has three main layers: devices (hardware), EPICS IOCs and data acquisition software (XLive), which can be subdivided in three other layers – Ophyd [3, 5], Bluesky [4, 5] and GUI.

Currently, the beamline gets data from:

- Three ion chambers;
- One PIPS detector;
- Multiple encoders;
- Analog and temperature inputs (PLC);
- SDDs - Silicon Drift Detectors (XIA PXI Crate [6]);
- BPM Cameras (Prosilica GT1290 [7]).

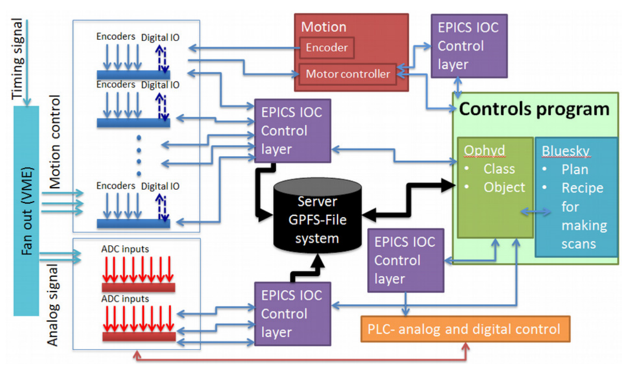

Figure 1: Data Acquisition System overview.

Since the beamline has analog inputs, digital outputs that can be used as triggers and digital inputs available, it is accessible to an assortment of detectors that ca be integrated into the data acquisition system to fulfill users' needs.

Each device is controlled by and share data through an EPICS IOC, which is responsible to control data acquisition and triggers and to generate data files.

Ophyd, a Python library developed by the Data Acquisition, Management and Analysis (DAMA) Group at NSLS-II, is responsible for the EPICS/Python abstraction of the hardware. It contains all the tools to define custom devices, allows direct EPICS PVs reading and writing and defines how each device will work when the system is running a scan.

Bluesky, also a Python library developed by DAMA group, works with objects created using Ophyd. While Ophyd defines the way motors, detectors and other devices will operate, Bluesky is responsible for experiment control and data collection. The beamline defines plans (recipes), containing which detectors and motors will be used and how the data collection will happen. At ISS, depending on the situation, both step and

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ODIN - A CONTROL AND DATA ACQUISITION FRAMEWORK FOR EXCALIBUR 1M AND 3M DETECTORS

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Abstract

Detectors currently being commissioned at Diamond Light Source (DLS) bring the need for more sophisticated control and data acquisition software. The Excalibur 1M and 3M are modular detectors comprised of rows of identical stripes. The Odin framework emulates this architecture by operating multiple file writers on different server nodes, managed by a central controller. The low-level control and communication is implemented in a vendor supplied C library with a set of C-Python bindings, providing a fast and robust API to control the detector nodes, alongside a simple interface to interact with the file writer instances over ZeroMQ. The file writer is a C++ module that uses plugins to interpret the raw data and provide the format to write to file, allowing it to be used with other detectors such as Percival and Eiger. At DLS we implement an areaDetector driver to integrate Odin with the beamline EPICS control system. However, because Odin provides a simple HTTP Rest API, it can be used by any site control system. This paper presents the architecture and design of the Odin framework and illustrates its usage as a controller of complex, modular detector systems.

INTRODUCTION

Diamond Light Source (DLS) are currently developing data acquisition and control software for several modular, high-performance detectors. Excalibur [1] is the result of a collaboration between DLS and STFC and has been implemented for the X-ray Imaging and Coherence beamline I13 to make use of the small pixel size of the detector in coherence diffraction imaging. The Hard X-ray Nanoprobe beamline I14 has more recently chosen a 3M Excalibur system for nanoscale microscopy. Another collaboration, between DLS, Elettra, the Pohang Light Source and STFC, is ongoing to develop the Percival detector [2] for soft x-ray experiments. At the same time, DLS is exploring commercial options in the Eiger from Dectris. Currently, the VMXi (Versatile Macromolecular Crystallography in-situ) beamline is commissioning the first of these; a 4M Eiger X detector [3]. With a multitude of modular and scalable detector systems in development concurrently, an opportunity arose to develop shared control and data acquisition software stacks to drive the systems, designed from the very beginning to be detector agnostic, but with a set of specific use cases to guide the design process.

EXCALIBUR DETECTORS

Excalibur [1] detectors are made up of identical sensor 'stripes', with 8 Medipix3 readout chips. Each stripe has its own FPGA data acquisition card, known as a front-end module (FEM), with a 10Gbit/s optical link. These stripes are combined into a pair to create what is called a 'module'; a 1M 2048 x 512 pixel sensor. A 3M simply consists of 3 stacked modules producing a 2048 x 1536 sensor. A primary feature of the Excalibur is the small pixel size of the sensors, at 55 um x 55 um. A schematic of the 3M Excalibur DAQ system is shown in Fig. 1. The design follows a generic data acquisition framework for detectors, where the Linux cluster receiving the data simply sees a set of parallel data links. This allows the software supporting the framework a large amount of abstraction, simplifying the architecture. The Excalibur is currently operated at DLS with an EPICS areaDetector driver [4] controlling and acquiring data from each individual FEM, with a top level IOC presenting PVs wired through to the underlying processes. However, this system is limited both in its control flexibility and its data throughput and is intended to be replaced by the Odin software stack, described in this paper.

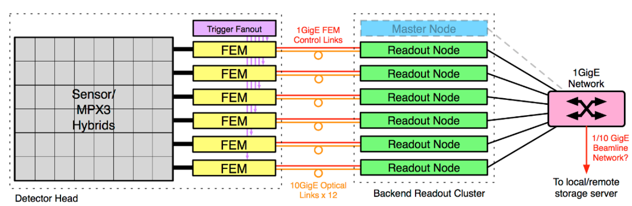

Figure 1: A schematic of the Excalibur 3M system [5].

AN OVERVIEW OF ODIN

Devices consisting of multiple individual parts can lead to complications in the control layer trying to get operate them together in unity. The Odin software framework is designed specifically for this modular architecture by mirroring the structure within its internal processes. The data acquisition modules have the perspective of being one of many nodes built into the core of their logic. This makes it straightforward to operate multiple file writers on different server nodes working together to write a single acquisition to disk, all managed by a single point of control. It also means that the difference in the data acquisition stack of a 1M system and a 3M system can be as little as duplicating a few processes and modifying the configuration of the central controller. Given the collaborative nature of the detector development, the software framework has been designed to

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EXPERIENCE AND PROSPECTS OF REAL-TIME SIGNAL PROCESSING AND REPRESENTATION FOR THE BEAM DIAGNOSTICS AT COSY

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Abstract

Diagnostics of beam parameters is vital for the operation of any particle accelerator and contributes to the precision of the physics experiments. At COoler SYnchrotron of the Forschungszentrum Jülich there are several beam instrumentation subsystems with data acquired and processed in real-time for machine and operator use to ensure safe and efficient performance. Here are presented current development for the Beam Loss Monitor (BLM) with regard to usage of field programmable gate arrays (FPGAs) to achieve fast data processing and integration into the Experimental Physics and Industrial Control System (EPICS) used at COSY. Also presented is a way to create and run Graphical User Interfaces based on EPICS variables with Control System Studio (CSS) connected to a data archiving system to display and use previously collected data.

COOLER SYNCHROTRON

Jülich particle accelerator and storage ring COSY (figure 1) is operated for proton or deuteron beams in the energy range of 45-2880 MeV for protons. Beam polarization,

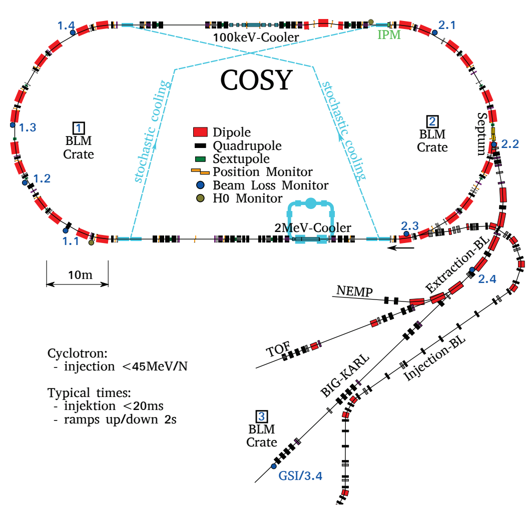

Figure 1: COSY elements: red, black, and smaller dark green blocks - magnets, blue circles - BLM detectors, green circles - H0 detectors (for neutral particles from electron cooling);

stochastic and electron cooling, storage times between few seconds to several hours and the flexibility of beam optics make COSY an ideal research site with a physics programme including machine studies and detector tests for FAIR project and preparations of the measurement of electric dipole moment experiments (EDM [1]). The same features are posing a diagnostic challenge for the beam parameter monitoring. One such parameter is beam loss rate.

BEAM LOSS MONITOR

The beam loss monitor system (BLM) shows loss of particles from the beam orbit. There are numerous processes during machine adjustment and operation contributing to beam losses, which are not easy to quantify or predict. This imposes several requirements on a BLM system: permanent and fast monitoring, logging, and feedback to the operators.

The BLM system in COSY consists of 9 radiation detectors (7 along the ring and 2 on the extraction beam line) (cf. figure 1). Figure 2 shows the signal flow scheme of each BLM crate.

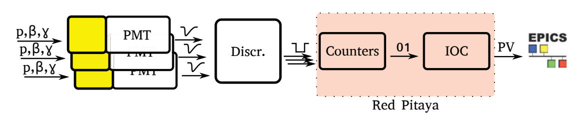

Figure 2: BLM signal flow scheme: particles produce light in the scintillator, which is then converted to analogue electrical signals in the photomultiplier; these are discriminated and then digitized by the Red Pitaya (DAQ); the counts are collected and published to the EPICS [2] network from the IOC.

HARDWARE

The radiation detectors are made of encapsulated scintillating material (plastic or liquid) coupled with photomultiplier tubes (PMT). The detectors were calibrated using radioactive sources and deployed along the ring in likely or known loss locations. Installation of more detectors is planned. Each BLM crate contains modules for PMT high-voltage and preamplifier voltage supply, as well as a discriminator module developed and produced in Forschungszentrum Jülich. The discriminators are able to process both positive and negative detector pulse polarities, with 2 mV granularity (figure 3) and have 5 analogue inputs. The data acquisition (DAQ) is performed by a Red Pitaya board [3], which is embedded in each discriminator module.

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CURRENT STATUS OF IPM LINAC CONTROL SYSTEM

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Abstract

This paper reports the progress of the control system for IPM 10 MeV accelerator. As an electron linac, it consists of beam injection acceleration tube, radio frequency production and transmission, target, diagnostics and control and safety. In support of this source, an EPICS-based integrated control system has been designed and being implemented from scratch to provide access to the critical control points and continues to grow to simplify operation of the system. In addition to a PLC-based machine protection component and IO interface, a CSS-based suite of control GUI monitors systems including Modulator and RF, Vacuum, Magnets, and electron gun. An overview of this system is presented in this article.

INTRODUCTION

The IPM Electron Linac is an 8 MeV (upgradable to 11 MeV) electron linear accelerator under development at the Institute for Research in Fundamental Science (IPM), Tehran, Iran. Design and development of this linac is in its final steps and it will be commissioned within next few months.

This machine is an S-band travelling wave linac with the current of up to maximum 10mA that works in $\pi/2$ phase advance operation mode. The main parameters of the machine are given in Table 1.[1]

Table 1: e-Linac Parameters

Parameter	Value
Beam Energy	8 MeV
RF operating frequency	2997 MHz
Max. Beam current	10 mA
Pulse Repetition Frequency (PRF)	250 Hz
Injection energy	45 keV
Pulse width	10 µs

While the accelerator is being built and brought online, a remote control system is being developed in parallel to run it, with features added on demand as the accelerator grew in complexity and as tasks amenable to automation became apparent. For this control system, we had several choices as the basis for the bulk of the control system. We used Siemens Step7-300 PLC which provide basic IO and machine protection functionality. For this reason, on the first steps of designing and implementing of the control system, we also selected WinCC because of its good integration with S7 PLC's. Some GUI screen designed by WinCC to operate the Beam injection subsystem.

In the latter design of the control system, we choose EPICS as the main control system architecture because of its flexibility to communicate with devices with various protocols and also gain the experience of using EPICS due to its wide usage in large accelerator facilities.

OVERALL ARCHITECTURE OF CONTROL SYSTEM

Control system of IPM e-Linac follows a standard "three-layer" model of distributed architecture, which are OPI layer (operator interface), the front-end layer, and the device control layer. One set of PC/Linux are used for EPICS IOC development and Client Apps. The platform of the control system is based on EPICS system, which is widely applied in large accelerator facilities. EPICS provides a structure of three parts: IOC (Input and Output Controller) running on server-end, CA (Channel Access), OPI (Operator Interface) running on client-end [2]. In this control system, EPICS plays an important role in order to connect different devices with different protocols to the control system. As shown in Figure 1, the Soft IOC runs on a Linux client console that communicates with client application such as CSS, Matlab etc. with channel access protocol.

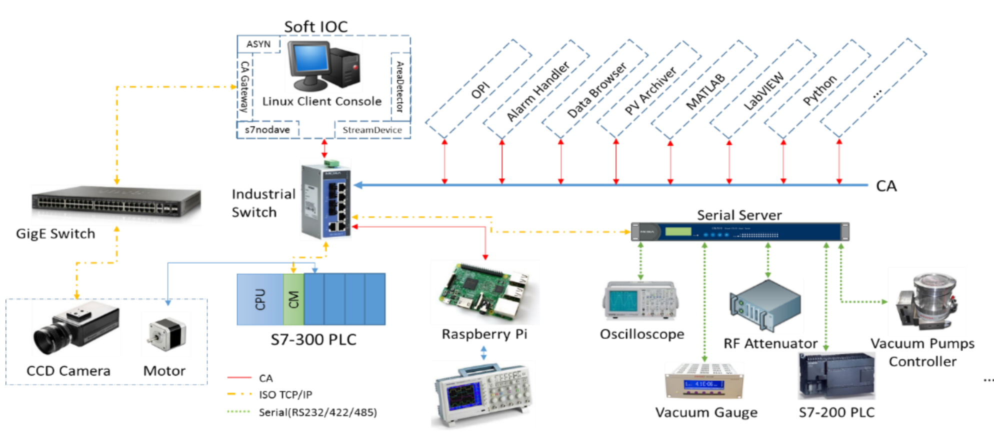

Figure 1: Layout of IPM e-Linac control system network architecture.

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CREATING INTERACTIVE WEB PAGES FOR NON-PROGRAMMERS*

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Abstract

This paper describes a new web page creation system that allows web developers with limited programming experience to create interactive displays of control system data. Web pages can be created that display live control system data updating in real-time, as well as data stored within our logging/archiving and database systems. Graphical, tabular, and textual displays are supported as well as standard interaction techniques via buttons, menus and tabs. The developer creates a web page using a custom web page builder. The builder presents a web page as a user-defined grid of tiled cells. The developer chooses the display style of each cell from a list of available cell types and then customizes its data content. Final polish can be applied using HTML and CSS. Specialized tools are available for creating mobile displays. This paper shows examples of the web pages created, and provides a summary of the experience of both the web developers and users.

INTRODUCTION

The Operations group within the Collider-Accelerator department at BNL has the job of setting up and running our many machines in a way that satisfies the physics experiments currently in progress. As part of that job, they need to communicate the status of the facilities to experimenters and internal machine specialists, as well as scientists around the world that are interested in our research.

Our Operations personnel are trained as physicists and generally have little or no web programming experience. So, they have had a difficult time over the years putting together web pages that provide user interaction and live displays. This paper describes work done to address this problem. The goal was to put together a web page construction tool that would let a developer create interactive and live updating web pages without having to understand web programming beyond some familiarity with HTML tags and CSS styling. A similar system was developed at DESY for building synoptic displays [1].

WEB PAGE BUILDER

The approach taken was to construct a web-based tool that lets the user create and view a web page in a way that closely matches the way that web page would be displayed. The user lays out the web page as a grid of tiled cells of varying sizes. Then the content of each cell is adjusted so that it either 1) displays data (label, table, chart, etc.), or 2) provides UI interaction (link, button, menu, etc.). The finished product is saved in an XML file. An example builder window is shown in Fig. 1.

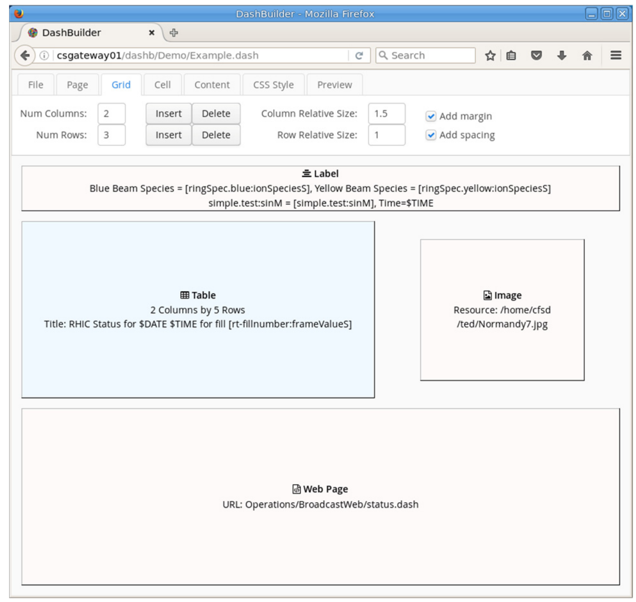

Figure 1: Web page construction interface

As seen above, the web page construction tool, which we call DashBuilder, is itself a web page that contains several tabs where the user defines various aspects of the web page that is to be built. Below is a summary of the functionality on each of the tabs:

- File – The web page description is stored in a file. This tab shows the file currently being edited and allows for saving, versioning, and switching the file.
- Page – Here a user indicates how frequently the web page should be updated (1-60 secs). The user can also specify the tabs to be shown and what should fill them. A theme can also be applied.
- Grid – This tab specifies the size (number of rows and columns) of the cell grid that should be used. Here the user can also specify the relative size of the selected row and column.
- Cell – Here a user defines the size of the selected cell by specifying the number of rows and columns that the cell spans. Adjustments can also be made in terms of width/height percentage and alignment.
- Content – The content of the selected cell is specified here. Choices include Label, Image, Video, Table, Link, Web Page, Slide, PPM Select, Time Select, Web Select, Tree Select, Pet Page, Gpm Monitor, Logged Data, FDA Plot. Once a choice is selected, the user can specify details, for example, the path to a Web Page or the contents of a Table.
- CSS Style – Final polish to the page can be specified on the CSS tab. Here, all the normal CSS styling rules apply. Each cell type has a known CSS class name, or the user can specify a CSS name for a cell.

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PShell: FROM SLS BEAMLINES TO THE SwissFEL CONTROL ROOM

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Abstract

PShell is a DAQ scripting tool developed at PSI, in use since beginning of 2015. Initially a beamline data acquisition system at SLS, PShell is being used by various groups for creating tools for the commissioning and operation of the SwissFEL machine.

New features were added to meet SwissFEL requirements, such as supporting beam synchronous data and streamed cameras. In addition to providing a workbench for developing data acquisition logic, PShell also offers a convenient way to create user interfaces ("panels") to trigger the execution of logic. In order to improve user experience and to simplify operation tools these panels can also be launched and used as stand-alone applications.

INTRODUCTION

The PShell project started in 2014. Data acquisition software is not standardized at PSI and the Controls Group aimed selecting a preferred solution, to which it could provide long term support. This tool was meant to be offered as an alternative to new systems, and also for replacing existing aged or ad-hoc solutions. It should be a natural successor of FDA, another DAQ software developed in-house, which had a graphical and declarative programming style, but showing limitations, as many use cases fit better the use of scripting.

The make or buy decision was not trivial. The group spent time assessing existing alternatives such as GDA [1], and Sardana [2], but a different concept was aimed. It was intended a lighter and more flexible solution, based in modern tools, aligned with the standard protocols at PSI: REST [3] for service configuration, ZMQ [4] for data streaming, EPICS for hardware access. Furthermore, a tool not attached to a GUI toolkit, not using any heavy framework. The GUI aspects should be entirely detached and the final goal is the use of web and mobile interfaces. Even if the main GUI environment (called "workbench") is currently Swing-based, it is a stepping stone towards a full functional web based front end.

Another non trivial decision was the technology to use – Java or Python. Java offers a more stable development platform, allowing more control of the project in the long time, providing greater reliability due to the nearly inexistence of native code, and also providing frictionless updates – what was particularly interesting for a server software intended to have high availability. Java offers great advantages regarding deployment as well, comparing to Python. Furthermore, it would simplify rich client development and enable scripting on any dynamic language supported by the Java scripting API, such as Python (with Jython 2.7 [4]) or JavaScript. The Python platform have, in other hand, NumPy and the scientific software stack based on it, which would enable data analysis embedded in the data acquisition scripts, using libraries known to the user. NumPy cannot be loaded directly in Jython because it contains native libraries.

The reasoning for the choice of Java was that, even in a pure-Python solution we cannot avoid interfacing to external data analysis software: for performance reasons, and also for interacting with code written in MATLAB or a different version of Python. Another push for the Java solution is the existence of ways to run CPython code in the same process with little overhead, such as JEP [5], which is a solution for non-demanding cases.

ARCHITECTURE

The project is based on Java 8. In the beginning of the project it was clear the great variety of uses of this software, as different beamlines had different experiences, tools and expectations. The focus was standardizing the logic and data layer, but leaving the users free on the choice of GUI. In this way even if beamlines have different preferences for interfaces, the DAQ code is homogeneous.

To reach this goal PShell provides architectural freedom. Logic is executed by a core engine, and interfaces can be CLI (using the command line interface), GUI (the embedded workbench, running on the same process as the core), remote (a custom developed application), web (using the built-in web client or a custom web application) or mixed. The core engine can also be embedded in other Java applications.

The workbench can be the user front end, or else just used as a development environment. PShell can be executed then in pure server mode, having custom user graphical interfaces.

Remote access benefit from a built-in web server and a REST interface. Writing client code is simple. Remote calls typically trigger and monitor script execution, evaluate interpreter statements, monitor devices and access data.

Regardless the architectural choice, PShell runs in a single process, and is deployed as a single jar file. Figure 1 shows a diagram of the relations between the system components.

Core Engine

The core engine consists of:

- Script interpreter based on the Java Scripting API. Python is the primary language (Jython 2.7) but JavaScript and Groovy are also supported. A set of built-in functions is available for user scripts, simplifying scanning, plotting, data persistence and data

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WEB AND MULTI-PLATFORM MOBILE APP AT ELETTRA

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Abstract

A few apps have been recently developed at Elettra Sincrotrone Trieste. The main requirements are the compatibility with the main mobile device platforms and with the web, as well as the "mobile-first" user interface approach. We abandoned the possibility of developing native apps for the main mobile OSs. There are plenty of libraries and frameworks for the development of modern cross platform web/mobile applications. In this scenario the choice of a particular set of libraries is crucial. In this paper we will discuss the motivation of our choice trying to compare it with the other possibilities in regard to our particular use cases, as well as the first applications developed.

INTRODUCTION

In late 2016 we developed a hybrid app called elettrApp, this app was based mainly on Apache Cordova and jQuery. In May 2017 started a 12 months project called PWMA (Platform for Web and Mobile Applications) based mainly on WebSockets and React Native. Although we are still at the beginning, the results already obtained are very encouraging and we are confident to reach much better results in the near future.

ELETTRAPP

Requirements

- **Multiplatform** We considered the possibility to build a hybrid app more attractive than a native app for Android because hybrid apps can run on all the main mobile platforms and on the web.
- **Fast development** Most of the development was done by a bachelor's degree student as his thesis. The time available wasn't much longer than two months. We expected to develop an app equivalent to a single synoptic panel already implemented as a native GUI (Graphic User Interface) written in C++ and Qt, but hybrid apps development was so quick that allowed to include a few other screens, one of them much more complicated.
- **All in one application** Our users asked explicitly for a unique mobile app as an interface for all tasks.

Technology

- **Apache Cordova** allows to develop hybrid apps that is: "Hybrid apps embed a mobile web site inside a native app. [...] This allows development using web technologies [...] while also retaining certain advantages of native apps (e.g. direct access to device hardware, offline operation, app store visibility)."[1]. We used an excellent documentation [2] which allowed us to be productive almost immediately. Apache Cordova runs on the mobile browser, but the browser is hidden to the user so that the application looks like a native application. The browser implies some inefficiency in comparison to native apps, but the only sector interdicted is interactive gaming. An other important feature of hybrid apps is the possibility to download from the web not only data but also templates (in form of HTML (HyperText Markup Language) and JavaScript files). This makes an app much more expandable and flexible [3].
- **jQuery** is a cross-platform JavaScript library designed to simplify the client-side scripting of HTML [4]. jQuery contributed significantly to speed up the development time in respect to vanilla JavaScript [5]. jQuery is responsible of connecting asynchronously to a REST (REpresentational State Transfer) server. We used only client to server connections (polling).
- **Bootstrap** is a free and open-source front-end web framework for designing websites and web applications. It contains HTML- and CSS-based (Cascading Style Sheet) design templates [6]. Bootstrap implements a “mobile first” design [7]. From the developer point of view, using Bootstrap requires little more effort than writing basic HTML, but the user experience is greatly improved.

- **Ionic** We tried to use Ionic [8] but the benefits from this framework didn't come quickly enough, so we aborted this part of our development. This was due to the fact that Ionic require AngularJS [9] which is a JavaScript framework completely different from jQuery.

Architecture

The first screen is a basic starter composed by a button for each task plus a tick which makes the task chosen the default.

The tasks are: synoptic status (for 2 accelerators and a complex system), cAstor, a starter administration tool similar to TANGO Astor (for 3 accelerator domains) and a shift calendar (for 2 groups).

- **Synoptic status** A common pattern is shared by all synoptic status. Each synoptic screen is composed by one or two charts. The charts are always on top because our users asked to put them in evidence. Charts are embedded in an <iframe> tag using

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ONLINE LUMINOSITY CONTROL AND STEERING AT THE LHC

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Abstract

This contribution reviews the novel LHC luminosity control software stack. All luminosity-related manipulations and scans in the LHC interaction points are managed by the LHC luminosity server, which enforces concurrency correctness and transactionality. Operational features include luminosity optimization scans to find the head-on position, luminosity levelling, and the execution of arbitrary scan patterns defined by the LHC experiments in a domain specific language. The LHC luminosity server also provides full built-in simulation capabilities for testing and development without affecting the real hardware. The performance of the software in 2016 and 2017 LHC operation is discussed and plans for further upgrades are presented.

INTRODUCTION

The luminosity at an interaction point of a circular collider with Gaussian beams is given by [1]

$$\mathcal{L} = \frac{f_{\mathrm{rev}} N_1 N_2 n_{\mathrm{bunch}} \gamma}{4\pi\beta^* \varepsilon} \mathcal{G}\,\mathcal{S} \tag{1}$$

where f_{rev} is the revolution frequency, $N_{1,2}$ are the average bunch intensities in beam 1 and beam 2, respectively, n_{bunch} is the number of colliding bunches, β^* is the β-function at the interaction point, γ is the relativistic factor and ε is the normalized transverse emittance. $\mathcal{S}$ and $\mathcal{G}$ are luminosity reduction factors due to separation and crossing angle.

For beams crossing at an angle, the *geometric factor* $\mathcal{G}$ is

$$\mathcal{G} = \left(1 + \left(\frac{\sigma_z}{\sigma}\frac{\alpha}{2}\right)^2\right)^{-0.5} \tag{2}$$

for a crossing angle α, a transverse beam size of σ and a bunch length of σ_z. The plane (horizontal or vertical) in which the crossing angle is applied is commonly referred to as the “crossing plane”, while the other plane is called the “separation plane”.

The *separation factor* $\mathcal{S}$ is given by

$$\mathcal{S} = \exp\left(\frac{-d^2}{4\sigma^2}\right) \tag{3}$$

for a total separation of d between the two beams and a transverse beam size of σ (Fig. 1). If the beams are separated in the crossing plane, an additional correction for the combined effect of separation and crossing angle has to be made [1].

At the LHC, the luminosity control software primarily controls the luminosity by displacing one or both beams using a closed orbit bump, effectively introducing a separation. However, a functionality for changing the crossing angle in collisions has been implemented for the 2017 LHC proton physics run, and using β^* for luminosity control is foreseen for the future.

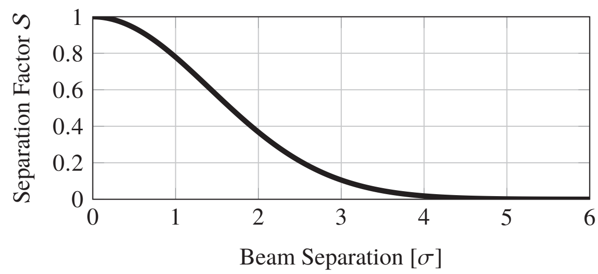

Figure 1: Separation factor as a function of the beam separation (in units of the beam size σ).

LHC Experiments

The LHC consists of two vacuum pipes where two particle beams travel in opposite directions. The two beams enter a common beam pipe in the four LHC interaction regions and collide at the Interaction Points (IP) inside the detectors of the experiments: IP1 (ATLAS experiment), IP2 (ALICE experiment), IP5 (CMS experiment) and IP8 (LHCb experiment). ATLAS and CMS are high-luminosity experiments designed to take data at the full LHC design luminosity of $10^{34}\ \mathrm{cm^{-2}s^{-1}}$. ALICE and LHCb take data at lower rates, and require to lower the luminosities in their IPs by partially separating the beams.

Use Cases

The operational use cases for the LHC luminosity control software stack include:

- **IP steering.** Let the operator directly modify the beam positions at any IP, e.g. for machine tests or at the request of the experiments.
- **Optimization.** Scan the beam separation while acquiring the luminosity signal to find the beam head-on position giving maximum luminosity [2].
- **Luminosity Calibration.** Perform separation scans synchronized with the experiments to calibrate the absolute luminosity measurement using the van-der-Meer method [3, 4].
- **Luminosity Levelling.** At a given IP, keep the luminosity constant around a target value, provided by the experiment or by the operator, by adjusting the beam separation [5].
- **Orchestration of setting changes.** Smoothly adjust machine parameters like the crossing angle and/or the β^* [6, 7] while the beams are in collision to optimally use margins while improving the luminosity (e.g. with decreasing beam intensities, the crossing angle can be decreased).

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THE LASER MEGAJOULE FACILITY: PERSONNEL SAFETY SYSTEM

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Abstract

The Laser MegaJoule (LMJ) is a 176-beam laser facility, located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy to targets, for high energy density physics experiments, including fusion experiments. The first 8-beams bundle was operated in October 2014 and a new bundle was commissioned in October 2016. The next two bundles are on the way. The presentation gives an overview of the Personnel Safety System architecture, focusing on the wired safety subsystem named BT2. We describe the specific software tool used to develop wired safety functions. This tool simulates hardware and bus interfaces, helps writing technical specifications, conducts functional analysis, performs functional tests and generates documentation. All generated documentation and results from the tool are marked with a unique digital signature. We explain how the tool demonstrates SIL3 compliance of safety functions by integrating into a standard V-shaped development cycle.

LMJ PROCESS HAZARDS

LMJ process hazards types are laser, high voltage, and radiations. These hazards are transmitted between bays as shown in Fig. 1. High voltage hazard are generated in capacitor bays and transmitted to laser bays. In laser bays, electrical energy is transformed into laser energy. Laser beams then travel to target bay, where physics experiment occurs. Experiments may generate radiations (X, neutrons…). These radiations may be transmitted to some diagnostics rooms.

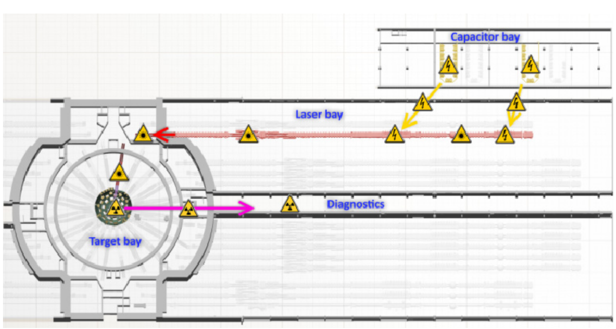

Figure 1: LMJ hazards.

PERSONNEL SAFETY SYSTEM

The PSS protects personnel by managing risks presence and transmission between bays, using safety interlocks and transmission barriers. The PSS manages personnel presence using access control and doors switches.

Conception follows International Electrotechnical Commission 61508 standard. The PSS is built around two systems named “BT1” and “BT2”. These systems are designed using different technologies. Both BT1 and BT2 systems manage hazards and the presence of staff. Figure 2 shows PSS architecture.

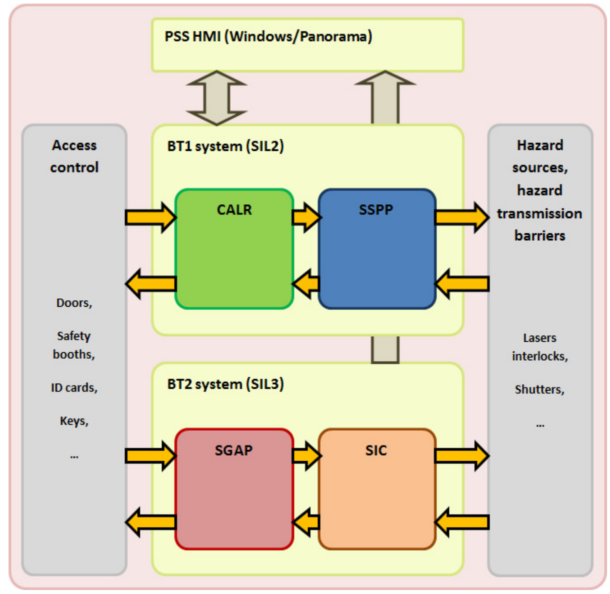

Figure 2: PSS subsystems.

The PSS architecture is detailed in a previous paper [1].

BT1 Subsystem

The BT1 system is designed using programmable technology, following IEC61508 requirements to achieve Safety Integrity Level 2. It is composed of two subsystems named SSPP (“Système de Sécurité du Personnel Programmé” – Programmed Personnel Safety System) and CALR (“Contrôle d’accès des Locaux à Risques” – Hazardous Premises Access Control).

SSPP subsystem manages all process hazards (lethal and non-lethal) of LMJ facility, such as pointing laser beams hazard.

CALR subsystem performs access control on all process bays using safety booths and contactless ID cards.

The BT1 system is operated through a computer HMI.

It is currently operational.

BT2 Subsystem

The BT2 system is designed using non-programmable technology, following IEC61508 requirements to achieve SIL3. BT2 logic is built using PLANAR4 products from HIMA. It is composed of two subsystems named SIC (“Système d’Inter verrouillage Centralisé” – Centralized Interlock System) and SGAP (“Système de Garantie d’Absence de Personnel” – Absence of Personnel Proof System).

The BT2 system focuses on nuclear safety and on lethal hazards.

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SYSTEM IDENTIFICATION AND CONTROL FOR THE SIRIUS HIGH-DYNAMIC DCM

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Abstract

The monochromator is known to be one of the most critical optical elements of a synchrotron beamline. It directly affects the beam quality with respect to energy and position, demanding high stability performance and fine positioning control. The new high-dynamic double-crystal monochromator (HD-DCM) [1], prototyped at the Brazilian Synchrotron Light Laboratory (LNLS), was designed for the future X-ray undulator and superbend beamlines of Sirius [2], the new Brazilian 4th generation synchrotron. The next generation machines demand higher stability performance than at the previous ones, both at the accelerator and at the beamlines, requiring improved solutions to deal with factors such as high-power loads, power load variations, and vibration sources. This paper describes the system identification work carried out for enabling the motion control of the mechatronic parts composing the HD-DCM. The tests were performed in MATLAB/Simulink Real-Time (RT) environment, using a Speedgoat RT Performance Machine as a RT target. Sub-nanometric resolution and nanometric stability at 250 Hz closed loop bandwidth in a MIMO system were the main design targets. Frequency domain identification tools, control techniques and the first partial results are presented in this paper.

INTRODUCTION

Sirius is a 4th generation synchrotron light source that is planned to be commissioned in mid-2018 in Brazil. Its low emittance (0.25 nm.rad) [3] makes it one of the world's brightest light sources of its kind. Due to the high quality of the photon beam, the Sirius beamlines are expected to present cutting-edge technologies in their fields.

In existing 3rd generation light sources X-ray beamlines, double-crystal monochromators (DCMs) are known to be one of the main current bottlenecks in their overall performance [4]. Indeed, the stability of this instrument affects both the energy selection and the position of the beam at the sample. Given the very small source sizes and large optical lever-arms in long beamlines, the DCMs must have the angular stability in the parallelism between crystals not greater than a few nanoradians to keep the source quality.

A new DCM concept started to be studied in 2015 at LNLS, after the output of the ESRF DCM Workshop in 2014. The target was to bring the parallelism stability levels to a new standard. To achieve this goal, it was decided to go to a totally innovative design, based on high-end mechatronics technology.

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The mechanical design is briefly presented in the next section. Next, the hardware, the software, and the background theory are described. Finally, the first results of system identification and closed loop control are shown.

The partial results of the core of the HD-DCM (Fig. 1) were 9.2 nrad in relative pitch and roll, and 0.9 nm in relative gap (RMS values integrated from 0 to 2500 Hz). These results were obtained with the fixed Bragg angle and in air at room temperature.

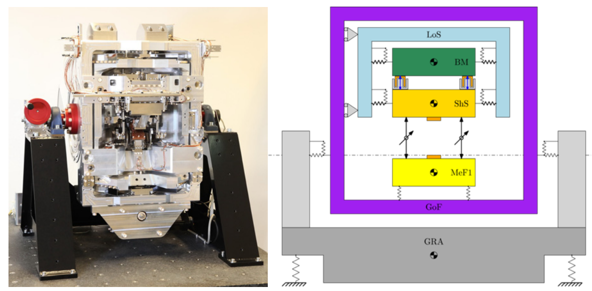

Figure 1: Left: core of the HD-DCM on dummy bearings; Right: HD-DCM core assembly schematic.

HD-DCM DYNAMIC CONCEPT

The system consists of a vertically deflecting DCM with 18 mm beam offset. It has a main rotating frame (Gonio Frame, GoF in Fig. 1) that is guided by bearings at both sides and driven by an in-vacuum direct driver motor, with an angular working range from 3 to 60°. (These bearings are stiffly mounted to the HD-DCM vacuum chamber and supporting structure, represented by a granite frame (GRA) in Fig. 1.) The HD-DCM was designed with two crystal sets, originally planned to be Si(111) and Si(311) in the energy ranges from 2.3 to 38 keV and from 4.4 to 72 keV, respectively. The first crystals are stiffly mounted to a reference frame (Metrology Frame, MeF1 in Fig. 1), which is in turn stiffly fixed to the GoF. By having the main rotation axis coincident both with the incoming beam and the surface of the first crystals, the beam walk and thermal bump effects in the first crystals can be minimized. To handle the power load of about 100 W, with a power density of about 50 W/mm^2, the crystals are indirectly cryocooled via compliant LN_2 feeding tubes.

Since the first crystals are fixed to the GoF, all the relative degrees of freedom (DoF) that are necessary for fine alignment between crystals are limited to the second crystals, which are also indirectly cryocooled simply by copper braids. Aiming at the highest repeatability and stability performance, only the essential DoF were implemented, namely: one translation for the gap between the crystals, which is necessary to keep constant beam offset; and two rotations, pitch and roll, for tuning. As a mechanism with nanometer level performance and several millimeter range

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uSOP: AN EMBEDDED LINUX BOARD FOR THE BELLE2 DETECTOR CONTROLS

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Abstract

Control systems for scientific instruments and experiments would benefit from hardware and software platforms that provide flexible resources to fulfill various installation requirements. uSOP is a Single Board Computer based on ARM processor and Linux operating system that makes it possible to develop and deploy easily various control system frameworks (EPICS, Tango) supporting a variety of different buses (I2C, SPI, UART, JTAG), ADC, General Purpose and specialized digital IO. In this work, we describe features and architecture of uSOP board and its deployment as a monitoring system for the Belle2 experiment, presently under construction at the KEK Laboratory (Tsukuba, Japan).

INTRODUCTION

In the last few years companies and no-profit organizations, exploiting availability of powerful microprocessors at low price, have developed various Single-Board Computers (SBCs) to fullfill different users requirements. Projects like Raspberry Pi [1], BeagleBone Black [2], are only some examples of this trend. Main advantages of SBCs usage are low price, good performance, compactness and widespread operating systems (e.g. Linux).

Despite such advantages a common SBC is not suitable “as is” for a custom task. In industrial or scientific fields there are standards or form factor to be compliant with, electronic interfaces or custom busses to adopt, and integration of an off-the-shelf SBCs is not so easy.

The availability of electronic schematics and PCBs with Open-source Hardware license for various SBCs overcome these integration problems making feasible the implementation of a custom SBC composed by a central core inherited from off-the-shelf SBC (microprocessor, static RAM, flash memory) and various peripherals required to integrate a new architecture into a specific environment. With this approach the custom SBC user will keep exploiting all supported tools and software provided by SBC community: a very powerful help in satisfying all constraints enforced by his scientific or industrial environment.

THE USOP BOARD

The uSOP board (Fig. 1) is derived from BeagleBone Black Open-source Hardware project. It has been designed as expandable platform to run applications in controls and monitoring of sensors, detectors and other complex scientific research equipment.

Physical Layout

The board has an Eurocard 3U form factor and it is possible to use it in stand-alone mode or as a plug-in unit inside an Eurocard crate. It is powered by an external regulated supply at 5V with a typical power consumption of less than 3W.

The on-board power distribution has been segmented to provide a clean supply for acquisition peripherals. The noisy digital domains are powered with high-efficiency Point-Of-Load switching regulators while linear regulators supply the more demanding, high-speed I/Os like USB and Ethernet. Thermal shutdown, over-current and short-circuit protection are guaranteed by design for safe operation in hostile and limited access environments [3].

Hardware Features

The processor of uSOP board is the Texas Instrument Sitara AM335x (Cortex-A8 SoC) which runs up to 1 GHz clock rate. It provides a large set of serial busses: I2C, SPI, CAN, USB and it is also equipped with Ethernet ports, mass storage interface and 12-bit ADC. Two coprocessors (Programmable Real Time Units – PRU) are also available.

In the present version, uSOP has 512 Mbyte RAM and 4 Gbyte of mass storage by on-board eMMC. Dual instances of SPI, I2C and UART are available and all of them are galvanically isolated with separate supplies (5V, 12V) in order to power remote sensors and acquisition boards with ADCs, DACs and other peripherals. JTAG protocol is also available by software using a set of galvanically isolated GPIO pins. Two 8-bit expansion connectors allow usage of additional GPIO pins for custom protocols implementation and four buffered 12-bit ADC are available to the user.

uSOP board has been designed to run in harsh and unattended environments and the most critical system operations can be performed remotely by a dedicated out

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MANAGING YOUR TIMING SYSTEM AS A STANDARD ETHERNET NETWORK

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Abstract

White Rabbit (WR) is an extension of Ethernet which allows deterministic data delivery and remote synchronization of nodes with accuracies below 1 nanosecond and jitter better than 10 ps. Because WR is Ethernet, a WR-based timing system can benefit from all standard network protocols and tools available in the Ethernet ecosystem. This paper describes the configuration, monitoring and diagnostics of a WR network using standard tools. Using the Simple Network Management Protocol (SNMP), clients can easily monitor with standard monitoring tools like Nagios, Icinga and Grafana e.g. the quality of the data link and synchronization. The former involves e.g. the number of dropped frames; The latter concerns parameters such as the latency of frame distribution and fibre delay compensation. The Link Layer Discovery Protocol (LLDP) allows discovery of the actual topology of a network. Wireshark and PTP Track Hound can intercept and help with analysis of the content of WR frames of live traffic. In order to benefit from time-proven, scalable, standard monitoring solutions, some development was needed in the WR switch and nodes. The paper describes these developments and shows many examples of the benefits brought about by this strategy.

INTRODUCTION

Timing networks are custom networks, with limited bandwidth and use of custom technologies. This limits possibilities of using many standard network tools and protocols.

For example, the General Machine Timing (GMT) used at CERN is based on uni-directional 500 kb/s RS422 links, and allows operators and users to synchronize different processes in CERN's accelerator network. The system has a number of shortcomings though, among which the most important are the limited bandwidth and the impossibility of dynamically evaluating the delay induced by the data links. White Rabbit is foreseen as a successor technology for GMT.

THE WHITE RABBIT NETWORK

The White Rabbit network [1] [2] achieves sub-nanosecond timing accuracy by implementing both layer 1 syntonization and an extension of The IEEE 1588-2008 (Precise Time Protocol, PTP) standard [3]. Layer 1 syntonization enables reference frequency distribution among devices in a WR network. On the other hand, IEEE 1588-2008 is a packet-based-protocol that performs the time synchronization among the WR nodes. The fact that data transmission is independent of clock transmission can reduce the cost of infrastructure needed for monitoring of end-nodes.

WR Network Architecture

Figure 1 shows the layout of a typical WR network. Data-wise it is a standard Ethernet switched network, i.e. there is no hierarchy. Any node can talk to any other node. Regarding synchronization, there is a hierarchy established by the fact that switches have downlink and uplink ports. A switch uses its downlink ports to connect to uplink ports of other switches and discipline their time. The uppermost switch (Grand Master) in the hierarchy receives its notion of time through external TTL Pulse Per Second (PPS) and 10 MHz inputs, along with a time code to initialize its internal International Atomic Time (TAI) counter.

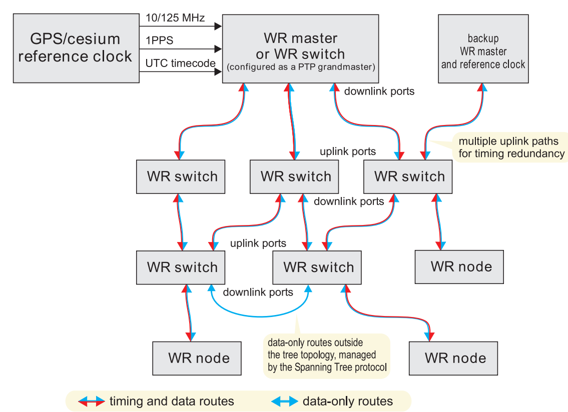

Figure 1: Layout of a typical WR network.

The WR Switch [4] is the main component of WR networks. It is in the form of a standard 19" chassis with 18 GbE ports and one management port in the front panel.

A typical WR Node [5] is a device with one GbE link, two voltage controlled oscillators and an FPGA that contains the WR PTP Core (WRPC) [6] together with application specific IP cores.

CONFIGURATION OF A WR NETWORK

For small networks it is convenient to configure and monitor switches and nodes manually, by using ssh or the web interface for switches and a direct console connection for nodes. However, such an approach does not scale well for bigger networks.

White Rabbit Switch Configuration

A White Rabbit Switch applies the configuration at boot time. The configuration file is in the format of Kconfig, the same format used by the Linux kernel for configuration at

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PRESENT AND FUTURE OF HARMONY BUS, A REAL-TIME HIGH SPEED BUS FOR DATA TRANSFER BETWEEN FPGA CORES

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Abstract

When feedback loops latencies shall be lower than milliseconds range the performance of FPGA-based solutions are unrivalled. One of the main difficulties in these solutions is how to make compatible a full custom digital design with a generic interface and the high-level control software.

In ALBA, we have simplified the new equipment development process with the use of Harmony Bus (HB). Based on the Self-Describing Bus, developed at CERN/GSI, it creates a bus framework where different modules share timestamped data and generate events. This solution lets the high-level control software in a Single Board Computer or PC, to easily configure the expected functionally in the FPGA and manage the real-time data acquired.

This framework has been already used in the new Em# electrometer, produced within collaboration between ALBA and MAXIV, which is currently working in both synchrotrons. Future plans include extending the FPGA cores library and high-level functions.

NEW FRAMEWORK FOR REAL-TIME DATA PROCESSING

Feedback loops take the system output into consideration, which enables the system to adjust its performance, to meet a desired output response. They are usually used to correct errors. When designing systems with target response times close to µseconds, the possibility to use high level software is limited and the only possibility is via hardware based solutions. Among those, nowadays FPGA is the most selected technology due to their low processing time, relatively low cost, reprogrammable capability, massive parallel complex operation capability and the availability of high number of input/outputs. That makes them quite appropriate for those designs that require integration times under milliseconds range. On the other hand, they are complex to program and offer limited possibilities to store or share data with other high level applications. PC's or Single Board Computers (SBC) are a good solution for those designs where the processing time is not so critical as required, latencies are higher than tenths of milliseconds and they offer complex data processing with multiple tools for data sharing to other high level applications or data transmission via network.

Since 2014, in ALBA computing division, we started to consider making our new in-house developments as versatile as possible and easily adaptable to changing needs from our scientists. Our target was to cover feedback system designs in the ranges from milliseconds to µseconds. In that sense we began the development of our new products based on a solution resulting from the combination of an FPGA and PC. The new design had to be flexible enough to perform real-time calculus, data pre-processing or feedback implementation, easy to configure and with sufficient capability of integration in any control system or configuration. The resulting design is shown in Figure 1, where the FPGA and the PC are connected via PCI Express and the PC is a Single Board Computer (SBC) with I2C and SPI ports to connect other peripheral devices, like a touch-screen display, control the power supply board or any other

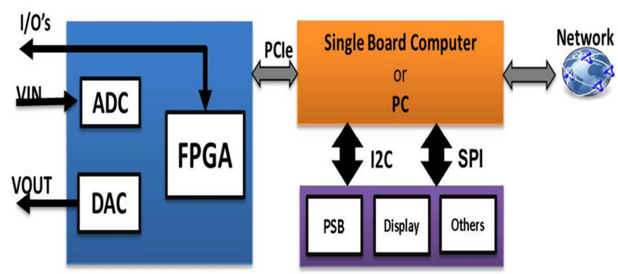

Figure 1: Electric block diagram of new ALBA development.

BASICS OF HARMONY BUS

Communication between FPGA and SBC is done via PCIe bus. This bus, even having a high transfer peak, is not easy to be deterministic and easy control the latency between different communications from high level software layers. To overcome this constrain, the new design clearly divides the functionality between acquisition and real-time data processing in the FPGA, while configuration and high-level data processing in the main processor (SBC). Following the versatility requirements, the FPGA was designed containing different functionality cores that are dynamically interconnected between them depending on the equipment configuration. Harmony Bus (HB) [1] is the easily configurable proposed bus to dynamically share data among the cores at high speed rate.

In the HB data is shared between FPGA cores in real-time with timestamp and with the identifier of the core that has generated it. Harmony follows the tree structure of Self Describing Bus (SDB) [2] developed by CERN, although it is not mandatory that all the cores defined in SDB had also and Harmony Bus connection. The SDB uses a standard bus protocol, the Wishbone bus [3], for the data exchange between the FPGA and the high level

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AUTOMATIC PID PERFORMANCE MONITORING APPLIED TO LHC CRYOGENICS

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Abstract

At CERN, the LHC (Large Hadron Collider) cryogenic system employs about 5000 PID (Proportional Integral Derivative) regulation loops distributed over the 27 km of the accelerator. Tuning all these regulation loops is a complex task and the systematic monitoring of them should be done in an automated way to be sure that the overall plant performance is improved by identifying the poorest performing PID controllers. It is nearly impossible to check the performance of a regulation loop with a classical threshold technique as the controlled variables could evolve in large operation ranges and the amount of data cannot be manually checked daily. This paper presents the adaptation and the application of an existing regulation indicator performance algorithm on the LHC cryogenic system and the different results obtained in the past year of operation. This technique is generic for any PID feedback control loop, it does not use any process model and needs only a few tuning parameters. The publication also describes the data analytic architecture and the different tools deployed on the CERN control infrastructure to implement the indicator performance algorithm.

INTRODUCTION

The LHC cryogenic control system is now very mature after more than 12 years of operation using the CERN control framework UNICOS (UNIfied COntrol System) [1]. Nevertheless, the cryogenic operation team is still optimizing the cryogenic system as much as possible and this task is demanding significant efforts due to the large amount of data generated by the whole LHC cryogenic system (about 4 GB per day).

In this context, advanced diagnostics methods based on data analytic have been developed and tested in collaboration between the CERN industrial controls and safety group and the cryogenic group. A method to automatically detect oscillations of sensors or actuators [2] and a model learning algorithm to detect abnormal behaviours [3] have already been developed.

This paper is presenting a method to identify poorly tuned PID (Proportional Integral Derivative) regulation loops as the LHC cryogenic systems embeds more than 5000 of those loops that cannot be permanently checked by the operators without appropriate tools. The regulation loops, which are poorly tuned, can trigger alarms whenever they exceed some thresholds. This allows engineers to adjust these loops to reach better performances and this corrective tuning has been done since the beginning. However, many regulation loops remain poorly tuned and do not provoke any critical alarms. A better tuning of these regulation loops is then necessary for several reasons:

- Too fast controllers can accelerate the aging of actuators (valves, heaters, motors, etc..) and can provoke breaking inducing significant stops of cryogenic installations during operation.
- Too slow controllers induce important oscillations of some process values (temperatures, pressures, etc.) and can induce undesirable mechanical movements provoking alignment problems in the accelerator or even breaking of components in extreme situations.
- Poorly tuned controllers can provoke undesirable interlocks and stops cryogenic installations after unexpected disturbances. These poorly tuned controllers are difficult to detect as they work acceptably most of the time and they only show bad behavior when a strong and rare disturbance appears.

For all these reasons, it was decided to implement an automatic performance monitoring of PID control loops to help operators to identify regulation loops showing abnormal behaviours. Then, operators may take the appropriate decision as for instance doing a new PID tuning, either manually, either by using the PID auto-tuning tool implemented in the UNICOS framework since 2016 [4].

After a brief description of the controller performance indicator that we have selected in a first section, its application to the LHC cryogenic system is presented and discussed with the different results. Then, in the third section, the implementation of the monitoring task within the CERN computing infrastructure is described and a conclusion summarizes the different results and outlooks.

REGULATION LOOP PERFORMANCE INDICATOR

Since 1980, there has been a lot of research to evaluate, in a generic way, the performance of a regulation loop, whatever is the regulation technique. Some methods use the variance of the mean square error between the measured value and the set-point as performance indicator [5]. This variance can be then estimated by time series and compared to the best achievable controller to obtain the performance of the regulation loop. This concept has been re-used more recently in 2007 by a Spanish team to compute a *Predictability Index* (PI), more convenient for a concrete industrial case where the number of tuning parameters is reduced [6].

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SIMULATION OF CRYOGENIC PROCESS AND CONTROL OF EAST BASED ON EPICS

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Abstract

The cryogenic system of Experiment Advance Superconductor Tokomak (EAST) is a large capacity system at both 4.5 and 80K levels at huge superconducting magnet system together with 80k thermal shields, complex of cryogenic pumps and small cryogenic users. The cryogenic system and their control are highly complex due to the large number of correlated variables on wide operation ranges. Due to the complexity of the system, dynamic simulations represent the only way to provide adequate data during transients and to validate complete cooldown scenarios in such complex interconnected systems. This paper presents the design of EAST cryogenic process and control simulator. The cryogenic process model is developed by the EcosimPro and CRYOLIB. The control system model is developed based on EPICS. The real-time communication between cryogenic process and control system is realized by OPC protocol. This simulator can be used for different purpose such as operator training, test of the new control strategies and the optimization of cryogenic system.

INTRODUCTION

The cryogenic system of Experiment Advance Superconductor Tokomak (EAST) is a large capacity system at both 4.5 and 80K levels at huge superconducting magnet system together with 80k thermal shields, complex of cryogenic pumps and small cryogenic users [1]. Pulsed heat load is the main different factor between the cryogenic system of full superconducting Tokamak system and other large cryogenic systems. The cryogenic system operates in a pulsed heat loads mode requiring the helium refrigerator to remove periodically large heat loads in time. It's very difficult to design the effective control algorithm to smooth the pulse loads and to improve the stability of the operation of the cryogenic system.

Dynamic simulation is as the only way to analyze the dynamic behavior and transient modes of a large scale of cryogenic system. From a simple Brayton cryogenic cycle to large scale cryogenic plants have been simulated. Maekawa R. et al have developed the C-PREST (Cryogenic Process REal-time SimulaTor) as a platform for process analysis and optimization tool to study coupled cryogenic phenomenon of helium refrigerator/liquefier for LHD [2]. Deschildre C. et al have simulated 400W@1.8K refrigerator at CEA based on hysys [3], and applied to refrigerator design to cope with the pulsed heat load [4]. A dynamic simulator, PROCOS (PROcess and COntrol Simulator), has been developed by Bradu B to improve knowledge on complex cryogenic systems for LHC [5].

This paper presents the design of EAST cryogenic process and control simulator. The cryogenic process model is developed by the EcosimPro and CRYOLIB. The control system model is developed based on EPICS. The real-time communication between cryogenic process and control system is realized by OPC protocol. This simulator can be used for different purpose such as operator training, test of the new control strategies and the optimization of cryogenic system.

CRYOGENIC SYSTEM OF EAST

As one of the important subsystems of EAST, the cryogenic system is mainly responsible for the cooling of the superconducting magnets and related components, ensuring the stable operation of superconducting magnets at various conditions. As shown in Fig. 1, the cryogenic system for EAST includes a helium refrigerator and the cryogenic distribution system. The helium refrigerator is composed of gas management system, compressors station, cold box and 10000 liter Dewar. All the heat exchangers, the absorbers and four turbine expanders are installed in the cold box. The design capacity of the helium refrigerator is 1050 W@3.5K +200W@4.5K +13g/s LHe +12~30kW@80K [1]. In order to maintain the proper cryogenic state of the EAST cold components, the helium refrigeration system (HRS) supplies three helium coolants: supercritical helium (SHe), liquid helium, and gaseous helium for the SC coils and their feeder lines, current leads, and thermal shield, respectively. The refrigerator usually operates at the mixed mode with liquefaction and refrigeration. The cryogenic distribution system is designed to distribute refrigeration to all of the cold components. The distribution system consists of a cryogenic valve box, four cryogenic transfer lines, supercritical helium feeders in the cryostat, two vacuum insulated tubes for superconducting buslines and two coldboxes for the high temperature superconductor current leads.

The EAST cryogenic control system was designed based on DeltaV DCS of Emerson Corporation. Fig. 2 shows the network of the cryogenic control system which is composed of three parts: cryogenic redundant control local area network (LAN), data exchange LAN and main control data server LAN. The control layer includes two local control cabinets for cold boxes and cryogenic

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NANOPROBE RESULTS: METROLOGY & CONTROL IN STACKED CLOSED-LOOP SYSTEMS

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Abstract

Over the course of four years, the Nanoprobe project worked to deliver prototypes capable of nm-precision and accuracy with long-range millimetric sample positioning in 3D- scanning tomography for long beamline endstations of Synchrotron Soleil and MAXIV. The ambition of the project necessitated a joint progress between several fields of expertise combining mechanics, metrology, motion control, and software programming. Interferometry in stage characterization has been a crucial point; not only to qualify motion errors but to actively integrate it into control systems with feedback and/or feedforward schemes in order to reduce XYZ position errors down to the nm- level. As such, a new way of characterizing rotation stages [1] [2] was developed and ultimately used in control schemes utilising the Delta Tau PowerPMAC platform [3] [4]. This paper details the obtained results as well as the methodology and approach of the project to achieve this.

INTRODUCTION & APPROACH

The Nanoprobe Project was initiated to deliver a scanning hard X-ray double Fresnel Zone Plate (FZP)- based microscope with a scanning sample stage for long beamline endstations in Nanoscopium [5] of Synchrotron Soleil and NanoMAX [6] of MAXIV. Some of the challenging aspects were to produce nanometric XYZ resolutions coupled with deca-millimeter range with 360° sample movement and rotation while also providing step-scans, Flyscans [7], and long-term stability. Figure 1 shows a schematic of the end-station setup with beam focusing stages (Fresnel Zone Plates, Central Stop, Order Sorting Aperture) and Sample Stage. The approach was, in addition of providing a stable environment in terms of vibration and thermals, to construct a modular and stacked design with an interferometric feedback system and the possibility of using position compensation (in feedforward control) to diminish repeatable errors. Interferometry was therefore not only used for feedback but also in measuring and characterizing stages to determine repeatable and non-repeatable errors. This paper will focus on the setup and evaluation of the sample- and FZP stages as these were the most challenging in terms of positioning stability and multi-axis synchronization.

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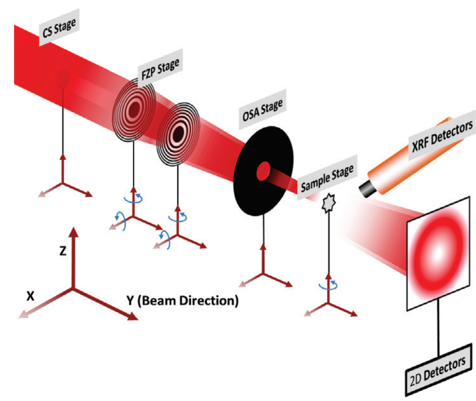

Figure 1: End-station scheme and XYZ- orientation of stages and detectors in respect to beam; each stage has its degrees of freedom (DOF) marked out.

SYSTEM OVERVIEW

Environment

The prototype was mounted, tested, and characterized in a thermally stabilized environment. Figure 2 shows the prototype environment; a marble table placed in a climate controlled room. The marble table itself was insulated in such a way to minimize XY-gradients (and thus XY- positionally induced thermal drifts), with water circulation and system enclosure to add for thermal impedance.

Figure 2: The system in a thermally stabilized environment; here with an insulated granite table, water circulation and system enclosure.

Sample Stage

The sample stage was, as seen in Fig. 1, tasked to move the sample in 4 degrees of freedom (DOF). The XYZ-space (Y being the beam direction) was to be scanned with nanometer

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PARC: A COMPUTATIONAL SYSTEM IN SUPPORT OF LASER MEGAJOULE FACILTY OPERATIONS

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Abstract

The Laser MegaJoule (LMJ) is a 176-beam laser facility, located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy to targets, for high energy density physics experiments, including fusion experiments. The first 8-beams bundle was operated in October 2014 and a new bundle was commissioned in October 2016. The next two bundles are on the way. PARC[1] is the computational system used to automate the laser setup and the generation of shot report with all the results acquired during the shot sequence process (including alignment and synchronization). It has been designed to run sequences in order to perform a setup computation or a full facility shot report in less than 15 minutes for 1 or 176 beams. This contribution describes how this system solves this challenge and enhances the overall process.

INTRODUCTION

LMJ facility is a very complex physic instrument. Many advanced technologies and knowledge are used in this project. All these functions come with dedicated instrument and software. Based on feedback from previous laser facility exploitation, the need of computational system to be able to perform complex and various computation with heterogeneous software has been identified. Such a system will insure performances, modularity and scalability.

MULTIPURPOSE COMPUTATIONAL SYSTEM

PARC is a generic computational platform [1] with four main features in charge of:

- Exchanging data (settings and results) with Control Command System (CCS),
- Executing sequentially heterogeneous code file from various physical field (laser, alignment, synchronization) ,
- Distributing computation in order to reduce execution time (less than 15 min) ,
- Building multi-level reports.

Communication with CCS

PARC is part of the Control Command Application Layer. It uses available API to read and write the following data:

- Settings from the central settings DB (GCI),
- Diagnosis results from the central shot DB (GTIR),
- Logistical data (e.g.: component replacement) from the central maintenance DB (GMAO).

PARC acts as a slave system of the supervisory control. It receives web service calls to perform automatic function (prediction, shot report, etc.).

An internal wrapper has been developed to manage the data transfer between PARC and CCS (and vice versa). It is based on a dictionary file describing the source data (CCS) and the target data (PARC). The wrapper fulfills three features:

- Type conversion : heterogeneous types from CSS are converted in PARC type (string, double), including file conversion (curve, multicurve, image),
- Unit conversion : heterogeneous units from CSS are converted in International System of Units (ISU),
- Data validity or lack: CSS validity attributes are associated to PARC parameter and a default value is defined for each expected but missing data.

These features insure to operate computation in a homogeneous environment (both type and unit). Specific mechanisms have been developed to propagate error code and message. The entry dataset consistency is essential for the computation. It makes the system stronger to unexpected error.

Computation Sequencer

Many elementary software have been developed for the LIL facility (LMJ bundle prototype). These small code modules were characterized by their feature, interface and language.

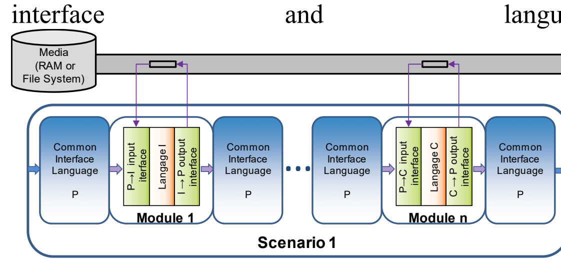

Figure 1: Modules and scenario structure.

In order to create an executable sequence composed of these elementary modules, it is necessary to define a Common Interface Language (CLI). This language is used as a container (Figure 1).

[1] PARC: French acronym for automatic bundle settings prediction.

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ON-LINE OPTIMIZATION OF EUROPEAN XFEL WITH OCELOT

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Abstract

FEL tuning and optimization within the OCELOT framework [1, 2] has been implemented in 2015 and has been since used for SASE pulse energy optimization at FLASH [3] and later at LCLS [4], as well as injection efficiency maximization in the Siberia-1 storage ring [5]. For the European XFEL [6] commissioning purposes the code was considerably improved and additional set of tools has been introduced. Here these tools and experience of their use during the European XFEL commissioning and initial operation will be presented. Future development directions will be outlined.

INTRODUCTION

Tuning of performance parameters such as photon pulse energy, beam pointing, or spectral width, are a considerable part of daily FEL operation. When done manually, such tuning is lengthy as tedious. Moreover, it has to be repeated often due to limited machine reproducibility. While tuning the whole machine might require human expertise, tuning a particular subsystem using a limited number of actuators can be done automatically by maximizing or minimizaing a certain objective function with standard functional minimization methods. Such approach was implemented for SASE tuning ([3,5,7]). The diffuculty in this approach lies primarily with processing (averaging) of detector data, defining hardware parameter limits, identifying the most effective control parameters, and selecting the objective function. This approach was extended to minimizing arbitrary objective functions, and an appropriate GUI was created. Examples of use of such a generic optimizer are given below.

Optimization based on function minimization typically results in significant changes of the objective function during the optimization process. So, a Nelder-Mead optimization of the SASE pulse energy usually leads to a significant signal drop before the optimum level is reached. This approach is thus not compatible with beam delivery to the users. It turned out that the method proposed in [8] (also implemented in OCELOT under the name 'adaptive feedback'), based on the slow adjustment of the orbit based on recent pulse energy history, can work simultaneously with user operation and results in significant pulse energy improvement.

Other tools – dispersion and orbit correction, generic correlation tool, and an on-line optics model, were also added to the software suite and are briefly discussed in what follows.

All the examples are drawn from the operation of the European XFEL (see Fig. 1), which has been successfully commissioned and is now in operation in Hamburg [9].

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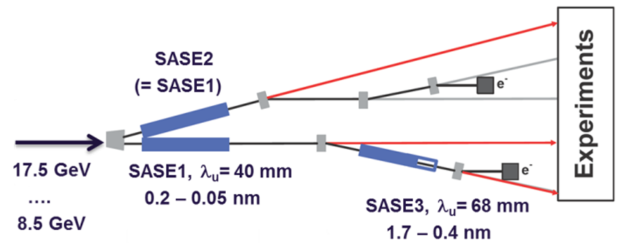

Figure 1: Schematic layout of the European XFEL beam distribution.

THE GENERIC OPTIMIZER

The Generic Optimizer is the next generation of the SASE optimizer developed for FLASH [7], and is described in this section. While initially the functionality of running through a sequence of minimization steps automatically and deciding on the stopping criteria was envisaged, presently the functionality is limited to a single optimization step, but an advanced GUI for setting that optimization is provided. Deciding on the sequence of steps is presently left to the operator. Command-line-based fully automated optimization tool is available, but rarely used. The optimizer was specifically designed to facilitate ad-hoc tuning and optimization of arbitrary subsystems, which could be expected during commissioning.

Interface to Control Systems

The architecture of OCELOT allows easy interfacing to different control systems by inheriting from the MachineIterface class and implementing the desirable API (getting and setting of scalar and vector data, definition of the photon pulse energy readout, definition of beam position and beam loss measurements). Implementations using pyDOOCS [10] and PyEpics [11] are available.

Optimization Algorithm and Noise Reduction

OCELOT extensively uses Python's NumPy (Numerical Python) [12] and SciPy (Scientific Python) [13] libraries, which enables efficient numerical computations within Python and gives access to various mathematical and optimization methods. The Generic Optimizer extensively uses the Nelder-Mead algorithm [14], which is included in the SciPy package. To deal with the photon pulse energy signal fluctuation which can "confuse" the optimization method, two steps are taken. First is averaging of the objective function. The GUI allows to choose the number of objective function readouts and time delay between

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EPICS ARCHITECTURE FOR NEUTRON INSTRUMENT CONTROL AT THE EUROPEAN SPALLATION SOURCE

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Abstract

The European Spallation Source ERIC (ESS) are currently developing a suite of fifteen neutron instruments, the first eight of which will be available for routine scientific use by 2023. The instrument conventional control system will be distributed through three layers: local controllers for individual instrument components; Experimental Physics and Industrial Control System (EPICS) software to implement higher level logic and act as a hardware abstraction layer; and a high-level experiment control program, which has an executive role, interacting with instrument components via the EPICS layer. ESS are now actively designing and prototyping the EPICS controls architecture for the neutron instruments, including systems which interface to core instrument components such as motion control systems, neutron detector readout systems, sample environment equipment, neutron choppers, instrument Programmable Logic Controller (PLC) systems, and the interfaces to the NICOSII experiment control program. Systems engineering methodologies are being applied through the control system development lifecycle to provide traceability. Prototyping activities have been executed in an integrated and coordinated manner to demonstrate the EPICS controls architecture in an environment representative of the neutron instruments to which the architecture will ultimately be applied.

INTRODUCTION

The European Spallation Source (ESS) European Research Infrastructure Consortium (ERIC) is an ambitious project to build the world's most brilliant neutron source near Lund, Sweden.

A total of 22 neutron research instruments are planned, with development of 15 of those currently funded and underway. In addition, the ESS Test Beamline will be developed to characterise the neutronic properties of the neutron source (spallation target and moderator) prior to the scientific instruments being available. At least eight of the instruments will be ready for routine scientific use by 2023.

The ESS accelerator, spallation target and neutron instrument suite are being developed in partnership with research facilities across participating countries, which enables the project to capitalise on existing European experience in these technological domains. This distributed nature of the construction project also presents challenges in terms of ensuring consistency in the architecture and composition of the deliverables to ESS. This has important long term ramifications, such as affecting recurring maintenance costs.

In order to maximise consistency of the neutron instrument controls, the following high-level architectural and organisational interfaces have been established:

- Personnel Safety System: The PSS is a safety system responsible for mitigating against radiation, oxygen depletion and other safety hazards stemming from fixed equipment on each instrument. The PSS is developed to the IEC 61508 functional safety standard and is an independent system outside the scope of the conventional controls discussed here.
- Neutron Instrument Technologies: ESS staff are working with partners to define standard components and interfaces, such as defining a standard motion controller, control interface to all ESS neutron chopper systems and a readout and control system for the neutron detectors.
- Integrated Control System: ESS has adopted the Experimental Physics and Industrial Control System (EPICS) framework to interact with individual hardware components, including lower level controllers. The ICS Division also define and develop standard hardware platforms for control system use.
- Data Management and Software Centre: The DMSC are responsible for the acquisition and analysis of the scientific data from the ESS instruments. This layer also includes the NICOSII experiment control program, which includes a graphical user interface (GUI) and a scripting environment for executing neutron science experiments.

The work described in this paper relates principally to the Integrated Control System (ICS) layer of the instrument controls architecture, including interfaces to the other layers. In the following sections, the systems engineering strategy will be described, then the major infrastructure components used by ICS, then the control system strategy for major classes of instrument component and finally some ongoing activities to demonstrate and refine the controls will be detailed.

SYSTEMS ENGINEERING

Due to the magnitude and particular challenges of developing the controls for the ESS instrument suite, ICS have adopted a mix of formal and informal processes to efficiently engage the individual instrument projects.

Developing an early synoptic view and preliminary overall design of the control system for each instrument is important, and this is where a flexible and iterative methodology has proven useful. Control system staff at

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ON-AXIS 3D MICROSCOPE FOR X-RAY BEAMLINES AT NSLS-II

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Abstract

A series of versatile on-axis X-ray microscopes with large working distances, high resolution and large magnification have been developed at NSLS-II [1,2]. These microscopes use reflective optics, which minimizes dispersion, and allows imaging from Ultraviolet (UV) [3] to Infrared (IR) with specifically chosen objective components (coatings, etc.). Additional customizations can be implemented to provide dual-view with high/low magnification [4], 3-D imaging, long working range, as well as ruby fluorescence measurement for high pressure samples. In this publication we discuss 3D imaging enhancement to on-axis microscopes.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) on Long Island, NY, USA is a new synchrotron user facility constructed to provide extremely bright x-rays for a broad range of basic and applied research. A typical NSLS-II hard X-ray beamline achieves routinely submicron beam sizes. To facilitate optics alignment and optimization, as well as for sample monitoring and characterization, on-axis microscopes [1] have been developed at NSLS-II to provide online imaging capabilities with high spatial resolution around the sample area. Utilizing the imaging capability, for example, beam focus from focusing X-ray optics, such as KB-mirrors, can be visualized directly, providing instantaneous feedback during the optimization process, vastly improving the efficiency of characterization compared to the more traditional knife edge scans.

The details of the on-axis microscope as implemented at the Inelastic X-ray Scattering (IXS) 10-ID beamline are presented in Figures 1, and 2. The microscope is located downstream of the KB mirror system. Figure 1 (upper panel) illustrates the schematic of the optical layout, where the objective is folded from upstream using a right-angle mirror containing a hole for the X-ray beam to pass through (see Figure 2). Due to spatial constraint, such as the need of a sample cryostat, the microscope design at 10-ID incorporates an additional mirror in “periscope” geometry as shown in Figure 1 (lower panel).

The image of high pressure diamond anvil cell sample obtained using the on-axis microscope at 10-ID is shown in Figure 2 (lower panel). The cross-hair indicating the X-ray beam incidence position is injected into the image stream using the Overlay Plugin of areaDetector [5] EPICS application. The position of the cross-hair is determined by visualizing the X-ray beam using high-Z scintillator, such as CWO, placed at sample position [6].

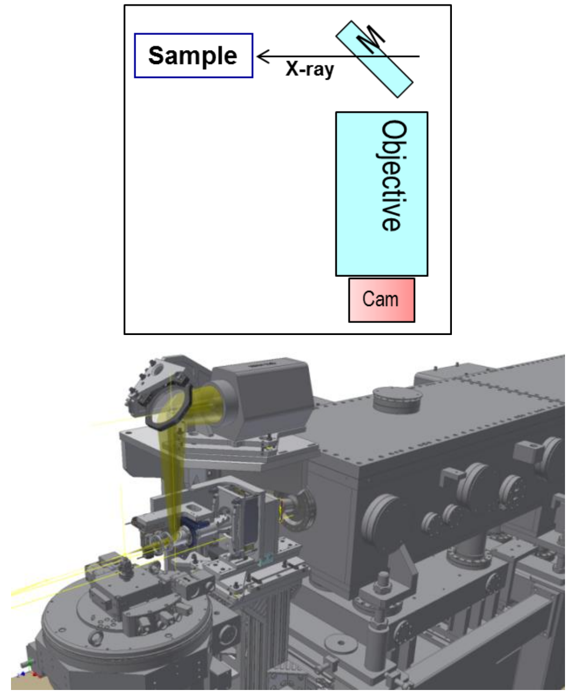

Figure 1: On-axis microscope schematics (upper panel), and the implementation at the IXS 10-ID beamline (lower panel).

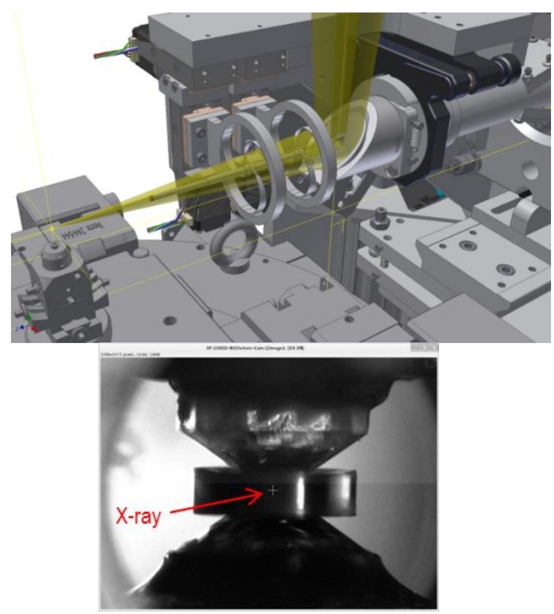

Figure 2: The on-axis microscope at 10ID with details near the sample area (upper panel), and image of a diamond anvil cell (DAC) sample (lower panel). The cross indicates the X-ray beam position.

The 10-ID on-axis microscope has a working distance of 600 mm and resolution of 3 um. An incorporated

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SOFTWARE ARCHITECTURE FOR BEAMLINE AUTOMATION – VMXi USE-CASE

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Abstract

Versatile Macromolecular in-situ (VMXi) is the first beamline at Diamond Light Source (DLS) to be entirely automated with no direct user interaction to set up and control experiments. This marks a radical departure from other beamlines at the facility and it has presented a significant design challenge to General Data Acquisition (GDA), the in-house software that manages beamline data collection. GDA has become a reactive controller for continual, uninterrupted processing of all user experiments. A major achievement has been to demonstrate that it is possible to successfully deliver a suitable architectural implementation for automation developed within a standard integrate development environment (IDE). There is no need for specialised software or a domain specific language for automation. The objective is to: review VMXi project with the emphasis on hardware configuration and experiment processing; describe the software and control architecture for automation; and provide a general set of guidelines for developing software for automation at a scientific facility.

VMXI OVERVIEW

In 2013 I02 - one of several MX [1] beamlines at DLS [2] - was selected for a major hardware upgrade. The scientific driver for the new beamline was to make it specialised for *in-situ* diffraction of crystallised macromolecular samples [3]. Multiple crystals of purified samples are grown under different chemical conditions within wells on crystallisation plates. Crystallisation experiments usually fall into two distinct stages: screening and data collection. Screening involves exposing a plate to X-rays to discover if any samples diffract. Data collection aims to maximise diffraction information output by applying a wide range of X-ray parameters on plate samples. One plate has many samples so that a great volume of data can be generated and processed in a concentrated period of beam time. A plate is designed for high throughput and robot handling. The new beamline VMXi [4] fully exploits this so that many plates can be stored at a time and continually processed, vastly increasing experiment throughput and optimising beam use. A schematic of the VMXi end station is shown in Fig.1 without the radiation shielding. Plates are sent to VMXi are stored in two temperature controlled storage units (Rock Imager 1000, Formulatrix) each storing up to 750 plates. Plates are conveyed through the radiation shielding to a local storage area within the data collection environment. This storage area can hold up to 12 plates and serves as a buffer for quick loading and unloading of plates to the goniometer.

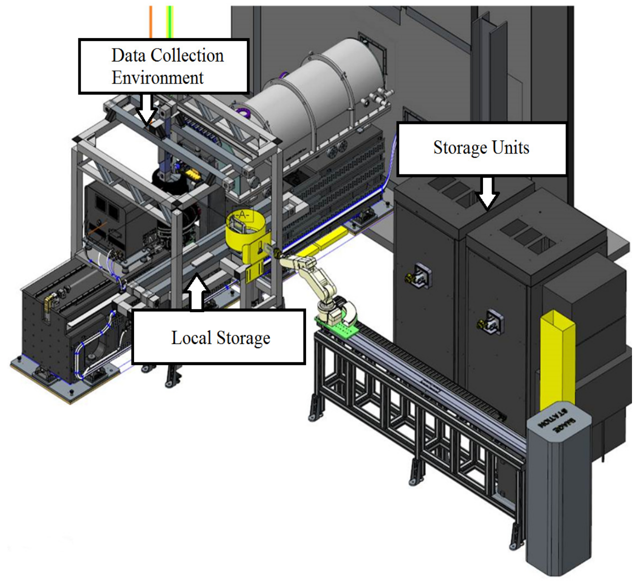

Figure 1: VMXi End Station.

The data collection environment hardware consists of a bespoke goniometer developed at DLS that holds a plate with submicron precision; the latest detector technology (Eiger 4M, Dectris AG); a fast shutter (operating at 4 milliseconds opening time); and a retractable, high resolution On Axis Viewing system (OAV) for sample imaging. VMXi is a high flux micro focus beamline to achieve high sample throughput. In-situ experiments are conducted at room temperature and when crystals are exposed to X-rays they are destroyed in milliseconds. The high specification detector and fast shutter optimise the diffraction information captured under these conditions.

DATA ACQUISITION SOFTWARE

The GDA [5] framework is software developed using Eclipse Java IDE [6] and deployed across beamlines at DLS to enable a high level interface for users to conduct experiments and collect data. A user runs experiments through GDA on site or (as is the case on MX beamlines) off-site through a remote client.

GDA is an implementation of a client server model. The client is an Eclipse RCP that provides a graphical interface through which a user can control and move beamline hardware and execute experiments. The server has many components but the main features to highlight are: Java Channel Access plugin to communicate with EPICS IOCs [7] (the hardware control layer); Java objects that are an interface to beamline hardware required for experiments; and a Jython server to run and execute scripts written in Python syntax. Taken as a whole scripts define the operational functionality of a beamline and as such are a crucial resource; in essence they are high level

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BLISS - EXPERIMENTS CONTROL FOR ESRF EBS BEAMLINES

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Abstract

BLISS is the new ESRF control system for running experiments, with full deployment aimed for the end of the EBS upgrade program in 2020. BLISS provides a global approach to run synchrotron experiments, thanks to hardware integration, Python sequences and an advanced scanning engine. As a Python package, BLISS can be easily embedded into any Python application and data management features enable online data analysis. In addition, BLISS ships with tools to enhance scientists user experience and can easily be integrated into TANGO based environments, with generic TANGO servers on top of BLISS controllers. BLISS configuration facility can be used as an alternative TANGO database. Delineating all aspects of the BLISS project from beamline device configuration up to the integrated user interface, this paper will present the technical choices that drove BLISS design and will describe the BLISS software architecture and technology stack in depth.

RATIONALE

Over the last 26 years, *Spec* [1] has been the main experiments control system at ESRF.

Spec is a software package for instrument control and data acquisition featuring a command line interface (CLI) with a read-eval-print-loop (REPL). Users can immediately call commands and more complicated sequences, written in the *Spec* macro language inspired by *awk* [2]. *Spec* has built-in step-by-step scans support, and features a long list of natively supported devices, from motor controllers to detectors. *Spec* can also communicate with beamline control systems like EPICS or TANGO, to extend the range of supported hardware. Last but not least, *Spec* features a client/server mode, to be able to control a *Spec* session from a remote process.

Spec success within the Beamline Control Unit (BCU) at ESRF, and among the synchrotron users community in general, is a vibrant example of a well-crafted piece of software, which has a limited, yet sufficient, set of features that satisfy users in their day-to-day activity, while offering enough flexibility for more advanced use cases. There is certainly a lesson to learn for any new software project.

However, at some point a limit was reached and tons of workarounds to circumvent *Spec* limitations have been implemented to be able to do continuous scans and to support multiple, fast detectors data acquisition, or to deal with *Spec* single-task execution model. The lack of extensibility of the *Spec* macros language combined with other limitations like the absence of debugging tools lead to the implementation of time-consuming, hard to maintain solutions.

Nowadays, with the perspective of the Extremely Brilliant Source (EBS) [3] program, new beamlines and new kinds of experiments require cutting-edge tools to support the more complex data acquisition protocols. This is the ambition for the BLISS project, that was started in December, 2015. Other drivers for the BLISS project include the *PaNdata* [4] initiative, to add metadata about all data produced at ESRF, that would benefit from more advanced data management from the experiment control software. Finally, beamline control can greatly benefit from latest advances in IT industry and one of the main goals of BLISS is to make the newest technology available for synchrotron experiments.

BLISS PROJECT SCOPE

The BLISS project brings a holistic approach to synchrotron beamline control. The scope of the BLISS project goes from hardware control up to the end-user interface. BLISS does not include data analysis, which is devoted to another software package at ESRF called *silx*. [5]

TECHNICAL CHOICES

BLISS is a software package composed of a Python library and a set of tools.

Python Library

Python is a de facto standard in the scientific community, and is very popular with a huge ecosystem. Python is a multi-paradigm, dynamic language, with a clear syntax. Python ships with an extensive standard library, and features advanced debugging and profiling capabilities. The interpreted nature of Python makes it very well suited as a programming language for running beamline experiments scripts in comparison with compiled languages. Last but not least, another essential asset of Python in the context of BLISS is that it can easily interface C or C++ libraries, which makes it really unavoidable as a glue language between low-level hardware control and BLISS library.

The idea of having BLISS as a Python extension package at the first place allows to embed BLISS into existing Python applications, and is also a very flexible way of writing tools around core functionalities for the BLISS project. A similar

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SARDANA BASED CONTINUOUS SCANS AT ALBA - CURRENT STATUS

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Abstract

A significant part of the experiments run at Alba Synchrotron [1] involve scans. The continuous scans were developed first ad hoc and latter the controls group dedicated important efforts to standardize them across the Alba instruments, enhancing the overall performance and allowing the users to better exploit the beamtime [2]. Sardana[3, 4], the experiment control software used at Alba, among other features, aims to provide a generic way of programming and executing continuous scans. This development just achieved a major milestone - an official version with a stable API. Recently the Alba instruments were successfully upgraded to profit from this release. In this paper we describe the evolution of these setups as well as the new continuous scan applications run at Alba. On the one hand, the most relevant hardware solutions are presented and assessed. On the other hand the Sardana software is evaluated in terms of its utility in building the continuous scans setups. Finally we discuss the future improvements plan designed to satisfy the ever-increasing requirements of the scientists.

BEAMLINE CONTROL SYSTEM AT ALBA

Alba is a third generation synchrotron located near Barcelona, Spain. Currently its eight beamlines host user experiments regularly, another beamline is under construction and two more under design.

An important part of the ALBA beamline control system is controlled directly by Tango. This includes numerous subsystems like vacuum, equipment protection, archiving or alarm handling [5, 6]. Likewise, some of beamline instruments still come with their own control software. However, both of these cases are out of the scope of this paper.

Sardana

The beamline control system at ALBA [7] is based on Sardana, a highly modular software package implemented in Python, built on the client-server model on top of Tango [8]. On the client side reside the GUI applications developed with Taurus library [9] and a CLI application called Spock built on top of IPython [10]. The server side is formed by two key components, the Macroserver and the Device Pool. The first one provides a controlled environment to develop and execute user procedures, written in Python, called macros and comes with a catalogue of standard and parameterizable macros which also includes generic scans. The second one offers a set of interfaces to the most common elements of the laboratory like, for example, motors or experimental channels and implements the hardware access layer by means of the plug-in controller classes also written in Python. Higher abstraction elements, like pseudo elements or groups, can be built on top of the physical elements e.g. the beam energy or mirror's angle pseudo motors which offer the possibility to optimize access to the hardware. Sardana is in charge of storing the experimental data and supports various data formats. We recommend the HDF5 [11] following the Nexus [12] conventions to our users but still, Spec [13] format is widely used. Even custom data recorders can be easily added for different data files or applications.

Each of the ALBA beamlines uses Sardana in its own way depending on the beamline design and the involved hardware. Usually, two Device Pool instances are defined per beamline, one to control the beamline elements and the other one to control the elements shared with the accelerator e.g. insertion device (ID) motors. One instance of the Macroserver with multiple Spock profiles is used in order to allow simultaneous macro executions. However, the number of Sardana elements differs significantly between the beamlines, for example, the number of moveables varies between 29 and 169, the number of experimental channels varies between 14 and 139, and the number of macros in some cases reaches 924.

Hardware

One of the aims of the ALBA's beamlines control system design was to limit the variety of hardware by choosing the standard models that could fulfill most of the requirements. This approach saved the significant amount of time necessary for their integration with the control software. Furthermore, the narrower the number of hardware, the more time the engineer can dedicate to deepen the specific knowledge [14]. For these reasons the vast majority of the moveable axes are stepper motors driven by the Icepap motion controllers. Just few of the servo DC axes are in use and all are driven by the Pmac motion controllers. Each of the beamlines has at least one industrial PC with a set of DAQ cards. The most popular are the 4-channels (16bit at 500kS/s) Analog to Digital Converter (ADC) card - ADLINK 2005 and the 8-channels counting/timing card (80 MHz) - NI 6602. These cards together with the ALBA Electrometer (AlbaEm) [15] - low current ammeter (from 1mA down to few pA) and the voltage to frequency converters (VTF) are the most common experimental channels in use. Other standard hardware was chosen for the CCD cameras, PLC, vacuum controllers, etc.

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IMPLEMENTATION OF WEB-BASED OPERATIONAL LOG SYSTEM AT RIBF

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Abstract

The electronic operational log is utilized in many accelerator facilities. It records relevant parameters and automatically specified actions performed by accelerator operators and stores them in a dedicated database. The Zope-based operational log system (Zlog) developed by the High Energy Accelerator Research Organization (KEK) has been utilized for the RIKEN Radioactive Isotope Beam Factory (RIBF) control system. Using the Web application of the Zlog, the information on the accelerator operation is represented on the Web browsers as character strings in a table. However, the character strings in the HTML table displayed on the Web browser consist of many lines, and in the case of Zlog, become complicated, because many parameters are altered during the RIBF operation. Therefore, an improved user interface should be introduced. To that end, we have developed a new Web-based operational log system for the RIBF control system that can provide operational logs with a variety of rich graphical user interface (GUI) components. The developed RIBF operational log system consists of a log monitor server, Web-application-based user interface, and PostgreSQL-based database. In addition, various types of user interface have been implemented for the equipment, such as the electromagnet power supply. Since 2013, this operational log system has functioned without experiencing serious problems, monitoring approximately 3,000 points of the Experimental Physics and Industrial Control System (EPICS) record.

INTRODUCTION

The RIKEN Radioactive Isotope Beam Factory (RIBF) accelerator facility consists of five cyclotrons, including a superconducting ring cyclotron, and two linear accelerators [1]. In the RIBF, we constructed a distributed control system based on the Experimental Physics and Industrial Control System (EPICS) for electromagnet power supplies, beam diagnostic instruments, vacuum control systems, and so on [2]. The electronic log system for recording daily accelerator operation during beam tuning, which is a control-system application, is called an operational log system. Operational log systems are widely used in place of paper-based logbooks at large accelerator facilities. In 2004, Zlog was developed by the High Energy Accelerator Research Organization (KEK) as a Web-based operational log system for EPICS-based system [3]. Since then, Zlog has been introduced not only at KEKB [4] and J-PARC [5], but also at RIBF [6].

Hereafter, we will report the operational experience of Zlog at RIBF after brief introduction of the Zlog system. Subsequently, we will introduce a new operation log system, which has rich user interface components suitable for various device types and is more effective for accelerator operation in RIBF.

ZLOG SYSTEM

Zlog is based on Zope [7], which is an object-oriented Web application framework, and consists of Web applications and a log monitor server written in Python. The operation record can be manually input through the Zlog Web application. In addition, when the EPICS record value is changed, a log can be automatically inserted using the caMonitor program, with Zlog acting as an event-driven log monitor server using the Zlog Python-CA interface [8]. The inserted logs are stored and managed in a PostgreSQL-based database. The Zlog database has a table structure with "*operations*," "*comments*," "*related_group*," and other columns, besides the standard "*id*" and "*timestamp*" columns. The Zlog system chart given in Ref. [3] is illustrated again in Fig. 1, and a screenshot of the Zlog display on the Web browser is shown in Fig. 2.

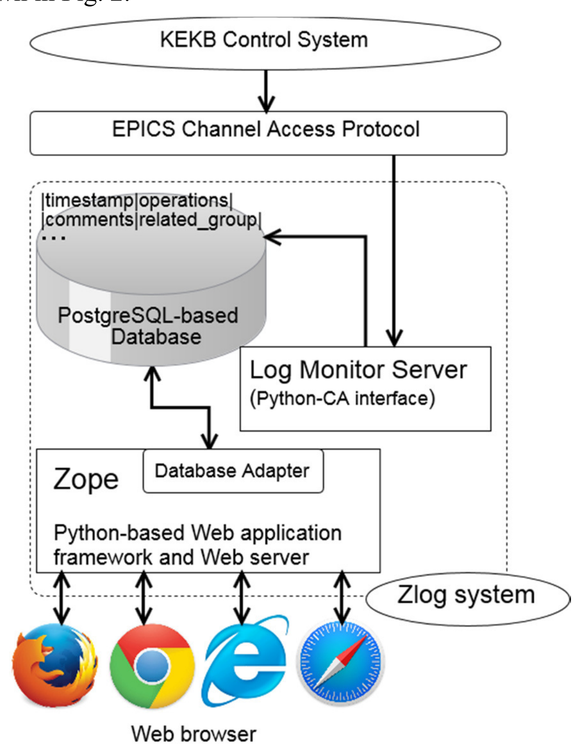

Figure 1: System chart of the Zlog system.

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BEST PRACTICES FOR EFFICIENT DEVELOPMENT OF JAVAFX APPLICATIONS

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Abstract

JavaFX, the GUI toolkit included in the standard JDK, has reached a level of maturity enabling its usage for Control Systems applications. Property bindings, built-in separation between logic (Controller) and visual part (FXML) that can be designed with Scene Builder, combined with the leverage of Java 8 features such as lambda expressions or method references, make this toolkit a very compelling choice for the creation of clean and testable GUI applications.

This article describes best practices and tools that improve developer's efficiency even further. Structuring applications for productivity, simplified FXML loading, the application of Dependency Injection and Presentation Model patterns, testability are discussed among other topics, along with support of IDE tooling.

JAVAFX OVERVIEW

JavaFX, the successor of Swing, has been around already for a few years. Since the version 1.0 released in 2008, it has been progressively maturing, gaining in functionality and robustness, to be included in the JDK 8.

FXML, Controller and Scene Builder

Swing interfaces have been traditionally created using procedural code. Initialization and configuration of all components and containers had to be coded in Java and visual verification of every change required restarting the application. This was the main driver for WYSIWYG (What You See Is What You Get) editors that aimed to speed up the development and ease the maintenance. However, these editors were mostly generating Java code from the visual representation, a code that was hard to modify and maintain. For this reason many developers preferred to write it manually, resigning from the graphical design.

As an alternative, JavaFX comes with FXML - an XML-based markup language used to describe user interface, and with Scene Builder - a WYSIWYG editor that persists the visual representation in the FXML format.

An integral part of the FXML format is a possibility of declaring an associated controller class and exposing to it UI elements, and event handler hooks. The controller is then responsible for reacting on the events and updating the view accordingly.

This is an example of the *Inversion of Control* [1] principle. The controller does not need to lookup the UI elements it needs to interact with and the invocation of its event listener methods is handled by the FXML logic.

This is a major improvement compared to Swing. The developer can design the interface much faster, without writing and maintaining a lot of boilerplate code, and focusing on the application logic.

Properties and Bindings

Property is a value that represents the state of an object that can be retrieved and set (if it is not read-only). In addition, a property can be observable i.e. registered listeners will be notified every time the property value has changed. This pattern has been used for years by the Java Beans component architecture.

JavaFX provides a set of built-in classes representing properties that extend and enhance this idea with some useful and extremely powerful features.

The properties are often used in conjunction with binding, a mechanism of expressing direct relationships between variables. The binding observes a list of source variables (dependencies) for changes, and updates itself automatically once the change has been detected, applying an optional conversion function.

Since all JavaFX components keep their state in properties, it makes it particularly simple to bind state of different widgets, considerably reducing the amount of necessary code. In the following example the button will be disabled as long as the check box is not selected:

```
button.disableProperty().bind(checkBox.selectedProperty().not());
```

In a similar way UI widgets properties can be bound to observable values of the corresponding view model.

APPLICATION STRUCTURE

Developing GUI applications is not a trivial task. Developers have to address various general software engineering issues as well as GUI-specific ones. Even a single-page application might contain multiple sub-views that need to interact with each other. This brings questions on how the graphical components and their logic should be organized.

There is a quite known statement about clean code by Ward Cunningam, inventor of Wiki and co-inventor of Extreme Programming:

"You know you are working with clean code when each routine you read turns out to be pretty much what you expected".

This statement is true not only with respect to the code and routines it contains, but also to the overall application structure. Without a good structure, the complexity might quickly grow, making the maintenance and further extensions unnecessarily difficult. In addition, the usage of the same structure by all developers in a given organisation greatly facilitates collaborative work, shared support and possible take over of the application by peer developers.

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USABILITY RECOMMENDATIONS FOR THE SKA CONTROL ROOM OBTAINED BY A USER-CENTRED DESIGN APPROACH

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Abstract

User-Centred Design is a powerful approach for designing UIs that match and satisfy users' skills and expectations. Interviews, affinity diagrams, personas, usage scenarios are some of the fundamental tools for gathering and analysing relevant information. We applied these techniques to the development of the UI for the control room of the Square Kilometre Array (SKA) telescopes. We interviewed the personnel at two of the SKA precursors, LOFAR and MeerKAT, with the goal of understanding what features satisfy operators' needs, which ones are missing and which ones can be improved.

What was learned includes several usability issues dealing with fragmentation and low cohesiveness of the UIs, some gaps, and an excessive number of user actions needed to achieve certain goals.

Low usability of the UI and the large scale of SKA are two challenges in developing its UI because they affect the extent to which operators can focus on important data, the likelihood of human errors and their consequences. This paper illustrates the followed method, provides examples of some of the artefacts that were produced and describes and motivates the resulting usability recommendations which are specific for SKA.

INTRODUCTION

SKA (Square Kilometre Array) is an international project to build the world's largest radio telescope [1]. The signal coming from hundreds of dishes and thousands of dipolar antennas will be combined using interferometry to reach sensitivity and resolution much higher than today's best radio telescopes. Given the operational costs of having such a system providing high quality scientific data, to maximise the observational success is a challenge that has to be won.

One of the critical aspect is the design of a User Interface (UI) capable of supporting the operators in the difficult task of running the telescope. Without adopting an adequate development process of the UI, complexity and size of SKA are likely to lead to negative performance by the people that have to operate the system and to unsatisfactory key performance indicators such as high error rate, low efficiency, poor quality of scientific data. In the end these would contribute to loss of time, loss of observing opportunities, poor quality of observations, increased operational costs, damages to equipment, safety problems.

For this reason, to identify the features that clearly help the users or those that, instead of helping, reduce their efficiency is crucial. The User-Centred Design (UCD) approach provides a well consolidated method to tackle the problem. A first step is to conduct appropriate analysis to learn about expected users of the UI to be designed, so that it becomes clear what they perceive being the problem that needs to be solved, and what is the physical, social and conceptual context in which the UI will be used.

Following this method we conducted structured interviews to the personnel involved in the operations of the LOFAR (LOw Frequency ARray) and MeerKAT telescopes.

LOFAR is a fully operational telescope consisting of 51 stations of dipolar antennas spread over Europe and operated by the Netherlands Institute for Radio Astronomy in collaboration with international partners [2]. The MeerKAT telescope has been designed to be the largest and most sensitive radio telescope in the Southern Hemisphere until SKA becomes operational. It is currently being built in South Africa and, when fully functioning in 2020 , it will comprise 64 dishes [3]. Even if MeerKAT will be able to produce high quality science on its own, the telescope will be part of SKA since the first SKA phase. Personnel at both telescopes contributes to SKA technology, science and operations activity.

The two telescopes, LOFAR and MeerKAT, differ in the operational status and in the type of receptors: this allowed us to have an overview of the differences in the two systems and the procedures and activities that are carried out during the normal operations and the commissioning phases.

The collected information has been categorised using affinity diagrams and helped the definition of user profiles, usage and interaction scenarios, sketches and storyboards. What was noticed is that some usability issues are present in the UIs at both the telescopes and are related to the low cohesiveness between different tools and to scalability. Moreover, the operators at both telescopes identified as fundamental the ability to rapidly access all the information needed to diagnose a problem and to understand its impact on the observation that is being carried on. At the moment they have to perform several steps in order to have a complete picture of the situation. Projecting these issues to the UI for SKA, given its size and complexity, it likely that an inadequate UI could emerge, that could lead to poor performance by the staff in charge with operations. Our work has the aim of preventing such a situation to occur by providing the designers of SKA UIs with essential information about the end users and the functionalities that support their work.

In the subsequent sections some background on UCD method is given, followed by a description of the conducted interviews and set of usability concerns that emerged from them and can drive recommendation for the design of SKA UIs.

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PYTHON FOR USER INTERFACES AT SIRIUS

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Abstract

Sirius is the new Brazilian Synchrotron and will be finished in 2018. Based on experiences at LNLS UVX light source along with researches and implementations, we present our new approach to develop user interfaces for beamlines control. On this process, the main tools explored are Python, Qt and some Python libraries: PyQt, PyDM and Py4syn. Powerful resources of these modules and Python straightforward coding guarantee flexible user interfaces: it is possible to combine graphical applications with intelligent control procedures. At UVX, EPICS and Python are software tools already used respectively for distributed control system and control routines. These routines often use Py4Syn, a library which provides high-level abstraction for devices manipulation. All these features will continue at Sirius. More recently PyQt turned out to be a compatible and intuitive tool to build GUI applications, binding Qt to Python. Also PyDM offers a practical framework to expose EPICS variables to PyQt. The result is a set of graphical and control libraries to support new user interfaces for Sirius beamlines.

INTRODUCTION

The Brazilian Synchrotron Light Laboratory (LNLS) started in 1997, building UVX, the first synchrotron light source of South Hemisphere. Today, UVX has 16 beamlines opened for user community. Since its foundation, control software used on UVX beamlines evolved in many ways. Starting with in-house software, EPICS [1] was adopted in 2011 and at the moment our control software solution is mostly based on it. EPICS led to a standard method of accessing different devices. However, other needs emerged at the beamlines regarding data acquisition, such as user-friendly monitoring and control as well as integration with complex experiment routines. In order to address these requirements, LNLS started to research more efficient user interfaces.

At the beginning control procedures at UVX were mostly based on direct access to EPICS PVs (process variables), using commands such as caget and caput. Then, many different ways of providing simple but powerful user interface were experimented. Chosen tools include frameworks written in C, Java and Python, and currently the most used ones are CS-Studio [2] and Python scripts that include Py4Syn [3, 4], library for high-level operations at synchrotrons.

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All this experience resulted in good guidelines for what will be selected for Sirius, the new Brazilian synchrotron LNLS is currently working on.

Sirius promises to be one of the most brilliant synchrotron light sources, planned to achieve higher energy and much lower emittance than UVX, with initially 13 beamlines and 40 ones as the final objective. This new synchrotron facility will allow experiments that are not possible today at the current Brazilian light source. The first electron beam is planned for 2018 and the early experiments at beamlines are expected in the course of 2019.

Constructing a new laboratory brings a lot of innovation challenges to all fields related to its project and on control user interface it is not different. Each beamline at Sirius will have different types of devices and they will be more numerous than they are at UVX. Also, different types of experiments will be available per beamline. For robust control of all equipment and experiments, we pursued a framework for intuitive and flexible user interfaces, not only for the end user but also regarding development.

On this process, experiences at UVX in the last years are highly valuable while defining what will be prepared for Sirius. Based on them, we summarize challenges and proposed solutions for user interfaces at Sirius.

CONTROL INTERFACES AT UVX

Providing a control interface for a beamline is not a simple task. Normally, there are many different equipment from different manufacturers and with particular software.

At UVX, since we started using EPICS this problem became simpler. EPICS brings a common interface to communicate with several devices, organizing and accessing their properties by creating process variables (PVs) through an IOC (Input/Output Controller). But EPICS doesn't provide a graphical user interface, but something closer to a middleware interface. Besides that, we chose to let on IOC just low-level code, that is, we didn't insert in IOC complex operation like a motor scan.

On LNLS user interfaces is grouped in two main groups: Simple Read/Write PVs and Experiments. Simple Read/Write PVs are usually used for tasks such as moving a motor, updating parameters of a picoamperimeter, monitoring values from a detector. All these tasks are resumed to read and write values from/to process variables. Experiments are tasks a bit more complex and involve working with different hardware together with performing a set of actions related to PVs. An example is a motor scan, a task where a motor is moved while a detector is read. On motor scan, a motor is moved only if detector has finished acquisition. These experiments are built as Python scripts and could be

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NOMAD 3D: AUGMENTED REALITY IN INSTRUMENT CONTROL

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Abstract

The life cycle of an ILL instrument has two main stages. During the design of the instrument, a precise but static 3D model of the different components is developed. Then comes the exploitation of the instrument of which the control by the Nomad software allows scientific experiments to be performed.

Almost all instruments at the ILL have moveable parts very often hidden behind radiological protection elements such as heavy concrete walls or casemate. Massive elements of the sample environment like magnets and cryostats must be aligned in the beam. All those devices have the possibility to collide with the surrounding environment. To avoid those types of accident, the instrument moves must be checked by a pre-experiment simulation that will reveal possible interferences.

Nomad 3D is the application that links the design and the experiment aspects providing an animated 3D physical representation of the instrument while it moves. Collision detection algorithms will protect the moveable parts from crashes. During an experiment, it will augment the reality by enabling to "see" behind the walls. It will provide as well a precise virtual representation of the instrument during the simulations.

INTRODUCTION

The classical tool for instrument design at the ILL is SolidWorks [1]. Typically, the projects are realised internally but they can integrate some components from external companies. The models at the end may contain errors, have different configurations showing different parts of the model in an exclusive way. The models are very precise — every part of the instrument is designed including the screws — and can be big. The model represents the different components with their real dimensions as the real parts are built from it.

On the other side, Nomad [2], the instrument control software is providing the full control of the instruments and the experiments. The axes driven by the motors can move in parallel on request of the user and Nomad is monitoring the actual positions of the axes by reading the encoder position of the motors. A simple movement of three parts around two axes is shown in Figure 1.

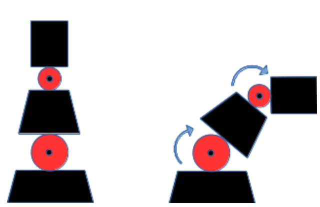

Figure 1: Diagram showing a movement with 2 axes.

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The goal of the project is to adapt the SolidWorks models to 3D models that will be loaded and animated into a dedicated viewer application. The positions of the axes are read from Nomad. We do not make any strong assumption on the client computer requirements so the viewer application must be scalable and be able to display big original models. Now we suppose that we are in the scope of an instrument for which we have a SolidWorks model and a Nomad configuration. To achieve our goal, we need to proceed in different steps. First we need to export the model to clean, correct and simplify it so that it is small enough to be displayed at a comfortable frame rate. Then we need to identify and map the axes of the model to the axes of Nomad, "augmenting" the data of the model. As Nomad only provides angle or distance values, a "calibration" phase is then required to position the axis in the 3D space and set the "zero". With these information, we are able to animate the 3D model precisely with the only actual values of the axis.

Nomad 3D is a cross-disciplinary project that links Computer-Aided Design (CAD) [3], instrument control and 3D graphics. The article will navigate through these different fields.

WORKFLOW

The Nomad 3D project is split into different applications for which the typical workflow is shown in Figure 2.

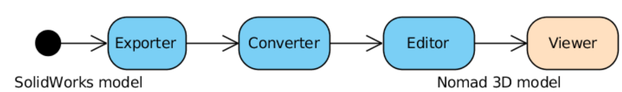

Figure 2: Workflow for an instrument model.

We provide details for each application in the following sections.

SolidWorks Introduction

Let's begin by a short introduction to CAD and the SolidWorks data model. SolidWorks and other CAD software are intended for mechanic's design.

A SolidWorks model is described as a tree hierarchy of components, each of them saved in a separate file. The component leaves also called "parts" are the geometries obtained by a combination of basic 3D geometric shapes - addition or subtraction of prisms, cylinders, spheres, etc. The components that are not the leaves, called "assemblies" are groups of parts or assemblies (called sub-assemblies in that case). They also describe how the sub-components are constrained to each other. A constraint between two components is called a "mate" and defines the degrees of freedom of the components from a relative perspective.

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C2MON SCADA DEPLOYMENT ON CERN CLOUD INFRASTRUCTURE

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Abstract

The CERN Control and Monitoring Platform (C2MON) [1] is an open-source platform for industrial controls data acquisition, monitoring, control and data publishing. C2MON's high-availability, redundant capabilities make it particularly suited for a large, geographically scattered context such as CERN. The C2MON platform relies on the Java technology stack at all levels of its architecture, and previously imposed the deployment of binary archives that needed to be unpacked and executed locally. Since end of 2016, CERN offers a platform as a service (PaaS) offering based on RedHat Openshift [2]. Initially envisioned at CERN for web application hosting, Openshift can be leveraged to host any software stack due to its adoption of the Docker container technology, including the Java dependency stack that C2MON is based upon. In order to make C2MON more scalable and compatible with Cloud Computing [3], it was necessary to **containerize** C2MON components for the Docker container platform. Containerization is a logical process that forces one to rethink a distributed architecture in terms of decoupled micro-services and clearly identify dependencies in terms of services, storage requirements, configuration and connectivity, without ever imposing any physical considerations, which would in any case jeopardize the redeployment of the distributed architecture in another cloud environment. In return, the deployment of the said distributed architecture becomes reproducible and entirely automatable.

This paper explains the challenges met and the principles behind containerizing a server-centric Java application, demonstrating how simple it has now become to deploy C2MON in any cloud-centric environment (ranging from Openstack Magnum to Docker Swarm, and of course Openshift).

C2MON USAGES AT CERN

C2MON [1] is a monitoring platform developed at CERN and since 2016 made available under an LGPL3 open source license. C2MON employs Java messaging, caching and clustering technologies to deliver robust, scalable and monitoring of data of any kind, with a particular focus on industrial control systems.

C2MON is at the heart of the CERN Technical Infrastructure Monitoring (TIM) that supervises the correct functioning of CERN's technical and safety infrastructure. TIM handles about three million messages per day.

C2MON is also used by DIAMON2 [4], CERN's accelerator infrastructure to monitor a large majority of the equipments that compose it, ranging from servers to consoles, through front-end computers and PLCs. DIAMON2 handles an average of twenty million messages per day.

ADAPTING FOR THE CLOUD

Over the past couple of years, CERN has embraced cloud technology by replacing the majority of its computing infrastructure by Openstack at a record pace [3]. Cloud technology presents significant advantages for large organizations by allowing a more precise and more agile sharing of available resources. It promotes device and location independence by forcing users to design their software architectures in terms of remote resources. It also simplifies reusing and duplication of entire groups of machines for testing and validation purposes. Last but not least, cloud deployments introduce support for load balancing, circuit breaking and rolling updates in a near-transparent manner, which prior to this would have required the usage of proprietary, complex and technology-specific solutions.

Cloud technology is perfectly suitable for deploying pre-cloud era legacy applications thanks to virtualization technology. Legacy applications that rely on low-level operating system devices (such as storage or network adapters) can easily be relocated on a cloud and thus gain a new home away from any cumbersome hardware constraints.

However, with regards to this last point, a number of aspects need to be carefully considered in order to benefit more completely of a cloud infrastructure :

- Usage of storage, process and network resources.
- Support for failures, low availability, health metrics.
- Support for clustering and configuration injection.

Usage of Storage, Process and Network Resources

Typical pre-cloud era applications expect a file system to be available along with one or more local network connections. Cloud-based deployment can certainly fulfil such expectations, but for scalability and relocation's sake, file systems are usually transient (i.e. they are reset upon restart) and network interfaces typically allocated on the fly with a randomly-generated hardware address and attached to a local private, non-routable network.

Likewise, the life cycle of a cloud container hosting an application is linked directly to its main process ; this means that a web application server process that stops will immediately terminate its hosting container and be signalled to the cloud infrastructure as inactive, ready to be removed. This is an essential feature of a cloud infrastructure which allows for unused resources to be garbage-collected and reallocated immediately. Processes

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BEHAVIOURAL MODELS FOR DEVICE CONTROL

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Abstract

ESO is in the process of designing a new instrument control application framework for the ELT project. During this process, we have used the experience in HW control gained from the first and second generation of VLT instruments that have been in operation for almost 20 years. The preliminary outcome of this analysis is a library of Statecharts models illustrating the behaviour of some of the most commonly used devices in telescope and instrument control systems. This paper describes the architectural aspects taken into consideration when designing the models such as HW/SW state representation, common/specialized behaviour, and failure management. An extension to Harel's formalism to facilitate reusability by dynamic creation of orthogonal regions is also proposed. The paper details the behaviour of some devices like shutters, lamps and motors together with the rationale behind the modelling choices. A mapping of the models to a concrete implementation using real HW components is suggested. Although these models have been designed following the principles of our conceptual architecture, they are still generic and platform independent, so they can be easily reused in other projects.

INTRODUCTION

For more than 20 years, the Control Instrument Software group at the European Southern Observatory (ESO), has provided to universities and consortia a software framework to build instruments for the Very Large Telescope (VLT) and Interferometer (VLTI) facilities located at Cerro Paranal in the Atacama desert in Chile.

Part of the framework is dedicated to the monitoring and control of devices such as shutters, lamps, motors, and piezos. For each type of device there are several implementations available on the market. These implementations usually differ in some mechanical or electrical characteristics like accuracy, speed, size, and power consumption, however their logical behaviour is often very similar. The goal of this paper is to promote the creation of libraries of behavioural models for devices commonly used in control systems, so that they can be shared in various projects and organizations. These models could be reused for design documentation, system analysis, simulation, and model transformations.

The rest of the paper is organized in five sections. The first section focuses on the motivation for the adoption of StateCharts XML as the modelling language. The following section describes an extension to the Statecharts formalism to introduce the concept of templates in the domain of state machines. The next two sections are dedicated to the description of the devices' common and specific behavioural models. The last section provides some indication on how to map the models into concrete SW artefacts.

MODELING BEHAVIOUR

The selection of the modelling language has been driven by two main requirements:

1. It shall allow to create models that are independent from specific implementation platforms
2. Syntax and semantic shall be standard and precise.

The motivation for the first requirement is to facilitate the usage of models in projects that have adopted different technologies and tools. The second requirement aims to avoid misinterpretation and to allow automatic model transformation and execution.

We have evaluated three possible modelling languages all based on variations of the Statecharts formalism [1, 2]:

- SysML State Machines
- OPC-UA data model for State Machines
- StateChart XML

SysML language [3] has been standardized by the Object Management Group (OMG) but only a subset of the language, the so called Foundational UML (fUML), has precise semantic [4]. Recently OMG has started a working group to specify the semantic of SysML/UML State Machines: the Precise Semantic for State Machines (PSSM) [5]. Unfortunately, no recommendation has been released yet and we are not aware of any available implementation.

Since the devices we want to model are very often controlled via PLCs, we investigated the possibility of modelling their behaviour using OPC-UA data model which is a de-facto standard for industrial automation and is defined by the OPC Foundation [6]. OPC-UA data model offers a syntax to model a subset of the Statecharts features leaving the definition of the missing parts to the user. The semantic specification is not provided.

StateChart XML (SCXML) is a recommendation released in 2015 by the World Wide Web Consortium (W3C) specifying an event-based state machine language derived from Statecharts [7]. At the moment of writing, SCXML seems to be the only option that provides a precise syntax and semantic definition and that can be easily exchanged thanks to the textual XML representation.

Textual models are easy to edit and compare but they can be more difficult to understand than diagrams. This is especially true for Statecharts since the notation takes advantage of intuitive topological concepts like composition [8]. To overcome this problem, we have defined a mapping between SysML/UML State Machines and SCXML and developed an open source tool, called COMODO, to transform SysML/UML State Machine models, saved in Eclipse

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A NEW ACS BULK DATA TRANSFER SERVICE FOR CTA*

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Abstract

The ALMA Common Software (ACS) framework provides Bulk Data Transfer (BDT) service implementations that need to be updated for new projects that will use ACS, such as the Cherenkov Telescope Array (CTA) and other projects, most of them having quite different requirements than ALMA. We propose a new open-source BDT service for ACS based on ZeroMQ, that meets CTA data transfer specifications while maintaining retro-compatibility with the closed-source solution used in ALMA. The service uses the push-pull pattern for data transfer, the publisher-subscriber pattern for data control, and Protocol Buffers for data serialization, having also the option to integrate other serialization options easily. Besides complying with ACS interface definition to be used by ACS components and clients, the service provide an independent API to be used outside the ACS framework. Our experiments show a good compromise between throughput and computational effort, suggesting that the service could scale up in terms of number of producers, number of consumers and network bandwidth.

INTRODUCTION

The Cherenkov Telescope Array (CTA) control software decided to reuse ALMA Common Software (ACS) [1], which is a distributed framework for high-level control specially tailored for array control [2]. ALMA itself is not developing new features nor upgrading actively their technologies because the observatory is currently in production phase. Further development has been taken over by the ACS Community Branch [3], a fully open source branch of ACS, with the objective of upgrading the software without the ALMA constraints, replacing closed components by open source alternatives and working on packaging to streamline installation and simplify future development.

Even though CTA will use ACS as its base distributed-system broker, the requirements are different from ALMA. Besides the straight-forward differences (e.g., hardware drivers, wavebands, two sites), the CTA instruments will generate much larger volumes of data in bursts (events), and not more or less continuously like in ALMA antennas. Therefore, the CTA software development group needs to upgrade this framework to avoid obsolescence and to meet the specific requirements of the planned instruments that CTA will deploy. Specifically, ACS must support the Observation Execution System (OES) work package, which is the control system of CTA that includes high-level control and coordination of the detectors, instrument control and configuration, triggering system for detecting target events, data acquisition pipeline and graphical interfaces for science and engineering use cases [4].

Between these new challenges for the framework, we found much more demanding bulk-data transfer (BDT) requirements, because CTA will use cameras with very large readout targets, and their respective servers will be not designed to store the data locally (e.g., [5]). Moreover, concurrent events in the array are expected (indeed events need to be stereoscopic to be considered as a detection), and simulations predict large event rates (> 10 KHz) [6]. Consequently, data needs to be transferred rapidly to a data center that will store the results. This paper presents our proposal for a new BDT service that uses state-of-the-art technologies to achieve this goal.

ACS BULK DATA TRANSFER SERVICE

The current next-generation BDT service (BDT-NG) used in ALMA is based on RTI Distributed Streaming System [7], and it is tailored for their transfer rates and the package sizes [8], which differ substantially compared to the needs of CTA. Also, it is closed-source solution which involves licensing issues. A previous open-source version was available, but it is considered deprecated and it is not supported any more, leaving the ACS community branch without an implementation of a key feature of its architecture.

Despite these technical differences, the core characteristics of the BDT service remain similar. The control software architecture of CTA, specifically the Data Acquisition subpackage (DAQ) [9], defines the requirements of the BDT service that suits CTA, and proposes using the ZeroMQ library for this task. ZeroMQ would be used for the data transference among servers, with the use of Protocol Buffers for data serialization and language abstraction, through its Interface Description Language (IDL) interface[1].

A ZeroMQ-based Bulk Data Transfer Service

Both ZeroMQ and Protocol Buffers are off-the-shelf tools that would allow in combination to transfer CTA's bulk-data

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[1] This IDL is different from the one used in CORBA-based systems such as ACS.

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THE DESIGN OF TANGO BASED CENTRALIZED MANAGEMENT PLATFORM FOR SOFTWARE DEVICES

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Abstract

Tango provides the Tango device server object model(TDSOM[1]), whose basic idea is to treat each device as an object. The TDSOM can be divided into 4 basic elements, including the device, the server, the database, the application programmers interface. On the basis of the TDSOM, we design a centralized platform for software device management, named VisualDM, providing standard servers and client management software. Thus the functionality of VisualDM are mutli-folds: 1) dynamically defining or configuring the composition of a device container at run-time; 2) visualization of remote device management based on system scheduling model; 3) remote deployment and update of software devices; 4) registering, logouting, starting and stopping devices. In this paper, platform compositions, module functionalities, the design concepts are discussed. The platform is applied in computer integrated control systems of SG facilities.

INTRODUCTION

The large-scale scientific experimental facility consists of a number of systems, units and components, For example: The National Ignition Facility (NIF)'s ICCS[2][3] is a layered architecture of 300 front-end processors attached to nearly 60,000 control points and coordinated by supervisor subsystems in the main control room. Each component is basically a control unit with independent control algorithms, such as valves, motors, CCD, etc. These associated control units are combined to a sub-system. These control objects in the software embodied as one of the software device, the relationship between software devices includes combinations and dependencies. After a large number of cases, the controlled device management becomes a problem, how to effectively deploy, monitor, upgrade and visualize a huge number of devices is a topic worthy of study. Centralized Management Platform named VisualDM is designed to address this issue.

DEVICE MONITOR BASED ON JIVE OR ASTOR

Jive[4] is a standalone JAVA application designed to browse and edit the static TANGO database. Jive can manage and create devices, properties and classes in Fig. 1. Jive also offers advanced search/selection features.

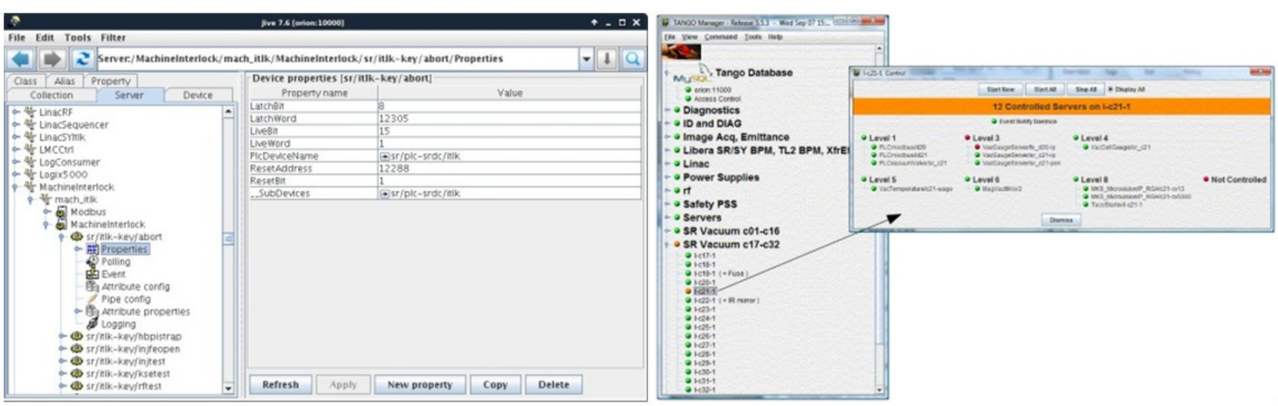

Figure 1: Jive and Astor running interface.

Astor[5] is a Java program using Swing classes. Astor displays a tree where nodes could be a family of hosts, and leaves are hosts where a Starter (a program belonging to tango) device server is registered in database, as provided in Fig. 1.

These two programs have a common feature: the managed device is equal, is flat, determined by the tango framework. This flat management of devices is suitable for the debugging phase, not suitable for the running phase. During the running phase the operator is facing the view of system objects, is a hierarchical view.

CONTROL SYSTEM SOFTWARE STRUCTURE

A human-built system with complex behaviour is often organized as a hierarchy[6]. For example, in Fig. 2 a command hierarchy has among its notable features the organizational chart of superiors, subordinates, and lines of organizational communication. Hierarchical control systems are organized similarly to divide the decision making responsibility. Each element of the hierarchy is a linked node in the tree. Commands, tasks and goals to be achieved flow down the tree from superior nodes to sub-

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THE ELT LINUX DEVELOPMENT ENVIRONMENT

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Abstract

The Extremely Large Telescope (ELT) [1] is a 39-metre ground-based telescope being built by ESO [2]. It will be the largest optical/near-infrared telescope in the world and first light is foreseen for 2024.

The overall ELT Linux development environment will be presented with an in-depth presentation of its core, the *waf* [3] build system, and the customizations that ESO is currently developing.

The ELT software development for telescopes and instruments poses many challenges to cover the different needs of such a complex system: a variety of technologies, Java, C/C++ and Python as programming languages, Qt5 [4] as the GUI toolkit, communication frameworks such as OPCUA [5], DDS [6] and ZeroMQ [7], the interaction with entities such as PLCs and real-time hardware, and users, in-house and not, looking at new usage patterns. All this optimized to be on time for the first light.

To meet these requirements, a set of tools was selected for the development toolkit. Its content ranges from an IDE, to compilers, interpreters, analysis and debugging tools for the various languages and operations. At the heart of the toolkit lies the modern build framework waf: a versatile tool written in Python selected due to its multiple language support and high performance.

ELT SOFTWARE NEEDS AND CHALLENGES

While choosing the software technologies that the new ESO telescope will use, many factors were taken into account, for example:

- Construction time and lifetime of the project; from the project start to the first light almost a decade will pass by and the operational time is estimated to be at least 30 years. Technology-wise these are very long timespans.
- Different scope; some parts of the new telescope require very fast, real-time, either computation hungry or low-level, operations while others are used for post-processing or data management where timing is not strict but high level abstraction may be required.
- Different developer base; the ELT project will be prepared with efforts of ESO engineers, external contractors and consortia of scientific institutes.

Given these factors a series of basic requirement are therefore set on the software technologies to be used:

- Must be maintainable in the long term and as accommodating as possible to new future developments and requests
- The software tools available must be able to cope with both low-level; real-time near hardware, and high-level; user facing or data abstraction situations depending on the scope of the software component being developed. Certainly it is difficult to find a single solution for all these so different needs. This may mean that a selection of complementary tools should be offered.
- The software environment must take into account a distributed and non-homogenous user base, working at different premises and with different knowledge bases and goals. Trying to simplify common use cases should be an important asset, while not limiting the possibilities for advanced users.

The current plan is to develop most of the software, with the exception of some PLC based development, on the Linux operating system. Where specifically needed the Linux real-time extensions [8] will be used and possibly specific lower level network throughput optimization libraries may be used to satisfy both timing and bandwidth requirements.

The main programming languages selected for the project are C/C++ chosen for its high performance and low level capabilities, Java for its higher level of abstraction and Python as a versatile scripting language that offers high productivity. Language standards requirements had been set to relatively new standards: C++11, Java 8 and Python 3.x are the current baseline.

The graphical user interface toolkit selected is Qt5, giving the possibility to build advanced, portable and performant interfaces in both C++ and Python.

Network communication will be IPv4 based and on a higher level the aim is to support multiple application level protocols to increase the expandability and interoperability of the project with different communication patterns and features that may be needed by a specific project feature implementation. While a general abstraction layer is planned to be developed to ease the integration, it is planned that OPCUA, DDS, ZeroMQ as well as an internal UDP based protocol will all be part of the project and extensively used.

A big challenge for the development environment is to try to make all these different technologies work together and in a harmonious way. While it may be easier to find optimized domain specific build systems, visual

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HIGH PERFORMANCE RDMA-BASED DAQ PLATFORM OVER PCIE ROUTABLE NETWORK

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Abstract

Current and upcoming 2D X-ray detectors for synchrotron radiation applications are capable of producing data rates in the range of 1-100 GB/s. Existing industrial protocols do not provide suitable data acquisition solutions for handling efficiently such a high-throughput data streams. A generic and scalable RDMA-based data acquisition platform called RASHPA, designed to address these detector needs, is introduced in this paper. The FPGA implementation as well as the Linux-based software stack is detailed. Finally, the paper presents a demonstrator integrating RASHPA over a routable PCIe network.

INTRODUCTION

The improvements of integrated circuits manufacturing technologies and processes, applied to the last generations of 2D X-ray detectors, result in a significant increase in the produced data rates. The ESRF has undertaken the implementation of a generic and scalable data acquisition framework as one of key essential components for the development of new advanced high performance detectors for scientific applications [1].

One of the key and specific features this new framework is the use of remote direct memory access (RDMA) for fast data transfer. RDMA consists on the transfer of data from the memory of one host or device into that of another one without any intervention of the CPU. This permits high-throughput, low-latency networking. Companies are investing more and more into this feature, already applied to high performance computing, by integrating it into their network cards and communication adapters. Some of the available technical solutions are Infiniband [2], RDMA over Converged Ethernet (RoCE) [3] and internet Wide Area RDMA Protocol (iWARP) [4], to name few.

The Peripheral Component Interconnect Express (PCIe) [5] bus is a high-speed serial computer expansion bus standard, which uses shared parallel bus architecture, in which the PCI host and all devices share a common set of addresses. In other words, PCIe have a direct access to the memory of the system. For RDMA based applications, PCIe is an ideal option due to its reliability, scalability, low latency and native integration. In fact, over the years, PCIe has become the default peripheral interconnect of x86 based platforms, it has a built-in support for control flow, data integrity and packet ordering, thus no need for additional protocol layers. In addition to that, its bandwidth can be adjusted depending on the number of used lanes. Many initiatives have been launched to start using the PCIe-based RDMA to accelerate communications in data centres [6-8].

Despite these benefits, the limited availability of PCIe over cable products and the lack of standardization of optical cabling form is still an issue [1].

RASHPA (RDMA-based Acquisition System for High Performance Applications) is the generic framework for detector data acquisition currently under development at the ESRF. It is optimised for the transfer of 2D detector data, i.e images, and it relies completely on RDMA mechanisms. When implemented over a low latency PCIe over cable network, RASHPA is able to push data, at very high speed into the address space of one or several backend computers. The scheme provides a high standardization level in the data transmission pipeline from the detector up to the software application for further processing, visualization or storage.

This paper details the FPGA implementation of RASHPA at the detector side, as well as its carefully designed Linux software stack. In addition to that, a demonstrator integrating RASHPA over a routable PCIe over cable network is also presented.

The paper is organised as follows: Section 2 introduces the RASHPA concept and architecture. Section 3, presents the hardware and software implementation of RASHPA and the interaction between both. Section 4 shows the RASHPA prototype and experimental results. Conclusions and future perspectives are discussed in section 5.

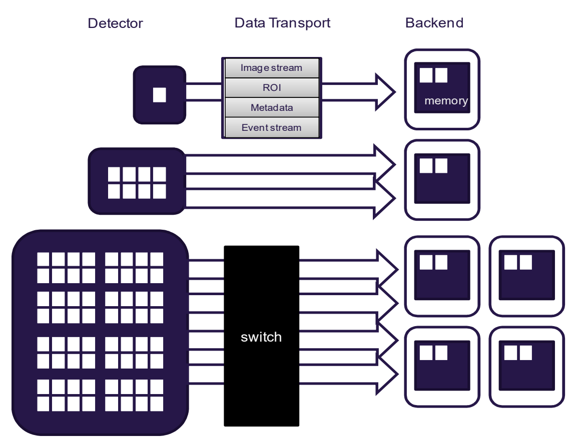

Figure 1: Block diagram of a RASHPA network.

RASHPA CONCEPT

As a framework, RASHPA defines a set of functional concepts as well as the hardware and software interfaces. It also implements a generic, non hardware specific middleware running on the backend computers. For practical

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CYBER THREATS, THE WORLD IS NO LONGER WHAT WE KNEW…

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Abstract

Security policies are becoming hard to apply as instruments are smarter than ever. Every oscilloscope gets its own stick with a Windows tag, everybody would like to control his huge installation through the air, IOT is on every lip…

Stuxnet, the recent Snowden revelations have shown that cyber threats on SCADAs cannot be only played in James Bond movies.

This paper aims to give simple advises in order to protect and make our installations more and more secure.

How to write security files? What are the main precautions we have to take care of? Where are the vulnerabilities of my installation?

Cyber security is everyone's matter, not only the cyber staff's.

INTRODUCTION

ICALEPCS is the conference where Large Experimental Physics Systems describe their Industrial Control Systems (ICS) architecture.

Most of these systems can be represented using the Purdue model, as shown in Figure 1.

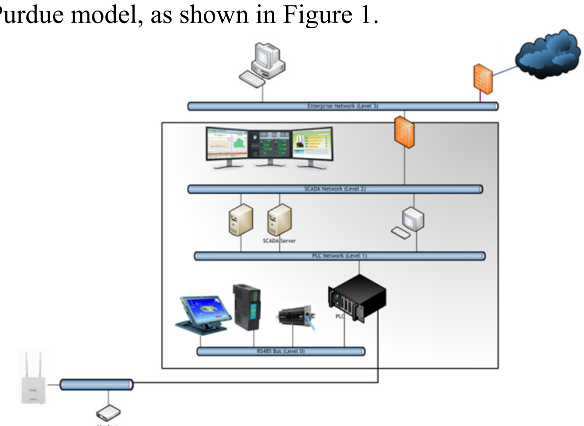

Figure 1: ICS Architecture.

The 4 main levels of this schematic include:

- Level 0: Sensors low level buses,
- Level 1: PLC network,
- Level 2: SCADA,
- Level 3: Office network.

External access can be added:

- Remote through WiFi, Bluetooth, modems…
- Internet.
- Contractors.
- Direct access through USB drives.

Figure 2: ICS Vulnerabilities.

But each benefit of this architecture shows us vulnerabilities (Figure 2):

- Remote access can be attacked using non secure access points,
- Firewalls may be non-sufficient if rules are not correct.
- Internet remote access is a source of multiple attacks (deny of services, open ports access, non-secured protocols…).
- PLCs can be trapped.
- Maintenance systems can be hacked and, by the way, give access to malware installations.
- The use of USB keys can compromise systems using rootkits, infected files, and macros or even destroy systems with devices like USB killers technologies.

In 2016, Security trends and vulnerabilities review shows that SACA and PLCs are on the top level of ICS component [1]. Particularly this study reported that Siemens and Schneider Electric represented 32% and 18% of the vendors concerned by the number of vulnerabilities. Between 2012 and 2015, there have been almost 150 to 200 vulnerabilities discovered each year. Center for Strategic and International Studies pointed out 218 cyber-attacks dated from May 2006 to August 2016 and this list is still growing [2].

SOME EXAMPLES [3]

Attack on the BP Baku-Tbilisi-Ceyhan Turkish Pipeline

In 2008, hackers planned a combined physical and cyber-attack on a pipeline located between Turkey and Azerbaijan that caused an explosion with flames as high as 50 meters… The attack was made through a non-protected wireless network, making disconnections of

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SECURING LIGHT SOURCE SCADA SYSTEMS

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Abstract

Cyber security aspects are often not thoroughly addressed in the design of light source Supervisory Control and Data Acquisition (SCADA) systems. In general the focus remains on building a reliable and fully functional ecosystem. The underlying assumption is that a SCADA infrastructure is a closed control ecosystem of sufficiently complex technologies to provide some security through trust and obscurity. However, considering the number of internal users, engineers, visiting scientists, students going in and out light source facilities, cyber security threats can no longer be neglected. At the European XFEL, we envision a comprehensive security layer for the entire SCADA infrastructure. Karabo the control, data acquisition and analysis software developed at the European XFEL, shall implement these security paradigms known in IT but not applicable off-the-shelf to the FEL context. The challenges are considerable: (i) securing access to photon science hardware that has not been designed with security in mind; (ii) granting limited fine-grained permissions to external users; (iii) truly securing control and data acquisition APIs while preserving performance; and (iv) for integrating external data analysis applications. Only tailored solution strategies, as presented in this paper, can fulfil these requirements.

INTRODUCTION

The security of Supervisory Control and Data Acquisition (SCADA) systems is an increasing concern [1] as they nowadays interconnect a significant number of Commercial off-the-shelf (COTS) computers via IP networks. The massive integration of off-the-shelf IT technologies into the SCADA realm owes to their affordability that keeps capital and operational expenditures low, in comparison to dedicated solutions. Indeed, the fierce competition among providers of Information Technology (IT) hardware and software, the maturity of de-facto standards (x86 PC architecture, Linux, TCP/IP, USB), the availability of number of engineers and scientists already trained on these standards fuel that trend.

These proven technologies have brought countless benefits: thousands of interoperable and often free Internet services, open source software packages, plug-and-play hardware. However, with undeniable benefits come collateral weaknesses: bugs, viruses, Trojan horses, ransomwares, worms [2] like Stuxnet [3] and zero-day exploits. They can spread across networks and systems and are no longer stopped by some intrinsic incompatibility of proprietary legacy SCADA. The situational irony is that light sources, in opposition to power plant facilities, have not been classical cyber attack targets to date. However, due to the proliferation of the aforementioned threats, automated blind intrusion are as likely to occur on light source SCADA as in any other connected place. Hence, the interest of external attackers might be triggered *after* they realize that they unintentionally infected a SCADA system built on vulnerable off-the-shelf software. They may then conduct further customized attacks for challenge, malice, cyber warfare or extortion purposes.

The European X-ray Free Electron Laser [4] is a light source of peak brilliance greater than 10^{33} photons $s^{-1}mm^{-2}mrad^{-2}$ per 0.1% BW [5]. It results from the acceleration of bunches of electrons along a 1.7 km superconducting tunnel to the energy of 17.5 GeV. Throughout the SASE process [6], they deliver coherent laser-grade X-ray pulses culminating to 4.5 MHz bursts. Currently six, but extensible to ten, instruments are attached to this unique machine to perform material science and structural biology experiments only the photon energy range (from 0.2 to 25 KeV), the resolution (less than 0.1 nm) and ultra-short pulses (10 fs) of the European XFEL beam might allow. Such a 1.4 billion-euro facility [7], with unique pieces of technology (AGIPD, LPD and DSSC detectors [8–10]) producing about 15 TB of data each beam day requires special care regarding its security.

This responsibility is shared at two stages. First is the general IT stage. It is in charge of applying state-of-art best practices and tools to secure the *infrastructure* running the SCADA system. It encompasses network security (segregation, firewalling, intrusion prevention and detection) and operating system password and permission management. The second stage consists in securing the SCADA system itself. This intends to mitigate the threats posed by an attacker who accessed the Control Network. The SCADA ecosystem at the European XFEL is Karabo [11]. It is essentially a set of agents denoted *devices* interacting by remote method invocation via a central message broker. Beyond broker-centric messaging, direct TCP/IP connections ensure fast data delivery between communicating devices or between GUI clients and GUI server devices.

The key contribution of this work is on fostering in Karabo, the public-key authentication of every user to device servers whatever their access method: GUI, command line (iKarabo) or any Karabo API call. To this aim, every serialized message in the control ecosystem shall convey a signed token or the token digest.

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THE BACK-END COMPUTER SYSTEM FOR THE MEDIPIX BASED PI-MEGA X-RAY CAMERA

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Abstract

The Brazilian Synchrotron, in partnership with BrPhotonics and CPqD, is designing and developing π-MƎGA (“pi-mega”), a new X-Ray camera using Medipix 3RX chips, with the goal of building very large and fast cameras to supply Sirius' new demands. This work describes the design and testing of the back-end computer system that will receive, process and store images. The back-end system will use RDMA over Ethernet technology and must be able to process data at a rate ranging from 50 Gbps to 100 Gbps per pi-mega element. Multiple pi-mega elements may be combined to produce a large camera. Initial applications include tomographic reconstruction and coherent diffraction imaging techniques.

PI-MEGA OVERVIEW

The new pi-mega X-Ray camera was designed to support the demands of experiments in Sirius. In its current prototype stage, the pi-mega is a 1.536x1.536 (2,4 MPixel, Fig. 1) X-Ray camera acquiring 24 bit images at 1.000 frames per second. Pi-mega cameras are also composable, with many of them forming a matrix to increase the pixel count, with the initial goal being a 2x2 pi-mega array (9,4 MPixel). The camera was designed with the following features:

- Fast readout (up to 2.000 continuous fps @ 12 bit)
- Dark image-free hybrid technology
- 55 µm square pixel size
- Gap minimizing (no dead area)
- Easy maintenance and replacement

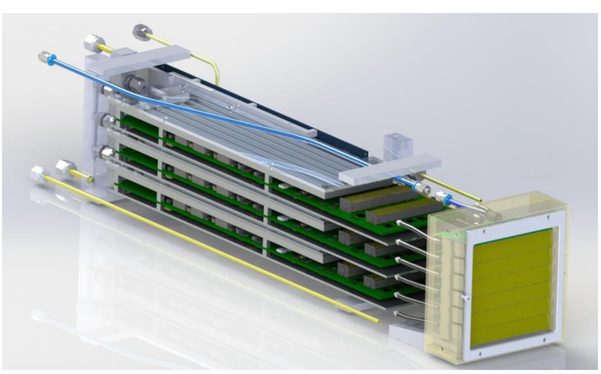

Figure 1: pi-mega design showing the square sensor, the medipix [1] frame boards (green) and the chassis (gray)

The camera is in prototyping stage and it was designed by the LNLS Detectors Group.

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SINGLE PI-MEGA BACK-END DESIGN

For a single pi-mega, it's possible to design a back-end computer including a 100 Gbps network card and 1 high-end GPU. In this system, the data flow can be understood as the following (Fig. 2):

1. The raw image data leaves pi-mega and arrives at the network card
2. It then goes to the GPU through some path (for example, it's stored in host memory, then copied to the GPU).
3. The GPU does some processing on the raw data and generates the resulting cooked image data.
4. The resulting data goes back to the network card through some path.
5. The data leaves the network card and goes to storage.

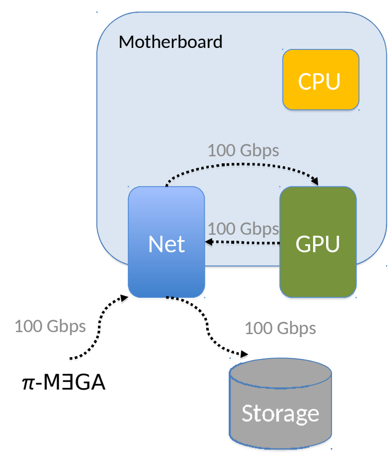

Figure 2: The high level data flow for a single pi-mega.

In the data flow, the incoming raw data may arrive at up to 56,6 Gbps (2,4 MPixel x 24 bit x 1.000 fps).

As a way to make the above data flow as efficient as possible, the RDMA technology (Remote Direct Memory Access [2, 3]) was chosen for both the pi-mega front-end and the network card. RDMA was specifically designed for high performance, low overhead network transfers by offloading the packet processing to hardware. With RDMA, the CPU only deals with the control flow, requesting transfers and receiving completion events from the network card, while the data packet building and processing is delegated to the card [4].

There are different types network cards that support RDMA transferm with different advantages and disadvantages:

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ORCHESTRATING MeerKAT's DISTRIBUTED SCIENCE DATA PROCESSING PIPELINES

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Abstract

The 64-antenna MeerKAT radio telescope is a precursor to the Square Kilometre Array. The telescope's correlator beamformer streams data at 600 Gb/s to the science data processing pipeline that must consume it in real time. This requires significant compute resources, which are provided by a cluster of heterogeneous hardware nodes. Effective utilisation of the available resources is a critical design goal, made more challenging by requiring multiple, highly configurable pipelines. We initially used a static allocation of processes to hardware nodes, but this approach is insufficient as the project scales up. We describe recent improvements to our distributed container deployment, using Apache Mesos for orchestration. We also discuss how issues like non-uniform memory access (NUMA), network partitions, and fractional allocation of graphical processing units (GPUs) are addressed using a custom scheduler for Mesos.

INTRODUCTION

The MeerKAT radio telescope [1] is currently under construction in the Karoo region of South Africa. In total it will have 64 dish antennas when construction is completed in 2018. It is a precursor to the larger Square Kilometre Array project [2], and will be integrated into the mid-frequency array, SKA1 MID.

The focus of this work is the recent advances in the deployment process of the Science Data Processing pipelines, leveraging so-called "container orchestration" tools that have become common in micro services architectures [3]. We are using Docker containers [4]. In this context, *container orchestration* refers to automating the following: deciding which host a container should be run on and launching it, connecting containers together, and monitoring and reporting on the state of the containers and the services they provide.

This containerised, microservices architecture was selected and combined with continuous integration and deployment tools to achieve a number of benefits: quick deployment which minimises downtime for upgrades, simple and consistent deployment, higher availability as faulty hardware is easily switched out, and improved package management — some software packages are difficult to install due to dependency issues, but by confining each to a dedicated container this problem is simplified.

This paper is organised as follows. First, the MeerKAT system is summarised for context. Next, the Science Data Processor is discussed, as well as the motivation for the changes to the orchestration process. The Apache Mesos platform [5, 6] and the role of scheduler frameworks is then presented. Details of our custom scheduler framework follow, before concluding.

MEERKAT SYSTEM OVERVIEW

This section provides only a brief overview — more details are available [7]. There are three major parts to the telescope data processing pipeline: antennas, correlator beamformer (CBF), and Science Data Processor (SDP).

Each antenna provides a digitised stream of data at a rate of approximately 34 Gb/s, depending on the frequency band, for a total of 2.2 Tb/s. This data is processed in real time by the CBF using banks of Field Programmable Gate Arrays (FPGAs). Tasks such as frequency channelisation, baseline correlation and beamforming are performed by the CBF.

The CBF output is ingested by the SDP which performs tasks such as imaging and calibration. The maximum data rate expected to be ingested by the SDP is approximately 600 Gb/s. This data is transmitted from the CBF in a number of streams, with up to 17 Gb/s in a single stream. While some streams can be split and distributed across nodes, others need to be processed in a single location. Thus, we need to extract the maximum performance from each node.

Overall management of all the telescope's subsystems, including antennas, CBF and SDP, is handled by the Control And Monitoring system (CAM).

SCIENCE DATA PROCESSOR

The physical hardware planned to implement the SDP cluster includes 10 Gb/s and 40 Gb/s Ethernet switches, approximately 50 dual-socket servers, most of which include multiple Graphics Processing Units (GPUs), and an array of spinning disk, solid state and tape drives for the archival of data. Other than noting that these nodes are heterogeneous, with different Central Processing Units (CPUs), GPUs, memory and networking capabilities, the details of each node are inconsequential for this paper and not discussed further.

The processing pipeline moves the data through various logical processes that are distributed over this compute cluster hardware. Depending on the science being performed, the configuration of the pipeline changes. This typically happens a few times per day. The design of the MeerKAT telescope requires multiple instances of the processing pipeline to be active simultaneously. Once the science workload for a pipeline is completed, the resources can be released.

While the SDP pipeline does consist of many small software processes each doing a part of the work, it is not a conventional micro-services architecture [8]. The control plane does not use Hypertext Transfer Protocol (HTTP) or a message bus. Instead it uses a simple remote procedure call protocol named KATCP — the Karoo Array Telescope

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IT INFRASTRUCTURE TIPS AND TRICKS FOR CONTROL SYSTEM AND PLC

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Abstract

The network infrastructure in Solaris (National Synchrotron Radiation Center, Krakow) carries traffic between around 900 physical devices and dedicated virtual machines running Tango 9 control system. The Machine Protection System based on PLCs is also interconnected by network infrastructure. We performed extensive measurements of traffic flows and analysis of traffic patterns that revealed congestion of aggregated traffic from high-speed acquisition devices. We also applied the flow-based anomaly detection systems that give an interesting low-level view on Tango control system traffic flows. All issues were successfully addressed, thanks to the proper analysis of traffic nature. This paper presents the essential techniques and tools for network traffic patterns analysis, tips and tricks for improvements, and real-time data examples.

INTRODUCTION

This paper is organized in six sections, where each section provides description of one real-life use case. The main goal of this paper is to provide recommendations for improvements of network architecture design.

USE CASE 1: MACHINE PROTECTION SYSTEM - PLC NETWORKS

Machine Protection System (MPS) is dedicated to ensure secure operation of machine elements. It is built on a dedicated PLC system collecting data from sensors (temperature, pressure etc.). When any of the predefined thresholds is reached, the MPS system stops the entire machine by closing valves, switching off power supplies or shutting down klystrons. Most of the equipment is capable of generating interlocks in the case of malfunction. Example: cooling water in klystron is not flowing properly – interlock is generated and MPS system stops the machine.

Figure 1: MPS CPU and IO.

The Solaris MPS is based on Rockwell Automation [1] PLCs . There are 6 CPU modules and hundreds of IO modules (Figure 1) interconnected via computer network. MPS traffic is logically separated into dedicated VLANs. There is a 20ms roundtrip for CPU – IO communication. It means that CPU is pooling for data every 20ms and expecting result from IO. If communication is broken, the MPS system generates “communication interlock”, which in turn triggers immediate shutdown procedure for the machine.

First Approach - Bad Results

There is a natural inclination to minimize cost and design computer networks to handle different sources and types of traffic within shared equipment. The separation of traffic is done in the logical layer, but different sources share the same links infrastructure. The first approach was to aggregate MPS PLC traffic with other sources and utilize shared links and switches infrastructure.

During the building phase, it appeared that there were random occurrences of “lost communication” interlocks which stopped the operation of the entire machine. It could happen once a week or once a month, so it was difficult to catch and correlate the single event that might lead to such a case. But it was evident that some bursty traffic from other sources could increase the latency in PLC traffic to an unacceptable value. Prioritizing PLC traffic also did not help.

Recommendations

In order to address the issue of “lost communication” interlocks, it was decided to build a separate fiber optics infrastructure for PLC traffic only. Most of the network equipment was reused, but the MPS system was provided with dedicated links, with no other traffic sent over the same interfaces. In addition, there were new switches dedicated to handle traffic from beamline MPS systems.

After applying this solution, no further interlocks were observed in the period of more than 2 years of operation.

USE CASE 2: TRAFFIC SEPARATION BASED ON DEVICE TYPE

The computer network for the control system carries traffic for different types of equipment and control system software running in virtualized environment. There are hundreds of ion pump controllers, power supplies, scopes, diagnostic systems, RF systems, timing, and PLC. Also, there are multiple virtual machines running Tango9 control system. All of the network-attached systems produce different patterns of traffic. Figures 2, 3, 4 present examples of traffic from Ion Pump controller, Modulator and Control Room computer.

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CONFIGURATION MANAGEMENT FOR THE INTEGRATED CONTROL SYSTEM SOFTWARE OF ELI-ALPS

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Abstract

ELI-ALPS (Extreme Light Infrastructure - Attosecond Light Pulse Source) is a new Research Infrastructure under implementation in Hungary. The infrastructure will consist of various systems (laser sources, beam transport, secondary sources, end stations) built on top of common subsystems (HVAC, cooling water, vibration monitoring, vacuum system, etc.), yielding a heterogeneous environment.

To support the full control software development lifecycle for this complex infrastructure a flexible hierarchical configuration model has been defined, and a supporting toolset has been developed for its management. The configuration model is comprehensive as it covers all relevant aspects of the entire controlled system, the control software components and all the necessary connections between them. Furthermore, it supports the generation of virtual environments that approximate the hardware environment for software testing purposes. The toolset covers configuration functions such as storage, version control, GUI editing and queries.

The model and tools presented in our paper are not specific to ELI-ALPS or to the ELI community, they may be useful for other research institutions as well.

INTRODUCTION

The primary aim of the ELI-ALPS research facility, currently under implementation in Szeged, Hungary, is to make a wide range of ultrafast light sources accessible to the user groups of the international scientific community. Laser driven secondary sources emitting coherent extreme-ultraviolet (XUV) and X-ray radiation confined in attosecond pulses is a major research initiative of the facility. The primary laser pulses will be provided by laser sources operating in the regime of 100 W average power in the near-infrared (NIR) and at 10 W in the mid-IR (MIR).

The constructed buildings will house the laser equipment, beam transport, secondary sources, target areas, laser preparation and other special laboratories. These state-of-the-art facilities require specialized design and cutting edge implementation of the latest technology for vibration levels, thermal stability, relative humidity, clean room facilities and radiation protection conditions.

The typical layout of the laser systems are shown in Fig. 1: each laser source is connected via a beam transport system to one or more beamlines consisting of a secondary source and an end station. Each laser system can contain a high number of controlled devices (translation stages, motorized mirrors, cameras, vacuum pumps, valves, gauges, etc.).

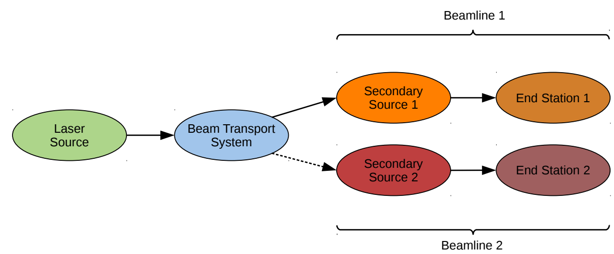

Figure 1: Simplified view of a laser system.

The control system as a whole consists of several interconnected and interoperating systems, each of these having several subsystems, such as vacuum control, optical alignment or an optical configuration subsystem. Each subsystem has a layered architecture, on the bottom being the hardware devices themselves. Above them are the logical devices, which are software components representing a single hardware device on the software side. The functionality of several logical devices are collected in higher level components as necessary, and a resulting system has a single service component representing it towards the rest of the system complex. The Central Control System uses the services of all the other systems and is responsible for monitoring, resource allocation, archiving, alarm handling, etc.

CONFIGURATION IN CONTROL SYSTEMS

Background

Typically configuration plays an important role in the command and control ecosystem, its purpose is to give a static description of properties and relationships of the relevant components. The command and control system accesses these settings from a configuration repository.

The configuration of an advanced control system should describe the system as complete as possible from a structural aspect. On one hand the main goal of the control system is to control hardware devices and various equipment contained in the facility. Networks, computers, motors, CCD cameras and other detectors build up the hardware equipment that has to be controlled, therefore the description of the hardware equipment must be part of the configuration. On the other hand the user requirements must be implemented in the control system. These are usually high level requirements regarding functionality, appearance, expert-mode vs. automated mode, logging, alarms, GUI and/or CLI, data visualization and analysis, etc. The high level architecture of the software that is being developed to implement the requirements of the users can be described in the configura-

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SPEAKING OF DIVERSITY*

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Abstract

Historically, attendance at the International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS) has not been particularly diverse in terms of gender or race. In fact, the lack of diversity amongst the attendees was noted during the closing session of the 2015 conference by an invited speaker from outside the accelerator community. Informal discussion and observations support the assertion that our conference attendance reflects the diversity of the broader accelerator controls workforce. Facing very low participation of women in our field and even lower minority representation, it is important to examine this issue, as studies point to the importance of diverse work groups to spark innovation and creativity as catalysts to solving difficult problems. This paper will discuss diversity in the disciplines that comprise the accelerator controls workforce, including background, barriers and strategies for improvement.

ABOUT DIVERSITY

By definition, diversity is about variety. We discuss social diversity in our communities, our schools and our workplaces. We enumerate our differences in terms of gender, race, ethnicity, age, disability, gender identity, sexual preference, socioeconomic status, religion, politics and more, when in fact, we have a lot more in common than not.

As professionals, it is easy to understand the importance of technical diversity as we consider the skills mix of our groups. We need people who are experts in hardware and software, operating systems and algorithms, user interfaces and device control. We might even think of the technical diversity of our control systems where we meet requirements for high speed data acquisition and relatively slow monitoring and readback. We may build our control system with a mix of different operating systems, computer hardware, languages, toolkits, controllers and interfaces. Certainly, our jobs would be easier if we supported a single type of CPU, one operating system, a single hardware interface and offered very narrow options for user interfaces. In reality, we build systems that are hardware and software diverse because it is necessary to meet the requirements of our facilities and customers.

Thinking more broadly, we should also consider the importance of social diversity in our work groups and by extension, our professional community. While expanding diversity can make people uncomfortable, including people with socially diverse characteristics in our ranks can enhance our ability to be more effective.

WHY DOES DIVERSITY MATTER?

Simply put, diversity matters because it can make us better, more innovative, more creative and in the end, more successful. A well-functioning, socially diverse group benefits from the different backgrounds, perspectives and life experiences of the members. These groups bring a more comprehensive set of ideas to the table and along with these ideas, more effective processes. Processes for vetting new ideas, design, development, implementation, training and testing. The way people think and approach their work permeates every aspect of their contributions. If we all think and approach our work the same way, we are bound to naturally narrow our options and constrain the results.

Many studies validate the higher performance of diverse teams, particularly when the work requires creativity or innovation. An article published in Scientific American in October 2014 [1] discusses research on the effects of team diversity on problem solving, decision making and even corporate profits. The article describes how the diversity effect goes beyond gaining different perspectives, but rather causes people to behave differently.

The author draws on different studies to demonstrate how diversity causes people to work harder and become better prepared for work assignments. This is attributed to a level of discomfort people experience when dealing with people they perceive as different from themselves in some way [2].

When someone presents a new idea or design to a room full of people who look and live just like themselves, they seem to naturally assume acceptance. The homogeneous group members tend to think alike, which is precisely what we want to avoid if we value innovation. The same presenter, faced with a socially diverse group, assumes they need a better presentation to gain consensus and do in fact come better prepared and more open to discussion. The article concludes that a diverse set of team members stimulates all team members to work harder, enabling better results.

THE CURRENT STATUS OF DIVERSITY

Workforce

While participation of women in the workforce varies by region and country, women make up 40% of the global workforce [3] and 47% of the United States (U.S.) workforce [4]. About 50% of women and 76% of men partici-

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HIGHLIGHTS OF THE EUROPEAN GROUND SYSTEM – COMMON CORE INITIATIVE

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Abstract

The European Ground Systems – Common Core (EGS-CC) is a European initiative to develop a common infrastructure to support space systems monitoring and control in pre- and post-launch phases for all mission types. In addition to the modernisation of legacy systems, this is expected to bring significant benefits in the whole process of developing, deploying and using monitoring and control systems, such as the seamless transition from spacecraft Assembly, Integration and Testing (AIT) to mission operations, cost and risk reductions, promotion of cross-fertilisation across organizations. The initiative is being performed as a collaboration between ESA, European National Agencies and European Industry. In this paper we describe the main highlights of the initiative along with the current status and future planning of the EGS-CC programme.

INTRODUCTION

Background

Within Europe there are many different systems for monitoring and control currently used by companies/agencies for space system operations, Assembly Integration and Testing (AIT) and other pre-launch phases. The vast majority of these systems have been designed specifically for operations or AIT, although some of them have been used in both scenarios. Another common problem is that multiple heterogeneous systems are used by the different companies involved in the different phases, from subsystem level integration up to launch and subsequent mission operations. The compatibility/exchange of information is jeopardised by the lack of a common infrastructure which leads to little synergy across missions and project phases. Last but not least, many of these existing systems are going to face soon significant obsolescence problems. The systems are often using old software technologies that are difficult to modernise. The maintenance and evolution costs are therefore expected to become excessive with time.

Given the difficulties mentioned above, during 2009-2010, the European Space Agency (ESA) discussed with the main European Large System Integrators, including Astrium Satellites, Astrium Space Transportation (both have now become Airbus Defence and Space), Thales Alenia Space (France and Italy) and OHB System, the possibility of a collaboration to develop the so-called European Ground Systems Common Core (EGS-CC), which will be described in detail in the following sections. Several national space agencies, (in particular the German one, DLR) also indicated their desire to join the initiative and a Collaboration Agreement was finalised in support of the EGS-CC initiative.

Objectives

The objective of the European Ground Systems – Common Core (EGS-CC) is to develop a common infrastructure to support space systems Monitoring and Control (M&C) in pre- and post-launch phases for all types of missions and target applications. This initiative is expected to bring significant benefits, including:

- Reduce development, sustaining and maintenance costs by sharing a single infrastructure across multiple organisations;
- Increase synergy across all pre- and post-launch mission phases, starting from the functional verification at subsystem level throughout spacecraft Assembly, Integration and Testing (AIT), launch and mission operations;
- Facilitate cost and risk reductions when implementing space projects through the provision of a stable common infrastructure which can be easily tailored for the needs of a specific mission and/or target application;
- Enable the modernization of legacy implementations of Electrical Ground Support Equipment (EGSE) and Mission Control Systems (MCS);
- Promote the cross-fertilisation and enable the exchange of ancillary implementations across organizations and across missions.

In order to meet these ambitious objectives, it is expected that the EGS-CC product provides features which go beyond the capabilities of the current implementations, namely:

- Support of all mission phases: the needs of pre- and post-launch utilisation scenarios as well as the transition between them are to be taken into account, without necessarily increasing the system complexity. Clearly the objectives of, and the approach adopted for space systems monitoring and control activities are largely different between pre- and post-launch phases;
- Support of all mission types: this feature is particularly relevant to post-launch scenarios as different types of missions (e.g. short visibility passes, continuous coverage, deep space, constellations) may imply significant variations in the functions to be supported by the monitoring and control system on ground in order to execute mission operations;

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A SUCCESS-HISTORY BASED LEARNING PROCEDURE TO OPTIMIZE SERVER THROUGHPUT IN LARGE DISTRIBUTED CONTROL SYSTEMS*

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Abstract

Large distributed control systems typically can be modeled by a hierarchical structure with two physical layers: Console Level Computers (CLCs) and Front End Computers (FECs). The control system of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven consists of more than 500 FECs, each acting as a server providing services to a potentially unlimited number of clients. This can lead to a bottleneck in the system, as heavy traffic can slow down or even crash a system, making it momentarily unresponsive. In this paper, we consider this problem from a game theory perspective. Specifically, we consider the case where the server has a varying capacity. First, we model this problem as an integer programming problem. Second, we adopt a regret-based procedure as a basic solution and then propose a success-history based scheme to better accommodate the dynamic server capacity. Finally, simulation results show that both algorithms perform well and lead to a significant improvement of system performance. Moreover, compared with the regret-based procedure, the proposed success-history based scheme results in a higher server throughput and lower crash probability under the dynamic environment.

INTRODUCTION

The control system of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven is a large distributed discrete system. It provides operational interfaces to the collider and injection beam lines [1]. The architecture consists of two hierarchical physical layers: Console Level Computers (CLCs) level and Front End Computers (FECs) level, as shown in Fig. 1. The console level is the upper layer of the control system hierarchy, which consists of operator consoles, physicist workstations and server processors that provide shared files, database and general computing resources. The front end system contains more than 500 FECs, running on VxWorks™ real-time operating system. Each of them consists of a VME chassis with a single-board computer, network connection, and I/O modules. FECs are distributed around 38 locations, including the control center, service buildings and 18 equipment alcoves accessible only via the ring tunnel. Along with data links and hardware modules, they are the control systems' interface to accelerator equipment.

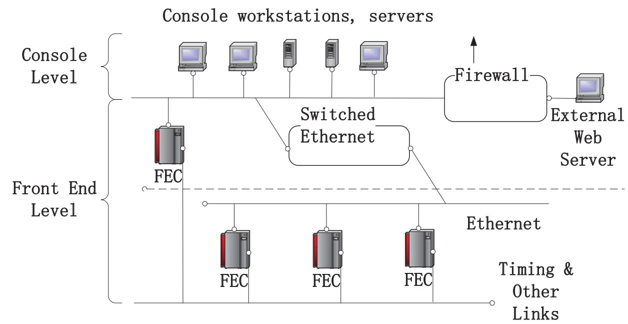

Figure 1: RHIC system hardware architecture.

One of the most fundamental concepts in RHIC control system is the Accelerator Device Object (ADO) [1]. ADOs are instances of C++ or Java classes which abstract features from underlying control hardware into a collection of collider control points known as parameters, and each parameter can possess one or more properties to better describe characteristics of devices. The number of parameters and names of parameters are determined by ADO designers to meet the needs of the system. The most important ADO class methods for device control are the *set()* and *get()* methods. They are processed by the ADO that acts as the interface to device drivers in order to access control hardware. The collider is controlled by users or applications which *sets* and *gets* the parameters in instances of these classes using a suite of interface routines.

In this paper, we consider a practical performance issue in the front end system, where every FEC acts as a server which holds different kinds of ADOs, providing services to a large number of clients. When the number of clients in an FEC reaches its limit, it slows down the system or even crashes it. When the system crashes, all current applications' communication get lost and it takes time to restore them.

Fig. 2 demonstrates this performance issue. In this example, the arrival procedure of clients' requests is represented by a Poisson process with various rates. For each of those different arrival rates, we measure the ratio of the time spent by the server to process requests between the case where the server has a certain message arrival rate and the case where the server has no arrival messages. The result indicates how well the system behaves for different server load. We can see that the performance of the system deteriorates dramatically when the number of clients[1] approaches the server's capacity.

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[1] Here we assume one client only sends one request at each time. The maximum number of clients the server can hold depends on the size of clients'

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SKA SYNCHRONIZATION AND TIMING LOCAL MONITOR CONTROL - SOFTWARE DESIGN APPROACH

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Abstract

The Square Kilometre Array (SKA) is a global project that aims to build a large radio telescope in Australia and South Africa with around 100 organizations in 20 countries engaged in its detailed design. The Signal and Data Transport (SaDT) consortium, includes the software and hardware necessary for the transmission of data and information between elements of SKA, and the Synchronization and Timing (SAT) system provides frequency and clock signals. The SAT local monitoring and control system (SAT.LMC) monitors and controls the SAT system. SAT.LMC has its team members distributed across India, South Africa and UK. This paper discusses the systems engineering methods adopted by SAT.LMC on interface design with work packages owned by different organizations, configuration control of design artefacts, and quality control through intermediate releases, design assumptions and risk management. The paper also discusses the internal SAT.LMC team communication model, cross culture sensitivity and leadership principles adopted to keep the project on track and deliver quality design products whilst staying flexible to the changes in the overall SKA program.

SOFTWARE DESIGN

Methodology

The SAT.LMC software architecture [1] and design process is kept simple and informal within the SAT.LMC team with focus on timelines and the quality of design artefacts produced. The design process is incremental with design artefacts released as products by SAT.LMC to the SaDT consortium [2] in the form of 'pack releases' (Fig. 1).

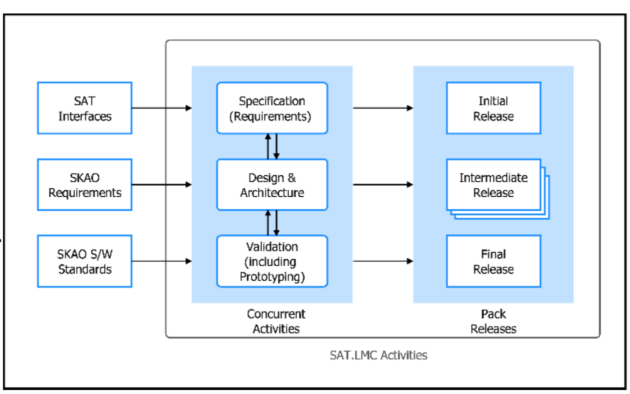

Figure 1: SAT.LMC Incremental Design Methodology.

These pack releases are checked for quality and consistency before releasing. The primary motivation for having pack releases is to enable the SaDT consortium to share consistent SAT.LMC design information with other stakeholders in the project. The pack releases also enable the SaDT management and the SaDT systems engineers to be kept up to date with the work package progress and provides a platform upon which comments, questions and critiques are presented allowing SAT.LMC to address them before progressing the with architectural activities.

Architecture Method

The SAT.LMC architectural artefacts are created and structured using the processes and structures recommended by The Open Group Architecture Framework (TOGAF) [3]. TOGAF provides a method, called the Architecture Design Method (ADM), for designing, planning, implementing and governing an architecture through a set of phases and iterations between phases (Fig. 2). The SAT.LMC architecture is modelled at four levels – Business, Application, Data and Technology.

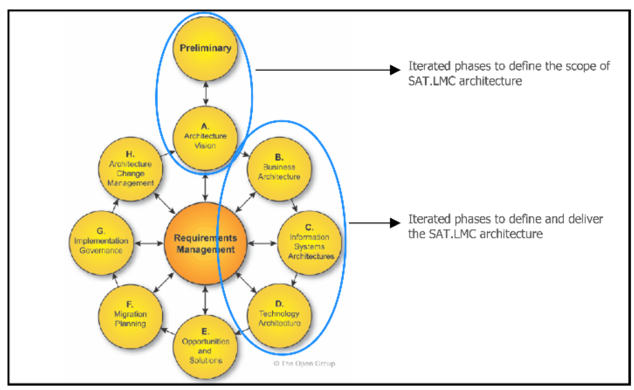

Figure 2: SAT.LMC TOGAF ADM phases and iterations.

SAT.LMC is primarily concerned with iterations involving the Preliminary phase and Phases A through to D of the ADM. The iteration between the preliminary phase and Phase A is to refine the scope of the architecture with changing requirements. The iterations from phase B through to phase D is used to architect and refine the SAT.LMC solution across the dimensions of business, application, data and technology. Phases E onwards are concerned with the implementation and the management of the SAT.LMC architecture, hence are not used.

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TANGO HEADS FOR INDUSTRY

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Abstract

The TANGO Controls Framework continues to mature and be adopted by new sites and applications. This paper will describe how TANGO has moved closer to industry with the creation of startups and addressing industrial use cases. It will describe what progress has been made since the last ICALEPCS in 2015 to ensure the sustainability of TANGO for scientific and industrial users. It will present TANGO web based technologies and the deployment of TANGO in the cloud. Furthermore it will describe how the community has re-organised itself to fund and improve code sharing, documentation, code quality assurance and maintenance.

INTRODUCTION

The Tango community continues to grow with more and more small and large sites adopting Tango. There are currently over 40 sites world-wide covering synchrotron light sources, lasers, wind tunnels, telescopes and physics experiments. At least 15 industrial companies provide TANGO support or use TANGO in their projects. The most recent large sites to join over the last 2-3 years are the 3 ELI laser sites, the SKA radio telescope project, a number of facilities in Russia, India and China. In addition to large sites a number of smaller sites have adopted Tango including some startups. Long standing members like the ESRF are basing new projects like the EBS [1] on Tango. The increased adoption of Tango for long term projects puts a strong requirement on the community to make Tango sustainable in the medium and long term i.e. 10 to 30 years. This is a tall order for any software project and needs specific actions to ensure it happens. This paper explores how the long term sustainability is being addressed with the help of industry for the community and industry.

SUSTAINABILITY

A good definition of Software Sustainability is

Sustainability means that the software you use today will be available - and continue to be improved and supported - in the future.

This definition comes from the Software Sustainability Institute [2] and covers the essential aspects of "**availability**", "**continued improvement**" and "**support**". These three topics illustrate well that software sustainability is not restricted to what is commonly called software maintenance (Fig. 1). There is no widely accepted unique definition of these topics [3] and so each project interprets sustainability according to its needs. In the case of the Tango Controls core the three areas are defined as:

1. **availability** – guaranteed open source licence, public source code repositories, open development workflow
2. **continued improvement** – continue to improve code to support new features, interfaces, languages, tools and paradigms to satisfy users needs
3. **support** – bug fixes, porting to new platforms, maintain backwards compatibility

Another very important issue is Sustainable Software Design [4]. The software has to be designed and architected in a way to make it sustainable. This means the core ideas must be kept intact or be able to adapt to new needs or new platforms without a huge effort. The core architectural features of Tango Controls are:

- **distributed devices** – Tango is based on network agents each implementing control algorithms, a state machine, methods and data fields accessed via the network. This central concept called the Device in Tango is implemented in the Device Server Model which provides a framework and guidelines for developing Device Classes and Servers.
- **orchestration** - Devices implement microservices [5] [6] which can be orchestrated to control simple, complex systems and systems of systems. Tango provides all the tools to configure, deploy and manage any number of Devices and Control Systems.
- **network transparency** – a fundamental design goal of Tango is to hide the network details from the developer e.g. the binary protocol is not exposed, while implementing all the necessary

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SUSTAINING THE NATIONAL IGNITION FACILITY (NIF) INTEGRATED COMPUTER CONTROL SYSTEM (ICCS) OVER ITS THIRTY YEAR LIFESPAN*

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Abstract

The National Ignition Facility (NIF) is the world's largest and most energetic laser experimental facility with 192 beams capable of delivering 1.8 megajoules of 500-terawatt ultraviolet laser energy to a target. Officially commissioned as an operational facility on March 21, 2009, NIF is expected to conduct research experiments thru 2039. The 30-year lifespan of the control system presents several challenges in meeting reliability, availability, and maintainability (RAM) expectations. As NIF continues to expand on its experimental capabilities, the control system's software base of 3.5 million lines of code grows with much of the legacy software still in operational use. Supporting this software is further complicated by technology life cycles and turnover of senior experienced staff. This talk will present lessons learned and new initiatives related to technology refreshes, risk mitigation, and changes to our software development and test methodology to ensure high control system availability for supporting experiments throughout NIF's lifetime.

INTRODUCTION

The National Ignition Facility (NIF) [1] provides a scientific center for the study of inertial confinement fusion (ICF) and matter at extreme energy densities and pressures [2]. Each NIF experiment, or shot cycle, is managed by the Integrated Computer Control System (ICCS) [3], which uses a scalable software architecture running code on more than 2000 front end processors, embedded controllers and supervisory servers. The NIF control system operates laser and industrial controls hardware containing 66,000 control points (e.g. motors, calorimeters, etc) to ensure that all NIF's 192 laser pulses arrive at a target within 30 picoseconds of each other, are aligned to a pointing accuracy of less than 50 microns, and orchestrate a host of diagnostic equipment collecting experimental data in a few billionths of a second. Every NIF shot cycle [4] consists of approximately 1.6 million sequenced control point operations, such as beam path alignment, pulse shaping and diagnostic configuration and each cycle is typically conducted within 4-8 hours depending on the experiment complexity.

NIF was commissioned as an operational facility in the Spring of 2009 and is expected to remain operational until at least 2039. The control system has grown to over 3.5M lines of code. Much of it has been running on hardware that has been used for 1000s of laser shots since operations commenced. While being a fully operational experimental system, there are ongoing requests to add capabilities as requested by the NIF user community, but also from external influences that are forcing involuntary change to ensure NIF's continued operation. The object-oriented, data driven, distributed nature of ICCS helps in managing the high volume of change, but designing for change is alone insufficient to ensure the continued high reliability, availability, and maintainability (RAM) requirements while NIF maintains its goal of 400 shots per year. This paper documents the various influences that are driving change within our control system, and how we have adapted to ensure the control system's reliability and sustainability over its 30+ year lifespan.

DESIGN AND DEVELOPMENT INFLUENCES

ICCS continues to provide new capabilities to support programs internal and external to LLNL. These capabilities are critical in understanding laser and target experimental conditions, but also to support enhanced operational efficiency. With the growth of these capabilities, the number of experiment and operational scenario permutations grew exponentially.

The Department of Energy's (DOE) budget for NIF has remained flat for the past several years. Increases in employee salaries, inflation, etc. results in a net decrease in NIF's purchasing ability under a flat budget. This is forcing us to look at internal process efficiencies in order to maintain the same level of service with fewer resources.

Cybersecurity has been a priority for DOE as well as internally in the lab. Several new regulations and policies that have rolled out have required changes within the control system, primarily in the underlying frameworks. In the early days of NIF, the primary mitigation for computer security related hazards was complete isolation of the control system from external systems. However, this is no longer sufficient and to further enhance our cybersecurity position, several enhancements have been implemented.

Coding for ICCS began in 1997 [5] with much of the same code base still in active use on NIF. Control system

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SAFETY INSTRUMENTED SYSTEMS AND THE AWAKE PLASMA CONTROL AS A USE CASE

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Abstract

Safety is likely the most critical concern in many process industries, yet there is a general uncertainty on the proper engineering to reduce the risks and ensure the safety of persons or material at the same time as providing the process control system. Some of the reasons for this misperception are unclear requirements, lack of functional safety engineering knowledge or incorrect protection functionalities attributed to the BPCS (Basic Process Control System). Occasionally the control engineers are not aware of the hazards inherent to an industrial process and this causes an incorrect design of the overall controls. This paper illustrates the engineering of the SIS (Safety Instrumented System) and the BPCS of the plasma vapour controls of the AWAKE R&D project, the first proton-driven plasma wakefield acceleration experiment in the world. The controls design and implementation refers to the IEC61511/ISA84 standard, including technological choices, design, operation and maintenance. Finally, the publication reveals the usual difficulties appearing in these kind of industrial installations and the actions to be taken to ensure the proper functional safety system design.

INTRODUCTION

The Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) is an accelerator R&D project based at CERN. It is a proof-of-principle experiment investigating the use of plasma wakefields driven by a proton bunch to accelerate charged particles. It is the world's first proton-driven plasma wakefield acceleration experiment and it constitutes an international scientific collaboration involving 14 institutes. The acceleration technique could lead to future colliders of high energy but of a much reduced length when compared to proposed linear accelerators [1].

The facility (Fig. 1) was successfully commissioned between June and November 2016 and the experiment took its first data in the final week of accelerator operations at CERN in 2016.

The control system of this experiment must ensure smooth working conditions of the plasma while ensuring strict control requirements during warm up and stability during normal operation. Special care was taken to bring the process to a safe state when detecting a hazardous event.

This paper shows the engineering lifecycle of the SIS (Safety Instrumented System) and introduces the BPCS (Basic Process Control System) of the AWAKE plasma vapour The major focus is given to functional safety aspects. The goal is to illustrate the issues found and how to overcome them, especially when dealing when predefined instrumentation and a lack of data to make the safety calculations.

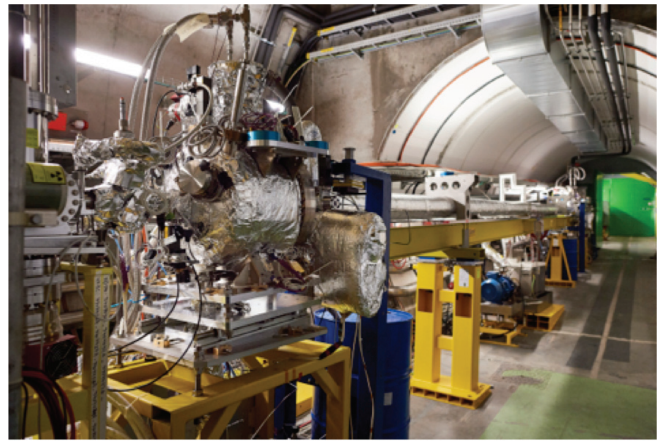

Figure 1: AWAKE plasma cell in the tunnel.

AWAKE Experiment and Its Plasma Cell

The use of plasma to accelerate particles is a potential alternative to traditional accelerating methods that rely on radio-frequency electromagnetic cavities. The AWAKE experiment injects a "drive" bunch of protons from CERN's SPS accelerator into a plasma column created by ionising a gas with a laser. When this bunch interacts with the plasma, it splits into a series of smaller bunches, in a process called self-modulation. As these shorter bunches move through the plasma, they generate a strong wakefield. It is the process of self-modulation that the AWAKE team is investigating, and from which it can infer the creation of the wakefield.

Two independent vapour sources are connected at each end of the 10 metre long plasma cell and are used to provide a flow of hot rubidium (Rb) vapour through the plasma cell during the experiment. The vapour is used to create the rubidium plasma required for wakefield generation within the plasma cell. The Rb flow is achieved by accurately controlling the temperature of the rubidium in each vapour source Rb reservoir. These control temperatures define the upstream and downstream Rb evaporation rates which set the net flow within the plasma cell. In addition, Rb vapour flows into an expansion chamber where it is condensed and solidified ready for recovery.

Industrial Control System

The control system must ensure proper operation of the facility and is composed of: (1) a basic process control system (BPCS): maintaining the whole system in an isothermal, avoiding cold spots and possible intermediate Rb condensation, (2) a safety instrumented system (SIS): providing a safe environment during operation with rubidium by detecting

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ESS ACCELERATOR SAFETY INTERLOCK SYSTEM

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Abstract

Providing and assuring safe conditions for personnel is a key parameter required to operate the European Spallation Source (ESS). The main purpose of the Personnel Safety Systems (PSS) at ESS is to protect workers from the facility's ionising prompt radiation hazards, but also identify as well as mitigate against other hazards such as high voltage or oxygen depletion. PSS consist of three systems: the Safety interlock system, the Access control system and the Oxygen deficiency hazard (ODH) detection system.

The Safety interlock system ensures the safety functions of the PSS by controlling all hazardous equipment for starting the beam operation and powering the RF-powered units and allowing its operation when personnel is safe. This paper will describe the ESS PSS Accelerator Safety interlock system's scope, strategy, methodology and current status.

INTRODUCTION

The ESS, currently under construction, consists of a 600-metre long linear accelerator (hereinafter referred to as the Accelerator), accelerating protons to 2 GeV. The Accelerator is operated in pulsed mode with beam pulses of 2.86 ms length at a maximum repetition rate of 14 Hz. The proton beam is sent to a rotating, helium-cooled tungsten target, where neutrons are created due to the spallation process. The neutrons are guided further towards the large variety of state-of-the-art neutron instruments. [1, 2] One of the key parameters to operate ESS is to provide and assure safe conditions for personnel. At the ESS organisation, the Integrated Control Systems (ICS) division is responsible for developing, implementing and operating the PSS relevant systems.

The ESS PSS has been split into three major sections: the Accelerator PSS, the Target PSS and the Neutron Instruments PSS (a separate PSS system is required for each neutron instrument). The focus of this paper is on the Accelerator Safety Interlock System, as a part of the Accelerator PSS. It includes PSS controlled areas in the Accelerator, as shown in Figure 1.

Accelerator

The ion source produces a beam at 75 keV that is transported through a Low Energy Beam Transport (LEBT) section to the Radio Frequency Quadrupole (RFQ) where it is bunched and accelerated up to 3.6 MeV. In the Medium Energy Beam Transport (MEBT) section the beam characteristics can be diagnosed and are further optimized for acceleration throughout the Drift Tube Linac (DTL) consisting of 5 tanks.

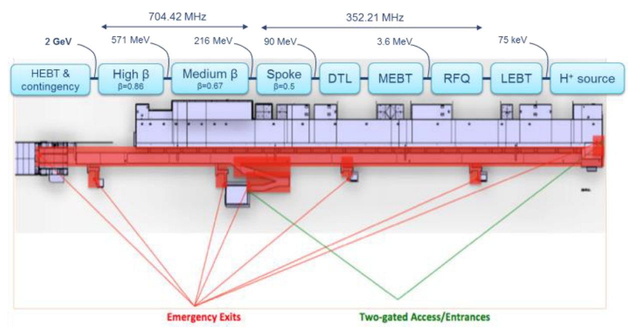

Figure 1: Accelerator PSS controlled area.

The superconducting section consists of 26 double-spoke cavities (SPK), 36 Medium-Beta Linac (MBL) elliptical cavities and 84 High-Beta Linac (HBL) elliptical cavities. [1, 2] After acceleration to 2 GeV, the beam is transported to the target through the High Energy Beam Transport (HEBT) section, where some contingency space is left for potential future upgrades.

ACCELERATOR PERSONNEL SAFETY SYSTEM

The main role of the Accelerator PSS at ESS is to protect workers from the facility's ionising prompt radiation hazards within the Accelerator controlled areas. This shall be valid for all operational modes of the facility. The system will also be used to mitigate against other hazards, and this section will briefly describe all identified hazards within the scope of Accelerator PSS, the approach for implementing functional safety and additional requirements that should be included in system design.

Scope

The Accelerator PSS will control access into the Accelerator area through the two entrances marked in green in Figure 1. Each entrance will have a double-gated access station to only allow authorised workers to gain entry into controlled areas. There are seven emergency exits doors, which mark the boundary of the Accelerator controlled area and the position of all these doors will be monitored by the Accelerator PSS control system.

No access to these controlled areas will be allowed when Accelerator is in operation or when some of Accelerator components are energised (see the list of interfaces with the Accelerator systems below).

Subsystems

The Accelerator PSS consists of two main subsystems: the SIS and the Accelerator Access Control System

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APPLYING LAYER OF PROTECTION ANALYSIS (LOPA) TO ACCELERATOR SAFETY SYSTEMS DESIGN

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Abstract

Large accelerator safety system design is complex and challenging. The complexity comes from the wide geographical distribution and the entangled control/protection functions that are shared across multiple control systems. To ensure safety performance and avoid unnecessary over-design, a systematic approach should be followed when setting the functional requirements and the associated safety integrity. Layer of Protection Analysis (LOPA) is a method in IEC 61511 for assigning the SIL to a safety function. This method is well suited for complex applications and is widely adopted in the process industry. The outputs of the LOPA study provide not only the basis for setting safety functions design objective, but also a reference document for managing system change and determining test scope. In this paper, SLAC's credited safety systems are used to demonstrate the application of this semi-quantitative method. Those examples will illustrate how to accurately assess the hazardous event, analyse the independence of different protection layers, and determine the reliability of a particular protection function.

INTRODUCTION

Layer of Protection Analysis (LOPA) is a semi-quantitative method to analyse and assess the risk. It is usually carried out after the hazard analysis stage. For each identified hazard, a multi-disciplined team of experts will further identify enabling conditions, condition modifiers, prevention/mitigation layers existing or plan to implement. Participants of the LOPA study should determine the initiating event frequency, the performance of each independent protection layers (IPL) and the effectiveness factor of the condition modifier, so that the mitigated risk can be calculated. The result will be compared with the pre-defined tolerable risk target to determine if the actual risk is tolerable. If not, additional risk prevention/mitigation measures need to be implemented to further reduce the risk until the goal is met.

Compared to full quantitative risk assessment methods such as fault tree analysis, LOPA requires only level of magnitude accuracy, and puts more focus on identifying IPLs and evaluating their effectiveness hence avoiding the huge amount of details required for a full quantitative assessment. It does not require dedicated software tools to carry out the analysis and simple spreadsheets will work.

This method was first developed in the 1990s by process industries. Later, the method was systematically developed and documented in the conceptual book [1]. This method has been submitted to the IEC 61511 standard committee by the United States and eventually was included in the informative standard [2] as a method to determine the Safety Integrity Level (SIL) of Safety Instrumented Systems (SIS). After more than two decades of industrial application, LOPA has become the most popular risk assessment method used in process industries in North America. Based on the lessons learned and field application records, Center for Chemical Process Safety (CCPS) recently published two more guidelines to help users correctly apply the method [3][4].

LOPA BASICS

Modern safety system design has switched to a risk-based approach, e.g. determining the system functionality and architecture based on how much risk reduction the safety system should provide to mitigate the risk to the tolerable level.

LOPA starts with consequence-cause pairs which are obtained from the outcome of a what-if analysis, FEMA (Failure Mode and Effects Analysis), or HZAOP (Hazard and Operability) study. For example, for a process without any protection functions, the risk associated with a particular cause can be expressed as:

$$R_i = f_i C_i$$

For the i-th event, R_i is the risk and f_i, C_i represent frequency and the consequence. The total risk is the sum of all individual hazardous scenario is:

$$R = \sum_{i=1}^{N} R_i$$

LOPA will be able to answer following questions:

- How critical is the risk
- Dependability and independence between protection layers
- How many independent protection layers exist and how many extra layers are needed
- Is the process safe enough or additional protection measures are needed

There are two categories of protection functions that can effectively reduce the risk, one is through prevention, which works on the original frequency f_i to further lower the frequency of the system, and the other approach is mitigation, which will lower the consequence C_i. For the former case, the reduced risk would be

$$R_i^C = \left(\prod_{j=1}^{M} PFD_i^j f_i\right) \times C_i$$

and

$$R^C = \sum_{i=1}^{N} R_i^C$$

With the underlining mathematics being straightforward, the correct application of the methods depends on properly evaluating the effectiveness of each IPL as well as other adjusting factors such as enable conditions and condition modifiers.

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DEVELOPMENT OF A SAFETY CLASSIFIED SYSTEM WITH LABVIEW AND EPICS

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Abstract

The Spiral2 linear accelerator will drive high intensity beams, up to 5 mA and 200 kW at linac exit. In tuning phase, or when not used by the experimental areas, the beam will be stopped in a dedicated beam dump. To avoid excessive activation of this beam dump, in order to allow human intervention, a safety classified system had been designed to integrate the number of particles dropped in it within each 24 hours time frame. For each kind of beam, a threshold will be defined and as soon as the threshold is reached a beam cut-off will be sent to the machine protection system. This system, called SLAAF: System for the Limitation of the Activation of the beam dump (Arret Faisceau in French) rely on LabView and EPICS (Experimental Physics and Industrial Control) technology. This paper will describe the specification and development processes and how we dealt to meet both functional and safety requirements using two technologies not commonly used for safety classified systems.

PRESENTATION

The Spiral2 project requires the possibility of human intervention on the Beam Dump and its surrounding. Hence the system must guarantee that the Beam Dump activation remain under an acceptable threshold. Since the Spiral2 accelerator will accelerate many ions species, the threshold depends on both mass number and energy of the accelerated ions. When preparing the accelerator parameters, the threshold, expressed in number of particles that can be dropped into the Beam Dump during a 24 hours time frame, will be calculated. The lower limit is a 20 MeV/A deuteron beam. In this case the 24 hour limit is 5.6 10^{18} atoms, corresponding to the shortest times after which the threshold is reached, specified in Table 1, as a function of the beam power.

Table 1: Worst Cases (20 MeV/A deuton beam)

Beam Power	Time to reach the threshold
200 kW	3 minutes
10 kW	1 hour
417 W	Always below threshold

MAIN REQUIRMENTS

Nuclear Safety

System classified in the second category of equipment involved in the safety in the Spiral2 classification system. This is the least requiring level, it can be considered equivalent to a SIL2 (Safety Integrity Level).

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Operational

- The system must run permanently as soon as beams with intensity greater than 11 µA are produced. It must be reliable.
- The system must be compatible with all the ions at all intensity (from 11 µA to 5 mA) and energy (from 0.75 MeV/A to 33 Mev/A).

Functional & Technical

- The system must integrate the number of particles over a 24 h period, a period starting at a configurable but fixed hour.
- The beam ions charge and threshold will be entered in the system at each beam change.
- As soon as 95 % of the threshold is reached, a beam cut-off request is sent to the machine protection system.
- The latest value of the integral must be back upped in order to be retrieved in case of failure (power supply failure for example).

SAFETY CLASSIFICATION CHALLENGE

Taking into account miscellaneous Spiral2 project constraints and the system requirements, labView technology was retained for the system. Moreover, it should be integrated in the Spiral2 Control System, consequently the labView-EPICS gateway and EPICS-CSS (Control System Studio) tool for HMI (Human Machine Interface) were required.

As a safety classified system, its conception has been submitted to a Failure Mode and Effect Analysis and a Conception review. Though labView and EPICS are generally not considered convenient for a classified system, we thought we could take advantage of the labView technology using the cRIO (Compact Reconfigurable Input Output) solution with FPGA (Field-Programmable Gate Array) in its backplane in order to be able to prove its reliability.

Architecture

Starting from all these technical choices, the architecture arises, the cRIO with the FPGA and CPU (Central Processing Unit), hosting the LabView-EPICS gateway on one side and CSS for the HMI on the other side. However, during the early stages of the conception, we evaluated the LabView-EPICS gateway and discovered too much limitation (too few record fields, Channel Access monitoring and EPICS alarms not working) in server mode (i.e., gateway used as an EPICS IOC (Input Output Controller)) forcing us to use it in Client mode and to add an intermediate IOC called “IOC

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A REAL-TIME BEAM MONITORING SYSTEM FOR HIGHLY DYNAMIC IRRADIATIONS IN SCANNED PROTON THERAPY: DERIVATION OF SAFETY TOLERANCES*

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Abstract

Patient treatments in scanned proton therapy exhibit dead times, e.g. when adjusting beamline settings for a different energy or lateral position. On the one hand, such dead times prolong the overall treatment time, but on the other hand they grant possibilities to (retrospectively) validate that the correct amount of protons has been delivered to the correct position. Efforts in faster beam delivery aim to minimize such dead times, which calls for different means of monitoring irradiation parameters. To address this issue, we report on a real-time beam monitoring system that supervises the proton beam position and current during beam-on, hence while the patient is under irradiation. For this purpose, we sample 1-axis Hall probes placed in beam-scanning magnets and plane-parallel ionization chambers every 10 µs. FPGAs compare sampled signals against verification tables – time vs. position/current charts containing upper and lower tolerances for each signal – and issue interlocks whenever samples fall outside. Furthermore, we show that by implementing real-time beam monitoring in our facility, we are able to respect patient safety margins given by international norms and guidelines.

PREFACE

A detailed report on software and firmware enhancements of the control system has been submitted as an ordinary paper [1]. In these proceedings, we concentrate on one part of the work and derive applicable safety tolerances supervised by the real-time monitoring system.

INTRODUCTION

In scanned proton therapy, we use a Gaussian-shaped beam of protons to irradiate cancerous tissue. The beam size σ in air amounts to a few millimeters. To cover the entire extent of the three-dimensional tumor volume with protons, the beam needs to be scanned transversally and in depth. At the Paul Scherrer Institute (PSI), we installed a dedicated super-conducting cyclotron that provides a continuous and mono-energetic proton beam of 250 MeV [2]. We realized transverse scanning with a pair of beam-deflecting dipole magnets; to scan the proton beam in depth, we change its energy (and, thus, penetration depth) by inserting variable amount of degrading material into the beamline [3].

The beam scanning process requires a discretization of the tumor volume: it is cut in slices of equal energy (or penetration depth) and a rectilinear scan grid of fixed transverse (or lateral) beam positions is imposed on all of those slices. In our second-generation treatment room at PSI, we require ~100 ms to change the beam energy between slices and ~3 ms to scan the beam from one transverse grid point to the next [4]. The beam is turned off completely during those transitions. We use this dead time, especially the latter, to validate that the correct amount of protons has been applied to the correct position. If the deviation between measurement and expectation exceeds a certain tolerance, we have the possibility to interrupt the treatment of the patient to investigate the source of uncertainty. International norms [5] and guidelines [6] demand such frequent checks to guarantee patient safety.

At PSI, we treat patients successfully using this discretized beam scanning technique since 1996. To maximize irradiation performance and possibly broaden the window of treatable indications, we pursue implementing a faster form of beam delivery, which we call line scanning [7]. In line scanning, the beam is moved continuously along straight lines in the transverse plane giving up the idea of the fixed grid in this dimension. The 3 ms dead times are reduced to changes between lines, which yields increased performance but, at the same time, fewer opportunities for validation checks.

To provide adequate safety measures for line scanning, we introduced a dedicated beam monitoring system. We reported on its design [8] and implementation [1] in previous works. A major enhancement with respect to the conventional monitoring approach is its real-time character: we compare the measured beam position and proton deposition to predefined tolerances every 10 µs. This cyclic comparison runs during beam-on, hence while lines are scanned. As such, we can react to errors in different beam delivery units very fast and issue beam-off commands rapidly in case of unforeseen inaccuracies or failures.

The scope of this paper is to provide a full derivation of our line scanning safety tolerances. We will focus on acceptable over/under-exposure of the healthy/malignant tissue to radiation and acceptable deviations in the transverse beam position. Based on our experience in patient treatments, we presuppose that errors in beam delivery occur rarely (less than once throughout the entire course of the treatment) and randomly. They cannot be linked to specific configurations of the machine and do not lead to any systematic effects.

* Work supported by the Giuliana and Giorgio Stefanini Foundation
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DEVELOPMENT OF AN EXPERT SYSTEM FOR THE HIGH INTENSITY NEUTRINO BEAM FACILITY AT J-PARC

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Abstract

A high intensity neutrino beam produced at J-PARC is utilized by a long-baseline neutrino oscillation experiment. To generate a high intensity neutrino beam, a high intensity proton beam is extracted from the 30 GeV Main Ring synchrotron to the neutrino primary beamline. In the beamline, one mistaken shot can potentially do serious damage to beamline equipment. To avoid such a consequence, many beamline equipment interlocks to stop the beam operation are implemented. Once an interlock is activated, prompt and proper error handling is necessary. We are developing an expert system for prompt and efficient understanding of the status to quickly resume the beam operation. An inference engine is one key component in the expert system. Although a typical inference engine of the expert system is rule-based, we adapt a Machine-Learning (ML) based inference engine in our expert system. We will report the initial evaluation of our ML-based inference engine.

INTRODUCTION

The T2K (Tokai-to-Kamioka) experiment [1] is a long-baseline neutrino oscillation experiment at J-PARC (Japan Proton Accelerator Research Complex). Figure 1 shows the overview of the T2K experiment. A high intensity neutrino/anti-neutrino beam is produced and propagates 295 km from J-PARC to Super-Kamiokande (SK). In July 2013, muon neutrino to electron neutrino transformation was firmly established [2]. In August 2017, T2K excluded CP-conservation at 95% confidence level using the latest data. In order to keep generating interesting physics, steady operation of the facility is very important.

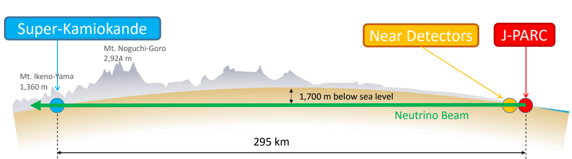

Figure 1: Overview of the T2K experiment.

Figure 2 shows a layout of the neutrino experimental facility (neutrino facility) at J-PARC. The neutrino facility is composed of two beamlines and a near detector (ND280). The beamline consists of the primary and secondary beamlines. In the primary beamline, the high intensity proton beam is extracted from the Main Ring synchrotron (MR) and guided through super and normal conducting magnets to the target station. In the secondary beamline, the proton beam hits a graphite target and produces pions. These pions decay into muons and muon neutrinos in a decay volume. The high intensity proton beam reached 470 kW in 2017 and ready to the design power of 750kW with a few years.

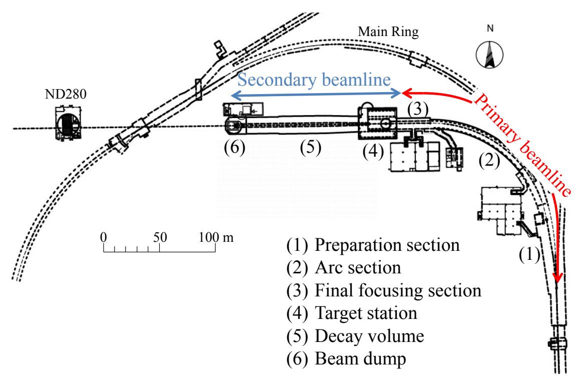

Figure 2: Layout of the T2K experimental facility.

MOTIVATION

We handle a high intensity proton beam at the J-PARC neutrino facility. If an interlock is activated, prompt and proper error handling is necessary. However it is not easy because of the following reasons:

- There are many interlock sources (~800)
- Multiple sources of interlock can happen at the same time

It is difficult for the beamline operators to understand the beamline status and recovery procedure and resume beam operation correctly and rapidly. To improve this situation, we plan to introduce a beamline expert system.

MPS IN THE NEUTRINO FACILITY

MPS, Machine Protection System, is an interlock designed to protect beamline equipment from the high intensity beam. If an MPS occurs, the beam in the MR is aborted and next beam spill is inhibited. The MPS is critical in a high intensity proton beam facility because one off-orbit beam spill potentially can do serious damage to the beamline equipment.

The number of MPS source channels at the neutrino facility is approximately 800. These contain interlock signals from each beam loss monitor (BLM), as well as the magnet power supplies, etc.

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CONFIGURING AND AUTOMATING AN LHC EXPERIMENT FOR FASTER AND BETTER PHYSICS OUTPUT

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Abstract

LHCb has introduced a novel online detector alignment and calibration for LHC Run II. This strategy allows for better trigger efficiency, better data quality and direct physics analysis at the trigger output. This implies: running a first High Level Trigger (HLT) pass synchronously with data taking and buffering locally its output; use the data collected at the beginning of the fill, or on a run-by-run basis, to determine the new alignment and calibration constants; run a second HLT pass on the buffered data using the new constants. Operationally, it represented a challenge: it required running different activities concurrently in the farm, starting at different times and load balanced depending on the LHC state. However, these activities are now an integral part of LHCb's dataflow, seamlessly integrated in the Experiment Control System and completely automated under the supervision of LHCb's 'Big Brother'. In total, for all activities, there are usually around 60000 tasks running in the ~1600 nodes of the farm, and the load balancing of tasks between activities can be done within 1 second. In addition, if/when some CPU power is still available, an extra activity for Offline Simulation can also be started concurrently. The mechanisms for configuring, scheduling and synchronizing different activities on the farm and in the experiment in general will be discussed.

INTRODUCTION

LHCb [1] is one of the four experiments at the Large Hadron Collider (LHC) at CERN. Around the end of 1997, a common project, the Joint Controls Project (JCOP) [2], was setup between the four LHC experiments and a Controls group at CERN, to define a common architecture and a framework to be used by the experiments in order to build their Detector Control Systems (DCS).

The JCOP Framework [3] adopted a hierarchical and highly distributed architecture providing for the integration of the various components in a coherent and uniform manner. The Framework was implemented based on a SCADA (Supervisory Control And Data Acquisition) system called WinCC-OA (formerly PVSSII) [4]. While WinCC-OA offers most of the needed features to implement a large control system, it was felt that a tool for implementing higher-level logical behavior was missing. For this reason, the JCOP project was complemented by the integration of SMI++ [5]; a toolkit for sequencing and automating large distributed control systems, whose methodology combines three concepts: object orientation, Finite State Machines (FSM) and rule-based reasoning.

Unlike the other LHC experiments, LHCb decided to use the JCOP concepts and tools not only for the DCS but for all areas of control in the experiment. The aim was to achieve an integrated and coherent Experiment Control System (ECS) by using a common approach and the same tools and components throughout the system.

THE EXPERIMENT CONTROL SYSTEM

LHCb's ECS handles the configuration, monitoring and operation of all experimental equipment in all areas of the Online System:

- The Experiment's Infrastructure: magnet, cooling, electricity distribution, detector safety, etc.
- The Detector Control System (DCS): gases, high voltages, low voltages, temperatures, etc.
- The Data Acquisition System (DAQ): front-end electronics, readout network, storage etc.
- The Timing and Fast Control System (TFC): timing and trigger distribution electronics.
- The L0 Trigger (L0): the hardware trigger components.
- The High Level Trigger (HLT) Farm: thousands of trigger algorithms running on a large CPU farm.
- The Monitoring Farm: A smaller farm running monitoring tasks to produce histograms for checking online the quality of the data being acquired
- Interaction with the outside world: LHC Accelerator, CERN safety system, CERN technical services, etc.

The relationship between the ECS and the other online components of the experiment is shown schematically in Fig. 1. This figure shows that the ECS provides the unique interface between the operators and the experiment's equipment.

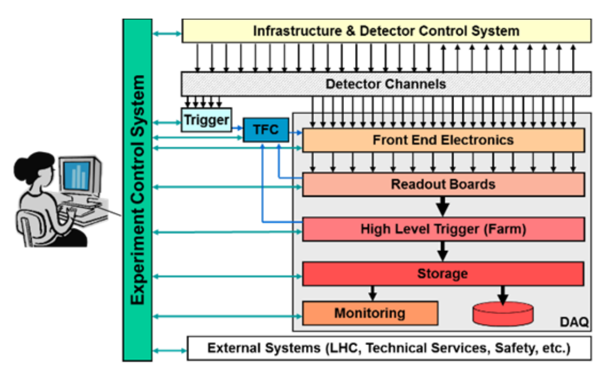

Figure 1: Scope of the Experiment Control System.

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GigaFRoST (GIGABYTE FAST READ-OUT SYSTEM FOR TOMOGRAPHY): CONTROLS AND DAQ SYSTEM DESIGN

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Abstract

The GigaFRoST (Gigabit Fast Read-out System for Tomography) detector and readout system used at the tomographic microscopy beamline TOMCAT of the Swiss Light Source will be presented. GigaFRoST was built at Paul Scherrer Institute (PSI) and designed to overcome the limitations of existing commercially available high-speed CMOS detectors. It is based on a commercial CMOS fast imaging chip (pco.dimax) with custom-designed readout electronics and control board. The latter is used for detector configuration, coordination of image readout process and system monitoring. The detector can acquire and stream data continuously at 7.7 GB/s to a dedicated backend server, using two data readout boards, each equipped with two FPGAs, and each directly connected with the server via four 10 Gbit/s fiber optics connections. The paper focuses on the implementation of the EPICS control system, data acquisition (DAQ) system, integration of the detector into the beamline infrastructure and implementation of efficient distribution of TTL triggers between the devices involved in the experiments (i.e., GigaFRoST detector, sample rotation stage, arbitrary external devices).

INTRODUCTION

The observation of the full volumetric structural evolution of a sample during a dynamic process with both high temporal and spatial resolution has been a key challenge for the tomographic microscopy beamline TOMCAT [1] at the Swiss Light Source. While spatial resolution has remained at the micrometer level, the temporal resolution has witnessed a considerable and rapid growth in the last years. Today it is shown that 20 tomographic scans may be acquired within one second [2]. Naturally this reflects in the vast amount of generated experimental data (up to several tens of TB/day of raw data). The main limitations under such conditions arise from the characteristics of commercially available high-speed CMOS detectors. The fact that these detectors store data in on-board memory results in (a) the inability of real-time process observation and (b) inability to acquire large number of frames due to the limited available memory. In addition, the consequent transfer of data from the internal memory onto the beamline storage server prevents the efficient use of the detector for experimental needs. In order to overcome these limitations, the GigaFRoST camera system was designed at PSI.

GIGAFROST CAMERA SYSTEM

GigaFRoST (Gigabit Fast Read-out System for Tomography) is a high-speed camera and readout system, built at Paul Scherrer Institute (PSI), and being able to sustain kHz frame rate image acquisition over prolonged periods of time. It uses the commercial CMOS sensor headboard from the pco.dimax detector with fast imaging chip with 2016x2016 pixels, 12 analogue-to-digital converters (ADC), and some auxiliary electronic in order to use its excellent high-speed characteristics (pco.dimax provides sub 20 µm pixel size and a multi-kHz frame rate) [3]. It is also possible to readout a limited Region of Interest (ROI), however due to the design of the imaging sensor (divided in 4 quadrants) and the implementation of the readout process (it stars from the centre of the sensor towards the outer part) the ROI has to be centred.

The problem with the limited on-board storage and lack of image preview is solved with custom-designed readout electronics. Two data readout boards, each equipped with two FPGAs are connected to the sensor headboard (each FPGA is responsible for reading out one quadrant of the imaging sensor (3 ADCs)). Each readout board is then directly connected with the dedicated backend server via four 10 Gbit/s fibre optics connections, which enables the detector to acquire and stream data continuously, without the need for an on-board storage (apart from a minimum amount needed for on-the-fly pixel correction). The maximum data throughput that can be reached is 7.7 GB/s.

The last component is a control board equipped with one FPGA with a built-in PowerPC (PPC) processor (PPC440) and attached RAM. It is responsible for the configuration of the detector system, system monitoring and coordination of the readout process. The control board is equipped with a 1Gbit/s network module used for communication with the camera and with a serial connection which can be used for debugging purposes (direct connection to the console).

Additionally, 6 BNC connectors (2 input and 4 output) using TTL logic, can be used for external image acquisition synchronization. The inputs are used for external enable and trigger signals, while the outputs are used for reporting different camera states (busy, exposure sync-out with optional delay, etc.).

Figure 1 shows a schematic view of the GigaFRoST camera system architecture, while Figs. 2 and 3. show the photos of the GigaFRoST camera (without housing covers).

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AREADETECTOR: EPICS SOFTWARE FOR 2-D DETECTORS

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Abstract

areaDetector is an EPICS framework to support 2-D detectors. It is modular C++ code that greatly simplifies the task of writing drivers for new detectors. It supports plugins, which receive detector data from the driver and process it in some way. For example, plugins perform statistics calculations, image processing, Region-Of-Interest extraction, file saving, color mode conversion, and export to EPICS Channel Access or pvAccess for image display in clients like ImageJ. Plugins can each run in their own threads, permitting parallel processing on multi-core machines. Drivers have been written for many of the detectors commonly used at synchrotron and neutron sources, including CMOS and CCD imaging and x-ray detectors, pixel array detectors and flat panel detectors.

INTRODUCTION

Most x-ray experiments whether at a synchrotron, FEL, or home laboratory use 2-D detectors. These include x-ray detectors such as direct-detect pixel array detectors and scintillation based detectors with CCD, CMOS, and amorphous silicon sensors. It also includes visible light CCD and CMOS cameras for imaging and optical spectroscopy. These detectors need to be integrated with the control system used for other components of the experiment. Many beamlines around the world use the EPICS control system [1], which is a collaborative open-source control system toolkit. areaDetector is an EPICS framework for controlling detectors [2]. An early (2010) version of areaDetector was described in [3]. This paper will briefly summarize the framework architecture, and then describe in greater detail the features that have been added since 2010.

The goals of the areaDetector module are to:

- Minimize the amount of code that needs to be written to implement a new detector.
- Provide a standard interface defining the functions and parameters that a detector driver should support.
- Provide a set of base EPICS records that will be present for every detector using this module. This allows the use of generic EPICS clients for displaying images and controlling cameras and detectors.
- Allow easy extensibility to take advantage of detector-specific features beyond the standard parameters.
- Have high-performance.
- Provide a mechanism for device-independent real-time data analysis such as regions-of-interest, statistics, image processing.
- Save files in industry standard formats.
- Provide drivers for commonly used detectors in x-ray and imaging applications.

ARCHITECTURE

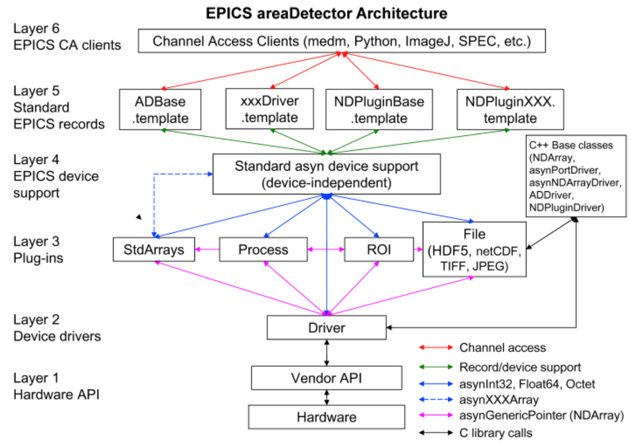

Figure1: areaDetector Architecture.

The architecture of the areaDetector module is shown in Figure 1. From the bottom to the top this architecture consists of the following six layers:

1. This is the layer that allows user written code to communicate with the hardware. It is usually provided by the detector vendor. It may consist of a library, a socket protocol definition, or other type of API.
2. This is the driver that is written for the areaDetector application to control a particular detector. It is written in C++ and inherits from the ADDriver class. It uses the standard asyn interfaces for control and status information. Each time it receives a new data array it passes it as an NDArray object to all Layer 3 clients that have registered for callbacks. This is the only code that needs to be written to implement a new detector.
3. Code running at this level is called a plugin. This code registers with a driver (or another plugin) for a callback whenever there is a new data array.
4. This is standard asyn device support that comes with the EPICS asyn module [4, 5].
5. These are standard EPICS records and EPICS database (template) files that define records to communicate with drivers at Layer 2 and plugins at Layer 3.
6. These are EPICS channel access clients that communicate with the records at Layer 5. areaDetector includes ImageJ client applications that can display images using EPICS Channel Access or pvAccess. It also includes detector and plugin screens for the EPICS display managers medm, edm, CSS BOY, and caQtDM.

IMPLEMENTATION

The areaDetector module depends heavily on asyn. It is the software that is used for inter-thread communication, using the standard asyn interfaces (e.g. asynInt32, asynOctet, etc.), and callbacks. areaDetector is implemented using C++ classes. The base classes, from which

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A SIMPLE TEMPORAL NETWORK FOR COORDINATION OF EMERGENT KNOWLEDGE PROCESSES IN A COLLABORATIVE SYSTEM-OF-SYSTEMS

[1] M.W. Maier, "Architecting principles for systems-of-systems," Systems Engineering, vol 1, no. 4, pp. 267-284, 1998.

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Abstract

The Z Machine is the world's largest pulsed power machine, routinely delivering over 20 MA of electrical current to targets in support of US nuclear stockpile stewardship and in pursuit of inertial confinement fusion. The large-scale, multi-disciplinary nature of experiments ("shots") on the Z Machine requires resources and expertise from disparate organizations with independent functions and management, forming a Collaborative System-of-Systems. This structure, combined with the Emergent Knowledge Processes central to preparation and execution, creates significant challenges in planning and coordinating required activities leading up to a given experiment. The present work demonstrates an approach to scheduling planned activities on "shot day" to aid in coordinating workers among these different groups, using minimal information about activities' temporal relationships to form a Simple Temporal Network (STN). Historical data is mined, allowing a "standard" STN to be created for common activities, with the lower bounds between those activities defined. Activities are then scheduled at their earliest possible times to provide participants a time to "check-in" when interested.

INTRODUCTION

"Linearity is an artificial way of viewing the world. Real life isn't a series of interconnected events occurring one after another like beads strung on a necklace."

– Ian Malcom, in Jurassic Park

The Z Machine (hereafter "Z") is the world's largest pulsed power machine, routinely delivering over 20 MA of electrical current to targets in support of various programs, including US nuclear stockpile stewardship and pursuit of inertial confinement fusion. A single experiment (or "shot") requires months of planning, design work, specialized hardware fabrication, and diagnostics configuration, all involving experts from a variety of specialized backgrounds such as plasma physics, hydrodynamics, dynamic material properties, laser technologies, atomic spectroscopy, neutron diagnostics, electrical engineering, mechanical engineering, and electromechanical controls. Regular operation of Z on a daily basis requires specialists from these fields as well as technicians and installers performing regular machine maintenance and configuration, which involves activities such as operating heavy machinery, refurbishing equipment, performing routine mechanical and electrical work, and even underwater diving, among others.

Challenges to Coordination

The activities, specialties, and organizations involved in Z experiments and operations have evolved over time, posing significant challenges to coordination of daily activities using static and deterministic plans and schedules. While much of the funding for the experiments and operations of the machine comes from a single organization, many activities and capability enhancements are funded at least in part through alternate sources and organizations, leading to varied and dynamic relationships between participating personnel and systems. Many of the supporting staff for diagnostics, targets, and subsystems have independent management and volunteer-like participation with Z experiment preparation and execution. These traits, especially varying levels of "operational independence" and "managerial independence" of constituents, place Z on the spectrum of a Collaborative System-of-Systems (SoS) [1]. This type of operation has no recognized central authority to provide top-down guidance on organization and execution of work, and often there exist no centrally or commonly defined roles and responsibilities. While individual sections and agents may generate their own activities and associated (implicit or explicit) plans and schedules for those activities, such plans and schedules may be communicated in an ad-hoc manner or simply adapted in-situ pursuant to perceived progress of a given experiment throughout a day. Such behaviors (i.e., ad-hoc communication and in-situ adaptation) significantly challenge efforts in higher-level planning and scheduling for experiments to aid in coordination across groups; static plans and schedules – even if fully informed (which is rarely the case) and even if created very close to "shot day" – can quickly become obsolete, causing wide-varying interpretations and even distrust of any schedule updates or future experiments' schedules.

The interfaces between participants on a given shot are sometimes known in advance but, as mentioned above, are often of an ad-hoc nature. Eliminating this behavior is not possible, nor is it desirable, since in fact this ability to adapt is widely recognized as essential to the success of Z experiments due to the research-oriented (and therefore often emergent) nature of much of the work. Such work is typical of Emergent Knowledge Processes (EKPs), which "involve intellectual activities, expert knowledge, and diverse people in unstructured and unpredictable combinations" [2].

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UPGRADE OF KEK ELECTRON/POSITRON LINAC CONTROL SYSTEM FOR THE BOTH SuperKEKB AND LIGHT SOURCES

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Abstract

KEK injector linac has delivered electrons and positrons for particle physics and photon science experiments for more than 30 years. It is being upgraded for the SuperKEKB project, which aims at a 40-fold increase in luminosity over the previous project of KEKB, in order to increase our understanding of flavor physics. This project requires ten-times smaller emittance and five-times larger current in injection beam from the injector. And many hardware components are being tested and installed. Even during the 6-year upgrade, it was requested to inject beams into light sources storage rings of PF and PF-AR. Furthermore, the beam demanding approaches from those storage rings are different. SuperKEKB would demand highest performance, and unscheduled interruption may be acceptable if the performance would be improved. However, light sources expect a stable operation without any unscheduled break, mainly because most users run experiments for a short period. In order to deal with the both requirements several measures are taken for operation, construction and maintenance strategy including simultaneous top-up injections.

INTRODUCTION

SuperKEKB, an asymmetric-energy electron-positron double-ring collider, is being commissioned with beams. The construction has been performed since 2010 till the end of FY 2017. It is expected to increase our understanding of new physics beyond the standard model of elementary particle physics with a 40-times higher collision rate compared to the world's highest luminosity at the previous project KEKB, by doubling the stored beam current and employing the nano-beam collision scheme [1, 2].

SuperKEKB consists of electron positron full-energy injector linac, 7-GeV electron ring (HER), 4-GeV positron ring (LER), and positron damping ring (DR), that is being constructed. The electron positron injector linac has delivered electrons and positrons for particle physics and photon science experiments since 1982. It has been rejuvenated since 2010 towards SuperKEKB collider for its extremely high luminosity, that requires injection beams with high current and low emittance in transverse and longitudinal directions [3, 4].

However, the injector linac had to continue the injection into two light-source storage rings of PF and PF-AR even during the SuperKEKB construction period, and then it is required to deliver beams into four multi-purpose storage rings with different qualities realizing the simultaneous top-up injections (Fig. 1).

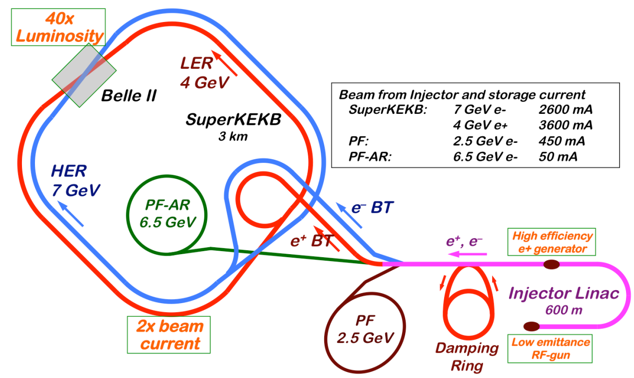

Figure 1: The configuration of electron/positron accelerator complex at KEK with linac and four storage rings of SuperKEKB-HER, LER, PF and PF-AR.

BEAM INJECTIONS FOR PARTICLE PHYSICS AND PHOTON SCIENCE

Natures of beam demanding approaches from those experiments of particle physics at SuperKEKB and photon science at PF/PF-AR are so different that the operation becomes tough to be planned, especially for the construction and maintenance period.

The particle physics experiment at SuperKEKB always pursues the limit of performance. They expect highest possible experimental data with long-term integrated performance (between every large international conference). It may continue for more than ten years. They often take risks of a short-term shutdown if the integrated performance would increase. Such a particle physics experiment at SuperKEKB may be characterized as below.

- Experiment by long-term and fixed user group.
- Performance oriented.
- Pursuing yearly integrated performance.
- Tendency to avoid preventive maintenance.
- May have enthusiasm for improvements.
- Can develop common understanding between experiment and accelerator groups.
- Operators are trained through everyday operation.

On the other hand, the photon science experiments at PF and PF-AR are performed for only a few days at a time, and the stability is most required over the performance improve-

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A NEW SIMULATION ARCHITECTURE FOR IMPROVING SOFTWARE RELIABILITY IN COLLIDER-ACCELERATOR CONTROL SYSTEMS*

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Abstract

The control systems of the Collider-Accelerator Department (C-AD) at Brookhaven National Laboratory (BNL) are complex systems consisting of approximately 1.5 million [1] control points. Instances of C-AD control systems are applied in the Linear Accelerator (Linac), Electron Beam Ion Source (EBIS), Tandem Van de Graff pre-accelerators, the Booster accelerator, Alternating Gradient Synchrotron (AGS), and the Relativistic Heavy Ion Collider (RHIC). Its performance has a crucial impact over the whole accelerator suite. In this paper, we propose a new simulation framework that can improve the robustness of the control system. It focuses on enhancing the reliability of its software codes by running automated testing. The architecture is described, followed by some key use cases in the current system. Moreover, the next development phase is proposed.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) is a world-class particle accelerator at BNL. It enables [2] scientists to study what the universe may have looked like in the first few moments after its creation. RHIC contains two 3.8 kilometers counter-rotating super-conducting rings to carry particle beams which can be collided in six crossing regions [3, 4] to provide possible interactions for experimenters to study.

The RHIC control system provides [5–8] the operational interface to the collider and injection beam lines. The architecture is hierarchical and consists of two physical layers with network connections: Console Level Computers (CLCs) level and Front-end Computers (FECs) level, as seen in Fig. 1. The front-end level comprises more than 500 FECs, running the VxWorks™ real-time operation system. Each FEC consists of a VME chassis with a single-board computer, network connection, and I/O modules. The FECs are distributed around 38 locations, including the control center, service buildings and 18 equipment alcoves accessible only via the ring tunnel. Along with [3, 4] data links and hardware modules, they are the control systems interface to physical accelerator equipment. The console level is the upper layer of the control system hierarchy, which consists of operator consoles, physicist workstations and server processors that provide shared file, database and general computing resources. Processes known as managers are also found at the console level. A manager can function as a sort of virtual FEC. Some managers perform data concentration or processing functions. Increasingly, CLC level manager

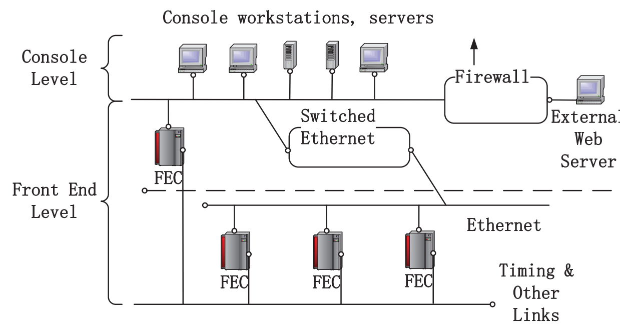

Figure 1: RHIC system hardware architecture.

processes bypass the FEC level and provide a direct interface to accelerator equipment. CLC managers communicate with accelerator equipment via direct network connections or via Ethernet-to-GPIB (General Purpose Interface Bus) or Ethernet-to-serial converters. These CLC level equipment interface managers have been chosen as the first target for our simulation architecture.

The software system for RHIC controls is structured with [5–8] well-defined layers and interfaces following a standard object-oriented design paradigm. At the front end level, it mainly consists of two broad categories: device drivers and Accelerator Device Objects (ADOs). Device drivers used in RHIC FECs are very similar to device drivers used in other applications in that they provide a standard interface for software to interact with various hardware devices. An ADO is a software object which serves as a collection of various related accelerator control points and provides standard methods through which higher-level applications can interact with those parameters.

Reliable functioning of control systems is critical to the proper operation of accelerators. In this paper, we propose a new simulation architecture for C-AD control systems, which will enable automated testing of controls software. The new simulation platform analyzes ADO code and generates a corresponding test bench. Test results are shown to users for codes analysis. Key use cases and future plans of the simulation platform will be discussed.

PRELIMINARIES

In this section, we describe the main components of the C-AD control systems for the new simulation framework.

Accelerator Device Object

The Accelerator Device Object (ADO) is the fundamental construct [4, 9] in C-AD control systems. The ADO model is a flexible way to view accelerator equipment. It was intro-

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TELESCOPE CONTROL SYSTEM OF THE ASTRI SST-2M PROTOTYPE FOR THE CHERENKOV TELESCOPE ARRAY

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Abstract

The ASTRI SST-2M telescope is an end-to-end prototype [1], installed on Mount Etna (Italy), proposed for the Small Size class of Telescopes of the future Cherenkov Telescope Array (CTA) [2]. The ASTRI prototype adopts innovative solutions for the optical system [3], which poses stringent requirements in the design and development of the Telescope Control System (TCS), whose task is the coordination of the telescope devices, performing of the observational functionalities and the maintenance, test and calibration activities.

In this contribution we plan to highlight how the ASTRI approach for the design, development and implementation of the Telescope Control System has made the ASTRI SST-2M prototype a stand-alone, intelligent and active machine, able to efficiently perform all the required engineering and operative functionalities, to receive commands, transmit monitoring data and eventually recover errors.

Furthermore, the ASTRI approach provides for a Telescope Control Software that can easily be integrated in an array configuration: a first set of nine ASTRI telescopes is planned to be produced for early implementation on the southern CTA site.

INTRODUCTION

The ASTRI Software, named Mini-Array Software System (MASS) has the task of making it possible to operate the ASTRI telescopes under the constrains and requirements defined by CTA, even in the case of the ASTRI SST-2M prototype.

The MASS package provides a set of tools able to manage all on-site operations: perform the observations specified in the short-term schedule, analyse the resulting data, store/retrieve all the data products to/from the on-site repository, as well as perform engineering, maintenance and calibration activities. The general architecture of MASS software, grouped in a control hierarchy is sketched in Figure 1. Starting from the bottom, the Local Control group contains all the software components related to monitor and control the hardware on board the telescope and the auxiliary devices, together with the infrastructure and power assemblies. The hardware controllers are managed and coordinated at the higher level by the Device Control software group, through the Open Platform Communications Unified Architecture (OPC-UA) protocol [4], which supports rich data model while offering high compatibility with the Programmable Logic Controller (PLC) platform.

At the highest level the Operator Control System (OCS) provides all the services necessary for the observations and manages the data flow from the telescope control system to the data repositories.

TELESCOPE CONTROL SOFTWARE

The Telescope Control package (grey boxes in Figure 1) includes low and high-level software components dedicated to:

1. Monitoring and control of the hardware devices onboard the telescope and of the auxiliary assemblies (e.g. weather station, all sky camera, sky quality meters), together with the managing of safety standard functionalities.
2. Coordinated execution, based on the Use-Cases defined [5], of the functionalities provided by Local controllers in order to perform scientific observations, tests and engineering actions.
3. Error handling and fault conditions recovery.

Every software component of the ASTRI telescope is developed using the state machine approach: any telescope device is conceived as an abstract machine that can be in one of a finite number of states. A particular state machine is defined by the list of its states, and the triggering condition for each transition. In this way every telescope device can perform a predetermined sequence of actions autonomously. So, starting from the low-level and going to the higher levels, all the states are logically assembled together in order to form the final telescope state machine, as shown in Figure 2.

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APPLYING ONTOLOGICAL APPROACH TO STORING CONFIGURATION DATA

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Abstract

Control systems of large experimental facilities need a great number of heterogeneous interconnected parameters to control software applications. As configuration information grows in volume, it becomes harder to be maintained manually and poses a potential threat to data integrity. To tackle this problem, we applied ontological approach to storing configuration data. Ontology is a formal representation of concepts and relations of the domain of discourse, enriched by rules for inferring assumed knowledge. We designed the ontology that describes the controlling electronics for the double-direction bipolar transfer line K-500, which transports beam from the Injection Complex to colliders VEPP-4 and VEPP-2000 at BINP, Novosibirsk, Russia. We populated the ontology by importing data from existing configuration files of the control system and developed the interface for querying configuration data. The designed storage has several benefits over the conventional approaches. It maintains heterogeneous objects with non-trivial dependencies in centralized form, performs data verification and can be expanded to the diverse ontology describing all information about the facility.

INTRODUCTION

Any large experimental facility uses a huge number of hardware devices and software applications to perform control and maintenance functions. Configuration data that describe this equipment has a convoluted structure, including various devices and their templates, physical and logical connections between them, accompanying cable and inventory information, etc. It is crucial for both physicists and facility operators to have access to these varied parameters; consequently, we should store them in a formalized and structured way and provide user interfaces for data access and modification.

Designing an entity-relation diagram and building a relational database based on it, seems to be a straightforward solution to the problem of storing configuration data. However, relational data model lacks flexibility when it describes complex relations. Apart from having a complicated structure, configuration parameters usually have non-trivial dependencies and interconnections. Reconfiguration of any single facility element calls for a sequence of changes related to other elements and they need to be applied in correct order. These peculiarities make it hard to apply any changes to existing system and avoid data inconsistencies when the control system grows in size and becomes more complex.

Therefore, we turned to more flexible graph data model as a basis of desired data storage. It is capable of reflecting complex relationships between heterogeneous objects, which makes it more effective in expressing interconnected configuration data parameters.

REQUIREMENTS ON THE CONFIGURATION DATA STORAGE

Facility

As a model system, we examined double-direction bipolar transfer line K-500 [1] at Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia. It connects Injection Complex and collider VEPP-4 by transporting electron-positron beam with a frequency of 1 Hz. 24 electronic devices of 8 types are used for controlling the facility power supplies and measuring their parameters. The electronics is controlled by the modular control system CXv4 [2], which configurations are stored in local files and include information about devices, device templates, control channels and their characteristics.

Offered Solution

To automatize the processes of configuration, documentation and maintenance of K-500 facility control system, we required a centralized data storage, flexible enough to describe diverse collection of facility elements and their relationships and reliable enough to provide multiple user access to data.

We defined the following main problems, which the developed storage should be able to solve:

1. Storing diverse facility data in a centralized way;
2. Avoiding data duplications and inconsistencies;
3. Automating configuration of software applications for control system;
4. Documenting control system information in various forms and views;
5. Tracking changes made by system users.

The desired storage should display a single source of actual information about the control system structure and should be interoperable with other control system software. We therefore needed to develop programming and user interfaces for data access, modification and analysis of stored data.

To achieve these goals, we decided to develop a knowledge base for the facility domain, rather than use a traditional database as configuration data storage and take advantage of semantic analysis possibilities. [3]

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CAMERAS IN ELI BEAMLINES: A STANDARDIZED APPROACH

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Abstract

The ELI Beamlines facility is a Petawatt laser facility in the final construction and commissioning phase in Prague, Czech Republic. The central control system connects and controls more than 40 complex subsystems (lasers, beam transport, beamlines, experiments, facility systems, safety systems) with hundreds of cameras.

This paper describes the approaches and solutions used in ELI Beamlines to manage the selection, integration and maintenance of cameras by providing a comprehensive set of standards. Hardware interface standards guarantee ad-hoc software integration (using vendor-independent drivers), for commonly used models, auxiliary hardware (triggering: optical/TTL, power supplies) is available. Information on key parameters (vacuum compatibility, noise levels) is collected. By using a strict model-based approach and a component-based design, all cameras and 2D-detectors can be controlled with the same C++-API.

INTRODUCTION

ELI Beamlines [1] is an emerging high-energy, high-repetition rate laser facility located in Prague, Czech Republic. Four laser beamlines (ranging from the in-house developed L1 with <20fs pulses exceeding 100mJ at 1kHz based on DPSS technology to the 10PW-L4, developed by National Energetics) will supply six experimental halls which provide various secondary sources to users. Facility commissioning, and installation work of lasers and experiments is progressing, and first user experiments are expected in 2018.

The central control system group connects, supervises and controls all technical installations used for the operation of this facility, which are more than 40 complex subsystems with hundreds of cameras.

In 2017, we worked with ca 40 stakeholders on the topic of cameras: This means supporting selection and procurement, helping with operation, software / hardware development and integration into the central control system. While 90% of the requests can be fulfilled using standard off-the-shelf machine vision cameras, we also work with highly specific detectors (for example: photon counters, x-ray detectors, wavefront sensors,..) and have even developed custom cameras.

This paper describes the approaches we chose for supporting our users, our process of camera selection and interface standards, and the soft- and hardware we developed to support them.

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SUPPORT APPROACH

Integrating a single camera into a control system is easy – vendor SDKs are freely available and can be wrapped into any middleware without problem. Almost all industrial cameras are supported by Matlab and LabVIEW, allowing easy access for users.

The key challenge for a control system team is scaling up and supporting potentially hundreds of different cameras. (in 2014, we counted 117 different models in ELI, a number that is probably much higher now). Individual solutions are simply not feasible any more.

In such situations, industrial SCADA teams often enforce **standard component catalogues** and restrict device choice to a few well-known models. Any deviation needs a good justification, explicit permission and a maintenance plan (spare parts, expertise).

We would have preferred this approach, because it reduces complexity, maintenance cost and unit-price (due to high-volume procurement); however, we did not succeed with introducing it in ELI: First, there was low acceptance from users, who are not used to such restrictions; and second, component prices in machine vision are currently falling rapidly, making yesterdays "top-notch" model obsolete and overpriced.

Therefore we settled for different, three-tier approach:

1. **Strictly enforced interface standards**
2. **Support with camera selection**, with guidance towards common models that can be borrowed for testing, prototyping and bridging delivery times.
3. **Complete and standardized vendor-independent software and hardware solutions**

CAMERA SELECTION

In ELI, any camera that fulfils the interface standard described below is called a **standard camera**. These cameras are known to work within our control system environment, and users can purchase them without previous consultation.

Any other camera is called a **special camera**, typically supplied by commercial-research companies or university spinoffs, performing niche measurement applications. These companies either use outdated/cheap cameras models, or developed their own interface for more complex detectors. Often there are no alternative suppliers, and we deal with these systems on a case-by-case basis, and try to wrap their acquisition solutions into our standard APIs.

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DARUMA: DATA COLLECTION AND CONTROL FRAMEWORK FOR X-RAY EXPERIMENTAL STATIONS USING MADOCA

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Abstract

To take measurements in X-ray experimental stations at the SPring-8 synchrotron radiation facility, station staffs and users occasionally need to reconfigure the system for new experiments. At such times, quick reconfiguration of the system is required, which involves extensive work. Additionally, there is a strong need to reuse basic software associated with the measurement applications, which can be difficult. To overcome these challenges, we propose DARUMA, a data collection and control framework for stations. DARUMA utilizes the control framework MADOCA II [1] that was developed for distributed control of accelerators and beamlines at SPring-8. It provides software functionalities for stations, such as data collection and image handling. As it has the flexibility of MADOCA II and shares general software applications, DARUMA can help to reduce management costs and improve the measurement system. As a first attempt, we developed DARUMA for BL03XU at SPring-8. At this station, the migration into the DARUMA system is proceeding smoothly. As a result, we have begun applying DARUMA at other stations. Some applications in DARUMA, such as image handling, are particularly useful and have been implemented into a partial set of control systems for several stations since this September.

INTRODUCTION

SPring-8 is a third-generation synchrotron radiation facility in Japan. Brilliant synchrotron radiation X-rays up to an order of 100 keV are produced from 8 GeV electron beams and utilized for various experimental measurements of scientific research and industrial applications. For the measurements, stations are equipped in each of 56 beamlines.

To extract valuable results from the experimental measurements flexibly, it is important to have a user-friendly measurement system for station staff and users. However, the current measurement system has several limitations, and there are several demands from staff and users as listed below.

- Easy reconfiguration of the measurement system to update experimental setup
- Rapid preparation of the measurement software
- Easy to plug in basic software such as image handling
- Cooperated controls among measurement applications
- Reuse of software applications

The current measurement software's structure, which makes it difficult to provide the aforementioned facilities, is shown in Figure 1.

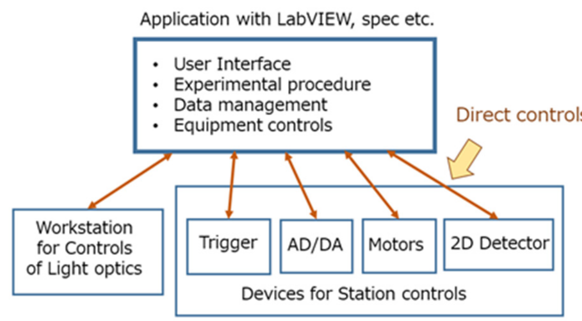

Figure 1: Schematic view of the structure of the typical measurement software for experimental stations.

Measurement applications in the stations are usually built with user interfaces such as LabVIEW [2], spec [3] and Visual Basic. As shown in Figure 1, one application contains all the functions of the measurements for the user interface, experimental procedures, and data management and equipment controls. Owing to the monolithic structure of the application, it is not easy to reconfigure the measurement system, because we need to update the application for the relevant sections by considering software dependencies in other sections as well. This constraint also prevents reuse of the application as general software, because many functions are combined in one application. Furthermore, the coding strategies of applications vary for each depending on the person who creates the application. Therefore, it takes time and resources to maintain the measurement system.

To solve these problems, we propose to apply a Data collection And control framework for X-Ray experimental station Using MADOCA, called DARUMA. Here, MADOCA stands for Message And Database Oriented Control Architecture and is used for distributed control of the accelerator and beamline for SPring-8. In this paper, we define the DARUMA software framework and show how DARUMA is useful for experimental measurements at stations. We also report the status of the implementation of DARUMA in BL03XU and other stations at SPring-8.

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THE SLAC COMMON-PLATFORM FIRMWARE FOR HIGH-PERFORMANCE SYSTEMS

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Abstract

LCLS-II's high beam rate of almost 1MHz and the requirement that several "high-performance" systems (such as MPS, BPM, LLRF, timing etc.) shall resolve individual bunches precludes the use of a traditional software based control system but requires many core services to be implemented in FPGA logic. SLAC has created a comprehensive open-source firmware framework which implements many commonly used blocks (e.g., timing, globally-synchronized fast data buffers, MPS, diagnostic data capture), libraries (Ethernet protocol stack, AXI interconnect, FIFOs, memory etc.) and interfaces (e.g., for timing, diagnostic data etc.) thus providing a versatile platform on top of which powerful high-performance systems can be built and rapidly integrated.

INTRODUCTION

The next generation Linac Coherent Light Source (LCLS) has many High Performance System (HPS) sub-systems:

- Beam Charge Monitor (BCM)
- Beam Length Monitor (BLEN)
- Beam Position Monitor (BPM)
- Low-Level Radio Frequency (LLRF)
- Machine Protection System (MPS)
- Timing System

While each specific HPS sub-system has some unique requirements, they all share the same base requirements:

- Intelligent Platform Management Interface (IPMI)
- Timing Network
- Experimental Physics and Industrial Control System (EPICS) Network
- MPS network

The motivation for developing a HPS common platform is to do the following:

- Identify areas of commonality within LCLS-II, LCLS-I, and SLAC in general
- Define intra HPS interfaces and interconnects
- Ensure application specific firmware and software is consistent with core library, portable, parameterized, and reusable in future systems

The HPS common platform provides the base hardware, base firmware, and base software for all LCLS-II (and eventually LCLS-I) sub-systems [1]. The common platform is an Ethernet Network Access Device (NAD) based module. Figure 1 shows the default packaging solution, which is a 7-slot Advanced Telecommunications Computing Architecture (ATCA) crate.

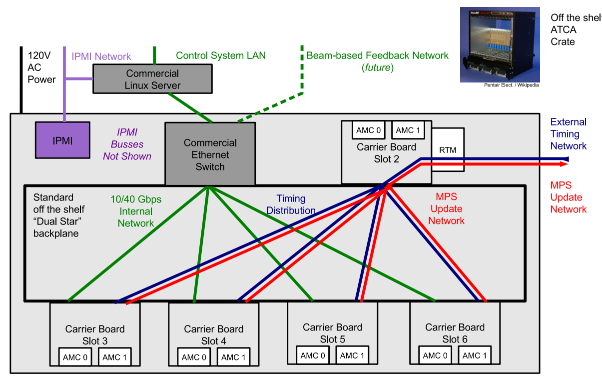

Figure 1: Crate Network Block Diagram.

COMMON PLATFORM HARDWARE

The common platform hardware is an ATCA Advanced Mezzanine Card (AMC) carrier board. A block diagram of the carrier board is shown in Fig. 2, and a photograph of the AMC carrier is shown in Fig. 3. The AMC carrier supports two double-wide, full height mezzanine cards. An AMC is where the application specific hardware exists for a given HPS sub-system. Figure 4 shows some examples of application specific hardware that has been developed for the common platform carrier board. The AMC carrier provides the following interconnects and power to each of the AMCs:

- Unfiltered, switching +12VDC power (up to 9A)
- Filtered, switching +2VDC power (up to 3A)
- Filtered, switching +4VDC power (up to 3A)
- Filtered, switching +6VDC power (up to 3A)
- Filtered, switching +15VDC power (up to 0.5A)
- Filtered, switching -15VDC power (up to 0.5A)
- 7 - 10 high speed FPGA I/Os, (Up to 10Gbps)
- 86 low speed FPGA I/Os, (Up to 1Gbps)
- 2 differential pairs between AMCs on the same carrier
- 2 differential pairs between AMC and RTM

The main controller on the AMC carrier is a Xilinx Kintex Ultrascale Field-Programmable Gate Array (FPGA). There are two loading options for this FPGA: XCKU040-2FFVA1156E (7 high speed links per AMC) or XCKU060-2FFVA1156E (10 high speed links per AMC). XCKU040-2FFVA1156E is the default loading option. Attached to the FPGA is a standard 8GB DDR3 SODIMM for local buffering of large amounts of data.

To help minimize cabling to the common platform hardware, the ATCA back plane is highly utilized. We are using a dual-star back plane. In ATCA slot#1 (1st star connection), we use a Commercial Off The Self (COTS) Ethernet switch

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VME BASED DIGITIZERS FOR WAVEFORM MONITORING SYSTEM OF LINEAR INDUCTION ACCELERATOR LIA 20

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Abstract

Waveform monitoring system plays a special role in the control system of powerful pulse installations providing the most complete information about the installation functioning and its parameters. The report describes the family of VME modules used in the waveform monitoring system of a linear induction accelerator LIA-20. In order to organize inter-module synchronization the VME-64 bus extension implemented in the VME64-BINP crates is applied in the waveform digitizers.

INTRODUCTION

Waveform monitoring system (WMS) includes "fast" and "slow" monitoring subsystems. To obtain the necessary waveforms with different duration, a several fast and slow models were developed. The models use unified hardware solutions in the interface part interacting with the VME bus. The interface part of the modules performs not only VME-bus standard procedures but also provides interface with additional synchronization lines that are present on the J2/P2 connector [1]. With these lines, the phased-clocking of analog-to-digital converters is provided for all digitizers in the crate.

Three types of digitizers are involved in “fast” subsystem. The first one, ADC4x250-4CH, is 4-channel 250 MSPS digitizer. The second one, ADC4x250-1CH, is single channel digitizer with sample rate of 1 GSPS. The third model intended for operations with signals in optical diagnostics which require bandwidth about 100 MHz and sample rate 250 MSPS. Resolution of devices is 12 bit. All of fast models are based on unified hardware platform and differ in timing as well as the structure and schematics of the input amplifiers.

"Slow" subsystem is based on ADCx32. This digitizer uses four 8-channel multiplexed SAR ADCs (1 µs conversion cycle) with 12 bit resolution. The total number of channels of ADCx32 is 32. Main feature of this module is program configurable channel sequencing which allows to measure signals with different duration.

FAST DIGITIZERS FAMILY ADC4X250

The most used model ADC4x250-4CH intended to record accelerating voltage waveforms. The total number of such signals reaches 840. These data allow us to determine the beam energy and monitor the correct operation of the high-voltage modulator.

The fastest model ADC4x250-1CH allows monitoring the voltage in kickers – the beam deflecting devices. The total number of these signals is about 10.

The third digitizer processes signals coming through optical lines and contains a photodetector at the input.

Unified Hardware Platform

A relatively small number of kicker signals makes uneconomical the development of the device with 1 GSPS sample rate if take into account labour expenditures. On the other hand, the purchase of a number of modules, each of which costs about $12,000, not a satisfactory one. However, it is clear that the structural schemes of all fast modules are very similar. In this regard, it looks attractive variant when all modules are designed as two separate PCBs that stacked with each other by mezzanine way. One PCB is unified mainboard shared by all fast digitizers. Its structural scheme is shown in Fig. 1. Sampling is performed by four 250 MSPS 12 bit analog-to-digital converters. Raw ADC data is stored into two SRAM chips with total capacity of 3 megasamples. Two FPGA Altera Cyclone III transfer samples from ADC to SRAM in the measure phase as well as applying calibration correction on-the-fly to reading out data. Furthermore, FPGA software performs common control functions and VME communication. Also board contains outstanding clocking chip for accurate ADC timing and synchronization.

Any device in family is obtained by connecting according preamplifier. Software of the module determines what kind of preamplifier is connected and then configure ADCs’ clocking scheme and internal registers in the correct way.

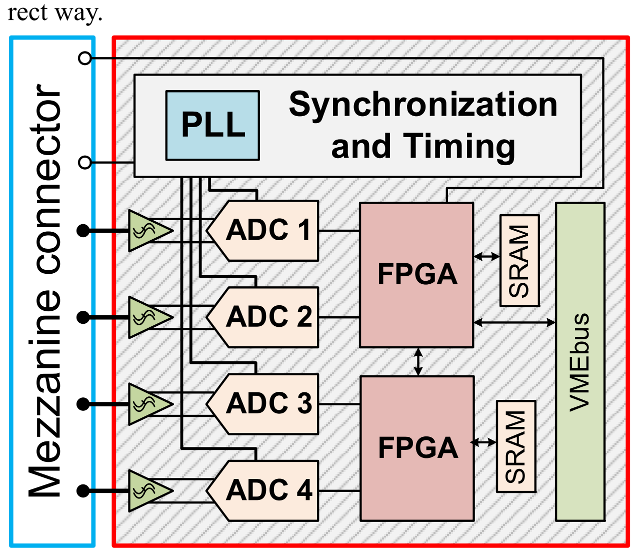

Figure 1: The structure of ADC4x250 mainboard.

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NEW VME-BASED HARDWARE FOR AUTOMATION IN BINP

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Abstract

A new VME-based crate and modules are presented in this work. This hardware is primarily intended for LIA-20 control system, but we also plane to use it for the upgrade of the controls of existing complexes such as: VEPP-2000, VEPP-4, VEPP-5 Preinjector. Modules were designed with an ability to be used planned projects such as Super c-tau factory. A crate is 6U VME64x compatible crate with additional synchronization, daisy-chain lines and 6U RIO-modules. Each crate has a built-in status monitoring over CAN-BUS with independent power supply. A family of VME modules is based on the same design sample and include: digitizers, timing modules, CAN-interface module, interlock qmodule. All modules are cost effective and have TANGO device servers developed for them.

INTRODUCTION

Budker Institute has a long history of developing it's own electronic modules for automation. Most of the modules that are still used on current installations in the institute (VEPP4, VEPP2000, injection complex, GOL-3 and GDL), were developed in CAMAC format in 1970-1980-s. Now they are obviously morally and technically outdated. Considering more contemporary standards our group had some experience with using NI PXI, we developed a line of modules for magnetic measurements in VME standard [1] and we had automated LIA-2 accelerator [2] using in-house cPCI modules. We need a new modular standard for automation electornics both for our new projects such as LIA-20 [3], Super c-tau Factory, magnetic measuremetns, etc., and for upgrade of existing complexes.

When choosing the modular standart for automation we have to take into account our specific economical conditions and the experience of our electronics team. From our current point of view we could formulate a following set of requirements to the standard. First of all it should be a widespread modular standard with available COTS modules. Second, it should have lines for intermodule synchronization. Third, it should have rear input-output modules for convenient cabling. Fourth, to reduce the overall system cost a standard should allow as much modules in crate, as possible. And lastly we should consider our experience using and developing modules for it. The table 1 summarizes standards that we analyzed.

After considering these standards we found that there is no one fully satisfying our requirements. VXI is very expensive and has a small crate. CompactPCI has no synchronization lines and only 8 modules are supported. PXIe has no rear IO modules and though 6U crates are available standard ones

Table 1: The Analyze of Modular Stanards

Name	Synchr.	RIO	Modules	Exp.
VXI	+	-	13	±
VME	-	+	21	+
PXI(e)	+	-	18	∓
CompactPCI	-	+	8	+
microTCA	*	-	21	-

are 3U. MicroTCA was found to be quite interesting, but it is excessively complex, not very widespread for automation and creating modules for it is an untrivial task. Our previous experience with VME was quite good, but it has no synchronization lines. Therefore we decided to create our modification of VME standard that will meet all our requirements. After the analyze we found out that there is CERN VME430 standard that is quite similar to what we have done though it uses 9U modules.

VME64-BINP CRATE

VME64-BINP is a 10U VME-64x compatible crate with 21 positions for 6U modules. The photograph of the crate is presented at fig. 1. There are two designated positions: position 1 is used for controller, and position 2 is used for timer/commutator module. Full-size 6U RIO-modules are used. An upper (J1) connector is a standard one while the lower (J2) has specialized U/D pins assigned to special functions. The crate is assembled by using a standard upper backplane and a specially developed 7U bottom backplane.

Figure 1: VME-BINP crate front and rear view.

Let us list the additional functions that are added on backplane: intermodule synchronization, intermodule commutation, daisy-chain lines, additional power lines, RIO-Module connectivity.

Synchronization lines include CLK125, USRCLK and SYNC. They are used to transfer a common 125 MHz clock, common user-defined clock and a precise synchronization pulse respectively. LVDS lines routed to each module in such a way that the first 8 positions are aligned better than 100 ps and the total propagation delay to 21st position is less

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THE INTERLOCK SYSTEM OF FELiChEM*

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Abstract

FELiChEM is an infrared free-electron laser user facility under construction at NSRL. The design of the interlock system of FELiChEM is based on EPICS. The interlock system is made up of the hardware interlock system and the software interlock system. The hardware interlock system is constructed with PROFINET and redundancy technology. The software interlock system is designed with an independent configuration file to improve the flexibility. The test results of the prototype system are also described in this paper.

INTRODUCTION

Tunable Infrared Laser for Fundamental of Energy Chemistry (FELiChEM) is the significant scientific instrument which is approved by the National Natural Science Foundation of China in 2013 [1]. FELiChEM contains one state-of-the-art infrared free electron lasers, one 60MeV linac and three research stations: photo-detection, photo-ionization, and photo-excitation setups.

EPICS is a set of software tools for building distributed control systems to operate devices such as Particle Accelerators and Large Experiments. For accelerator, the interlock system takes the charge of machine protection and the personal protection. As we adopted EPICS to establish the control system in FELiChEM, we also design the interlock system based on EPICS. This system comprises of the hardware interlock system and the software interlock system. The hardware interlock system has two parts: Machine Protection System (MPS) and Personal Protection System (PPS). We adopt redundancy technology and PROFINET to improve the reliability in the hardware interlock system. In the design of the software interlock system, we use an independent configuration file to improve the flexibility.

HARDWARE INTERLOCK SYSTEM

In the hardware interlock system of FELiChEM, the requirement of response time is about 100ms. We use PROFINET for field communication. PROFINET is an industrial internet standard. Depending on the PROFINET definition, it has PROFINET IO controller layer and IO device layer. For the hardware interlock system, PLC is the controller for dealing with interlock logic. Meanwhile, the distributed IO stations are the IO devices to get field signal and achieve interlock action. IOC is used to integrate the hardware interlock system into EPICS environment.

As shown in Figure 1, the IOC layer, PROFINET IO controller layer and PROFINET IO device layer form the three-layer interlock system architecture. Each layer is separate and can be configured in redundant mode. Furthermore, the link media between IO controller layer and IO device layer can also adopt redundant technology.

IOC layer includes master IOC and slave IOC which are running on the VMware virtual machines (VM). The two VMs use Fault Tolerance (FT) mechanism to achieve redundant function. VMware FT achieves zero downtime and zero data loss by creating exactly the same VM from the master VM. The master VM and the slave VM use heartbeat mechanism for monitoring mutual status. So when the master VM shutdown, the slave VM can take it works over as a redundant function implementation [2].

The PROFINET IO controller layer uses a pair of redundant Phoenix RFC 460R PLCs. The master PLC and the slave PLC synchronize data via fiber. They can switch roles with each other. IOC communicates with master PLC by Ethernet, and the corresponding driver is developed via TCP/IP protocol [3]. PROFINET supports three types of protocol: TCP/IP, Real-Time (RT) and Isochronous Real-Time (IRT). In FELiChEM interlock system, we use RT protocol between the controller layer and the device layer.

We also set up redundant network link media topology based on Rapid Spanning Tree Protocol (RSTP) to improve the reliability. RSTP can provide network path redundancy.

PROFINET IO device layer has several IO stations, and each station has several IO modules. IO device layer divides into MPS and PPS. MPS part includes 8 sub-systems: electron gun, vacuum, power, modulator, microwave, cooling water, undulator and resonant cavity. PPS includes access control system, check button, emergency stop button and dose measurement alarms. In the hareware interlock systelm of FELiChEM, we haven't use redundancy configuration in IO device layer.

TEST OF PROTOTYPE HARDWARE INTERLOCK SYSTEM

Response time and redundant switch-over time are the key parameters in the hardware interlock system. We establish a prototype system for measuring these parameters.

In the prototype system, the PROFINET IO devices layer has two IO stations for simulating MPS and PPS separately. Each station has one 16-channels DI module and one 16-channels DO module. Figure 2 is the operator interface developed with Control System Studio(CSS).

We use two Phoenix SMCS 8TX industrial switches for setting up the PROFINET network, and it can support RSTP protocol.

Test of Response Time

The response time refers to the time difference between IO station receiving input DI signal and setting interlock DO

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INVESTIGATIONS OF SPATIAL PROCESS MODEL FOR THE CLOSED ORBIT FEEDBACK SYSTEM AT THE Sis18 SYNCHROTRON AT GSI *

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Abstract

A closed orbit feedback system is under development at the GSI SIS18 synchrotron for usage during the whole acceleration cycle including the acceleration ramp. Singular value decomposition (SVD) is the most widely used technique in global closed orbit correction for eigenmode decomposition, mode selection and pseudo-inversion of Orbit Response Matrix (ORM) for robust calculation of corrector magnet strengths. A new faster inversion technique based upon Discrete Fourier Transform (DFT) has been proposed for SIS18 ORM exploiting the circulant symmetry, a class of matrices which can be diagonalized by the DFT using only one row or column of the matrix. The existence of a clear relationship between SVD modes and singular values to DFT modes and coefficients for such matrices has been described. The DFT based decomposition of circulant ORM gives hints on physical interpretation of SVD and DFT modes of perturbed closed orbit in a synchrotron. As a first practical application, DFT modes were used to provide robustness against sensor failures such as one or two malfunctioning BPMs.

INTRODUCTION

GSI's SIS18 synchrotron will be the booster ring for the SIS100 synchrotron at the upcoming FAIR facility. SIS18 upgrade is underway to cope with higher beam intensities planned for the FAIR facility [1,2]. The closed orbit feedback system aims to supplement the SIS18 upgrade efforts by stabilizing the beam orbit during the full acceleration cycle. There are many of challenges for the closed orbit feedback system (COFB) for SIS18,

- The change of lattice from triplet to doublet in course of the acceleration ramp leads to orbit and tune changes [3]. Figure (1) shows a plot of typical position movement during the acceleration ramp.
- Influence of power supply ripple on orbit especially visible in horizontal plane. A ≈ 2 kHz bandwidth system would be required to suppress these ripple. Figure 2 shows the phase shifted ripple of two consecutive cycles.
- Several users (up to 16) can be supported in "parallel" operation presently at SIS18 where the users can request dynamic changes in beam energy and intensity. This often leads to non-reproducible orbits due to magnet hysteresis. Strategies to avoid the hysteresis problems are under discussion at FAIR [4].
- BPM failures due to radiation shower inside the accelerator tunnel is a regular occurrence especially during high intensity operation. Feedback systems should be robust to such sensor/actuator failures.
- Intensity-dependent tune movements are already seen at moderate intensity operation of SIS18. Such effects are expected to aggravate during FAIR operation and the COFB should be prepared to deal with them.

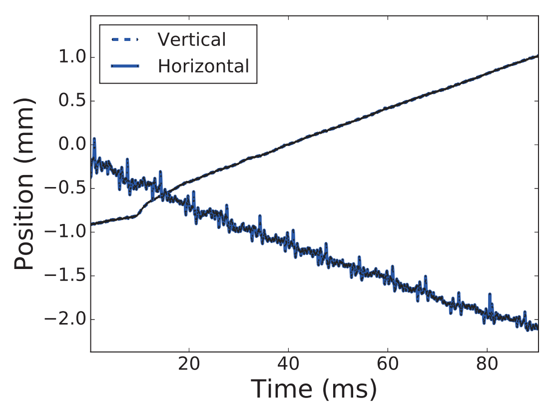

Figure 1: Position in both planes measured at BPM in section 8 during first 90 ms in the acceleration ramp.

A feed-forward orbit correction system can overcome some of these challenges but non-reproducible cycle-to-cycle effects such as hysteresis, intensity-dependent orbits and power supply ripple cannot be easily accounted for. This calls in for a fast feedback system which is robust to uncertainties in machine model and unavailability of sensors.

The backbone of the closed orbit feedback correction is the orbit response matrix (ORM). It is the effect of corrector magnets on the transverse position of closed orbit measured at the locations of BPMs. Equation (1) describes a generalized orbit response matrix (one for each transverse plane) [5]

$$\mathbf{R}_{mn} = \frac{\sqrt{\beta_m \beta_n}}{2\sin(\pi Q)} \cos\left(Q\pi - |\mu_m - \mu_n|\right) \quad (1)$$

where β and μ denote the beta function and phase advance while subscripts m and n mark the locations of BPMs and

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A SIMULATION SYSTEM FOR THE EUROPEAN SPALLATION SOURCE (ESS) DISTRIBUTED DATA STREAMING

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Abstract

European Spallation Source (ESS), the next-generation neutron source facility, is expected to produce an immense amount of data. Various working group mostly associated with the European Union (EU) project Building a Research Infrastructure and Synergies for Highest Scientific Impact in ESS (BrightnESS) aim at developing solutions for its data-intensive challenges. The real-time data management and aggregation is among the top priorities. The Apache Kafka framework will be the base for ESS real-time distributed data streaming. One of the major challenges is the simulation of data streams from experimental data generation to data analysis and storage. This paper outlines a simulation approach based on the DonkiOrchestra data acquisition and experiment control framework, re-purposed as a data streaming simulation system compatible with ESS-KAKFA infrastructure.

INTRODUCTION

Elettra Sincrotrone Trieste is a multidisciplinary international research center specialized in generating high quality synchrotron and free-electron lasers (FEL) light and applying it in materials and life sciences.

The electron storage ring Elettra provides state-of-art techniques to lead experiments in physics, chemistry, biology, life sciences, environmental sciences, medicine and cultural heritage. It is the only third-generation synchrotron radiation source in the world that operates routinely at two different electron energies, i.e., 2.0 GeV for enhanced extended ultraviolet performance and spectroscopic applications, and 2.4 GeV for enhanced x-ray emission and diffraction applications. Currently 26 beamlines utilize the radiation generated by Elettra source.

The FEL FERMI light source has been developed to provide intense and fully coherent radiation pulses in the ultraviolet and soft x-ray range. The peak brightness of about 6 orders of magnitude higher than third generation sources generated by its single-pass linac-based FEL allows the performance of time-resolved experiments based on coherent diffraction imaging, elastic and inelastic scattering, photon and electron spectroscopy and transient grating spectroscopy. FERMI can operate in the 100-40 nm energy region in the initial phase and down to 10 nm in a subsequent phase. Currently 6 versatile experimental stations carry out outstanding research in diverse fields and disciplines.

The EU-founded BrightnESS project [1] aims at support the construction of the ESS in key technical areas and in-kind coordination. Elettra has been introduced and integrated to the main workload of BrightnESS Work Package 5 [2] which has the objective to maximize the scientific output of the ESS by enabling real time processing data taken on ESS instruments.

EXPERIMENTS IN NEUTRON AND ELECTRON FACILITIES

Each scientific setup is unique, not static and is periodically upgraded with new instrumentation, so a constant evolution of software and control systems technologies is necessary.

Computational Requirements

Neutron and electron facilities have demanding computational requirements; not only for their accelerators but also for their experimental stations and laboratories. Since these facilities are in a constant upgrade and change (as science always does) the computational systems require scalability and should allow for easy customization. Naturally such systems should permit concurrency as in parallel data processing, storage and data transfer. The latter requires intelligent and efficient architectures for transfers with minimal overheads. As expected, advanced workflow systems are used to facilitate communication, control and data flow.

Workflow Systems

A workflow system for the above-mentioned scenario should provide an infrastructure for the set-up, performance and monitoring of a defined sequence of tasks, arranged as a workflow application. From the workflow point of view, scientific experiments consist of a sequence of specifics tasks that can be organized in many different ways according to the experiment requirements. Schematically, an experiment sequence is composed by three consecutive phases: planning, collection and closeout. During the planing phase the sequence of the operations to be performed as well as its priority level should be set up. Once the planning phase is finished the system starts a sequence of triggers to communicate the operations to execute its tasks. Once a task is completed the current operation notifies the system, then proceed with the new task, and so on. Finally, in the closeout phase the system should perform any needed closing procedure to ensure all the operations were done.

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RF-ENERGY MANAGEMENT FOR THE EUROPEAN XFEL

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Abstract

The European XFEL is in its commissioning phase at this time. One of the major tasks is to bring up all the 25 installed RF-stations, which will allow for a beam energy of up to 17.5 GeV. It is expected, that a klystron may fail every 1-2 month. The accelerator is designed at the moment with an energy overhead corresponding to 2-3 RF-station, as the last 4 accelerating modules will be installed in a later stage. This will allow recovering the missing energy with the other functioning RF-stations to keep downtime as short as possible in the order of seconds.

The concept and corresponding High-Level software accomplishing this task will be presented in this paper.

XFEL RF LAYOUT

The European XFEL consists of four linac sections to accelerate the electron beam. The injector I1 accelerates the beam to 130 MeV and uses a 3.9 GHz module to linearize the beam profile. This beam is injected through a dogleg into the second section called L1, which is build of one RF-station of four modules each containing eight 1.3 GHz superconducting cavities. After L1, the beam reaches energy of about 700 MeV, gets compressed in the bunch compressor B0 and then further accelerated in the section L2 to approximately 2400 MeV with three RF-stations again with four modules each. After passing bunch compressor B1, the beam enters the long L3 section, where the beam reaches its final energy of up to 17.5 GeV. This section contains of 20 RF-stations, in a later stage with 21, and is laid out with an energy overhead of 10 % to compensate for an outage of up to 3 RF-stations in the final configuration [1][2].

Every RF-station in the sections L1 to L3 is build of a 100 kV pulse transformer driving a 10 MW klystron. This klystron powers via two waveguide arms 4 accelerator modules containing 8 cavities. So 32 cavities are feed by one klystron giving a possible energy gain of such a RF-station between 600 and 900 MeV depending of the gradient of the individual cavities.

Table 1: XFEL Energy Gain Configuration

Linac Section	*ΔE* [GeV]	*N*	*ΔE / N*	*V* [MV/m]
Injector	0.13	1	130	16.5
Linac 1 (L1)	0.57	1	570	17.8
Linac 2 (L2)	1.7	3	567	17.7
Linac 3 (L3)	15.1	21/20	719/755	22.5/23.6

DESIGN MATTERS

There are several reasons why a RF-energy management is required. Some of them are the following:

One klystron tube is expected to break once per month and needs to be exchanged, which takes several hours so that it should be possible to postpone it to the next maintenance day.

There are other sources of failures like coupler interlocks or broken computer hard disk and electronic devices, which resides inside the XFEL tunnel in restricted areas. In order to get those failures repaired, experts are required and may not be available at a time.

So in case of any kind of failure, the RF-energy management should help to reduce the time to recover beam operation in an automated way.

DESIGN IDEA

The purpose of the RF-energy management is to control the overall energy gain in the L3 section of the XFEL. The operator should just set the energy for the whole XFEL. So the required energy in L3 is simply given by:

$$E_{L3} = E_{total} - E_{I1} - E_{L1} - E_{L2}$$

The energy E_{L3} has to be distributed now to the active RF-stations along L3. Active RF-stations are stations, which are marked as operational by the Finite State Machine FSM and when the timing trigger is set in a way to allow this station to accelerate the beam or may shifted into this position.

There are in principle two ways to change the beam energy:

- Change the amplitude of the RF-stations [3]
- Change the phases in counter-rotating way [4]

Changing the amplitudes seems the more obvious way of doing it, but has the disadvantage, that several LLRF tuning parameter, like cavity tuning or klystron linearization need to follow. So bigger amplitude changes may make the LLRF regulation unstable. Changing the phases is much easier to handle by the LLRF regulation, but may have an impact to the beam dynamics, as the beam is accelerated off-crest at every station and only the total phase of L3 becomes zero. So the beam could develop a chirp, which may harm SASE performance.

Both methods are implemented to study its feasibility.

Use cases

The RF-Energy Management should fulfil the following use cases:

- Allow to change the overall Linac energy by one property

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THE AFP DETECTOR CONTROL SYSTEM

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Abstract

The ATLAS Forward Proton (AFP) detector is one of the forward detectors of the ATLAS experiment at LHC/CERN aiming at measuring momenta and angles of diffractively scattered protons. Silicon Tracking and Time-of-Flight detectors are located inside Roman Pot stations inserted into beam pipe aperture. The AFP detector is composed of two stations on each side of the ATLAS interaction point and is under commissioning. The detector is provided with high and low voltage distribution systems. Each station has vacuum and cooling systems, movement control and all the required electronics for signal processing. Monitoring of environmental parameters, like temperature, is also available. The Detector Control System (DCS) provides control and monitoring of the detector hardware and ensures the safe and reliable operation of the detector, assuring good data quality. Comparing with DCS systems of other detectors, the AFP DCS main challenge is to cope with the large variety of AFP equipment. This paper describes the AFP DCS system: a detector overview, the operational aspects, the hardware control of the AFP detectors, the high precision movement, cooling, and safety vacuum systems.

INTRODUCTION

AFP [1], currently in commissioning phase, is a forward detector installed in the LHC tunnel away from the ATLAS [2] Interaction Point (IP). It consists of four detector stations, two in each side of the IP at 205 and 217 m. Both stations are equipped with a Silicon Tracking detector (SiT), while the one that is placed further from the IP contains, in addition, a Time-of-Flight detector (ToF). Each AFP detector (SiT or SiT+ToF) is inside of a Roman Pot that protects it from the LHC high vacuum with a secondary safety vacuum.

The SiT is made of four planes with a 3D pixel sensor connected to a front-end chip (FE-I4B) providing 336×80 pixels with a size of 50×250 μm^2 given a active area of $1.68{\times}2.00$ cm^2 where the readout is done at 40 MHz through a flexible printed circuit. The sensors are mounted in a structure separated by 10 mm between planes.

The ToF calculates the interaction vertex location by measuring the arrival time difference of the forward protons in the two arms with pico-second accuracy. It consists of quartz bars positioned at the Cherenkov angle with respect to the proton flight direction. The bars are in L shape and perform as radiator and guide material (LQbars [3]). The 4×4 LQbars are connected to a 4×4 pixel Microchannel Plate Photomultiplier (MCP-PMT).

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THE AFP MAIN DCS SYSTEMS

System Overview

The SIMATIC Siemens WinCC Open Architecture (WinCC OA) [4] is a Supervisory Control and Data Acquisition (SCADA) system, a commercial package chosen by the Joint Control Project (JCOP) [5] for developing DCS systems in all the LHC experiments. The JCOP goal is to provide standards for the use of DCS common hardware components, implementation policies, Back-End (BE) software and operational aspects for all experiments.

The AFP DCS [6] is hosted in a server (DELL Power EdgeR620) with Linux SLC6 as native operating system. The control interfaces of some commercial components work under Windows operating system so the server hosts also a virtual machine (VM) with Windows Server 2008.

To control and monitor the complete detector two SCADA systems under WinCC OA 3.11 were built. The main system hosted in the Linux server is the core of the AFP DCS. It manages communication with the hardware which is controlled by an Open Platform Communications (OPC) Unified Automation (UA) servers, like ELMBs (Embedded Local Monitor Board) [7] and high voltage system or by using native drivers, like Programmable Logic Controllers. It runs all control scripts, displays information, contains the Finite State Machine (FSM) and is the interface for the ATLAS DCS. A scattered project with a client for OPC Data Access server is running in the VM.

The hardware is located in 3 places: (i) at the detectors and Roman Pots, (ii) at the crates with the readout electronics, voltage regulators, optoboards, and the AirCoolers on the tunnel floor below the detector, and (iii) at the power supplies and the computer in the USA15 service cavern.

High Voltage Power Supply

The high voltage is provided by an ISEG power supply crate equipped with two modules with 16 channels each. The ISEG modules supply power to the silicon sensors of the SiT detector (-500 V) and to the ToF photomultipliers (-3000 V). The control and monitoring is performed via CAN bus using OPC UA server.

Low Voltage Power Supply

A two-stage low voltage power supply system (based on Insertable B-Layer (IBL) [8] solution) was developed for dedicated powering and protection for overvoltage. Wiener PL512 power supply and a dedicated patch panel for precise current measurement as a first stage located in USA15 service cavern and Voltage Regulator (VREG) crate as a second

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BUILDING CONTROLS APPLICATIONS USING HTTP SERVICES*

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Abstract

This paper describes the development and use of an HTTP services architecture for building controls applications within the BNL Collider-Accelerator department. Instead of binding application services (access to live, database, and archived data, etc) into monolithic applications using libraries written in C++ or Java, this new method moves those services onto networked processes that communicate with the core applications using the HTTP protocol and a RESTful interface. This allows applications to be built for a variety of different environments, including web browsers and mobile devices, without the need to rewrite existing library code that has been built and tested over many years. Making these HTTP services available via a reverse proxy server (NGINX) adds additional flexibility and security. This paper presents implementation details, pros and cons to this approach, and expected future directions.

INTRODUCTION

Application development has changed dramatically over the last 20 years. These changes encompass the computer languages that we use, the infrastructure that binds software modules together, and the development tools used to build the software. This paper focuses primarily on changes to the software infrastructure.

Figure 1: Traditional Monolithic Application.

Twenty years ago, most applications were built using a single computer language, with software tools bound into the application running as a single executable program. This is known as a monolithic application [1]. As seen in Fig. 1 above, a monolithic Controls application might be written in C++ or Java and consist of a custom user interface utilizing standard toolkits to access control system devices, interact with database systems, and/or extract data stored by archiving or logging systems.

Of course, this is still a viable way to put applications together and will remain so for many years to come. The process is well established and highly optimized. And the applications produced have very good performance and are relatively straightforward to test and troubleshoot. However, this type of application development does have some limitations. The next section describes the issues that drove our group to look for an alternative.

Limitations of Monolithic Applications

Language and Code Reuse Twenty years ago, all of our applications were built as monolithic applications using C and C++. A few years later, we started investigating what it would take to use Java for application development. Java had in many ways surpassed C++ in terms of its basic tools and development environment and had become the language of choice for many software developers.

The problem was that we had invested many years of effort into building a set of modular C++ tools for streamlining application development. And we wanted to reuse these tools if possible. We explored, and then rejected as too complicated, the use of Java Native Interface (JNI) [2], which allows Java programs to call C/C++ code. We followed a similar path when exploring the Common Object Request Broker Architecture (CORBA) model [3]. Instead, we invested our time into rewriting many of our C++ tools in Java.

However, it was clear, even before we were finished with that effort, that supporting other types of applications (LabView, MatLab, python, web browser, synoptic displays) would be necessary as well. We needed a more flexible way to reuse the software tools that we had built using C++ and Java.

Remote and Mobile Clients A second arc in our application development needs revolved around using our applications outside of the BNL campus, especially from employee homes. This was driven mostly by the expansion of broadband to homes and the associated increases in broadband speeds.

Our first solution to this problem was to have users login and run applications on BNL computers, but display them on their local home computers. This is possible because most of our applications are written for a Linux/X Windows environment, which has remote display built into the X Windows protocol [4]. This solution works, but requires users to install special software on their home computers. In addition, remote displays can be slow, even with relatively fast home connections. Recently, we've improved display performance by using a commercial product specifically designed to speed up X Windows network communication [5].

Though the above solution works, and is still in use today, it ultimately limits users to running Linux/X Windows applications on remote computers that are specially configured for that purpose. It would be preferable if the computer could run applications in its native environment. This would allow a user to run an application from a computer not specially configured (for example, in a hotel) or run an application from a universally available environment like a web browser.

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IMPROVEMENT OF TEMPERATURE AND HUMIDITY MEASUREMENT SYSTEM FOR KEK INJECTOR LINAC

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Abstract

A new temperature and humidity measurement system at the KEK injector Linac consists of 26 data loggers connected to around 700 temperature and humidity sensors, one EPICS IOC, and CSS archiver. CSS archiver engine retrieves the temperature and humidity data measured by the data loggers via ethernet. These data are finally stored into the PostgreSQL database system. A new server computer has been recently utilized for the archiver of CSS version 4 instead of version 3. It can drastically improve the speed performance for retrieving the archived data in comparison with the previous system. The long-term beam stability of Linac is getting a quite important figure of merit since the simultaneous top up injection is required for the independent four storage rings toward the SuperKEKB Phase II operation. For this reason, we developed a new archiver data management application software with a good operability. Since it can bring the operators a quick detection of anomalous behaviour of temperature and humidity data resulting in the deterioration of beam quality, the improved temperature and humidity measurement system can be much effective for the daily beam operation. We will report the detailed system description together with the future plan.

INTRODUCTION

The KEK injector Linac is a linear accelerator with a total length of about 600 m, which is composed of the ground floor (klystron gallery) and underground floor (tunnel). Approximately 60 rf sources (high-power klystron and modulator) for accelerating the beam are installed in klystron gallery. The klystron gallery is divided into sectors of about 80 m. A part of device name and EPICS PV name include the corresponding sector name. The klystron gallery is divided into 8 sectors in order from the upstream electron gun to the downstream.

In order to operate the beam of injector Linac stably, the temperature of each subsystem and its surrounding environment are very important information. The stability of the cooling water temperature of the acceleration tube and the SLED should be within 30 ± 0.3 °C in KEK injector Linac. Furthermore, it is necessary to adjust the temperature of klystron within 30 ± 0.5 °C. A change of the room temperature or the cooling water temperature may cause the variation of beam acceleration phase. Eventually, it could result in the change of beam energy. For this reason, the present measurement system has been introduced for monitoring the temperature and humidity [1] in 2006.

In the KEK Linac control system, the version of CSS [2, 3] was updated from version 3 to version 4 in January 2017. In addition, a new server computer based on Linux has been utilized aiming at the improvement of data retrieving speed performance. The SuperKEKB Phase II operation is going to start the early stage of next year.

Since the simultaneous top up injection to the downstream five rings will be carried out, the higher beam stability is strongly required. In such case, the precise temperature and humidity measurements are quite important, and they are required the fine control of them. For this purpose, we developed a new data viewer with a good operability. It can also show the large number of data points with a quick response, and has an alarm function for detecting the abnormal values all the time. We have deployed them for the daily operation. In this paper, we report the details of this temperature measurement system and the alarm display panel.

SYSTEM DESCRIPTION

The temperature measurement system operated at the KEK injector Linac has a total of 720 sensor units consisting of resistance temperature detector (RTD, Pt 100), thermocouple (K), humidity sensor, and 26 data loggers. The resolution of the data logger is 0.01 °C. Its sampling speed and communication rate are 10 Mbps and 56 Hz, respectively. The sensors were installed at the upper side of the klystron gallery in each sector to measure the room temperature. For the cooling water of accelerating structure, each sensor is attached to the input and output ports. Figure 1 shows the pictures of the sensors for the room temperature and cooling water temperature measurements.

Figure 1: Pictures of the temperature sensor in the klystron gallery (left) and for the cooling water of accelerating structure (right).

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PROCESSING OF THE SCHOTTKY SIGNALS AT RHIC*

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Abstract

Schottky monitors are used to determine important beam parameters in a non-destructive way. In this paper we present improved processing of the transverse and longitudinal Schottky signals from a hi-Q resonant 2.07 GHz cavity with the main focus on providing the real-time measurement of beam tune, chromaticity and emittance during injection and ramp, when the beam conditions are changing rapidly. The analysis and control is done in Python using recently developed interfaces to Accelerator Device Objects [1].

INTRODUCTION

Instrumentation

The high Q cavity [2] is mounted on a dual axis moving frame. It has four probes to detect signals from the different modes in the cavity. Peak frequency of the vertical probe is 2.067 GHz, horizontal probe: 2.071 GHz, longitudinal probe: 2.742 GHz. The signal processing diagram is shown on Fig. 1.

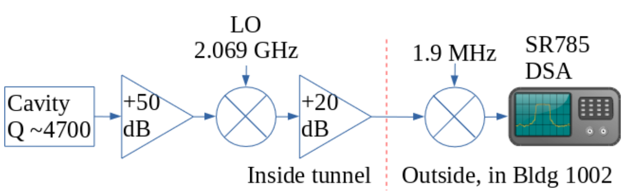

Figure 1: Signal processing diagram.

The signal from the cavity is amplified, filtered, down converted on a mixer with local oscillator (LO) and measured by a digital spectrum analyser (DSA).

Schottky Spectrum

The frequency domain signal of the bunched beam near the cavity resonant frequency is demonstrated on Fig. 2.

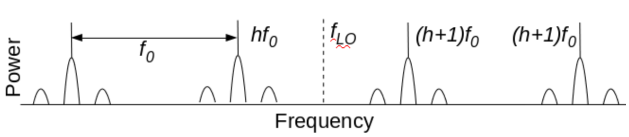

Figure 2: Schottky power spectrum.

The frequency of the local oscillator f_{LO} is positioned in the middle of the neighbouring harmonics of the revolution frequency f_0, to eliminate images from the highest harmonics. The high harmonic number h = 26525.5 helps to reduce power of the parasitic coherent peak. The signal registered by DSA is a superposition of differences between f_{LO} and several nearest harmonics.

Extraction of Beam Parameters from Signal

Figure 3 shows a typical transverse Schottky signal from proton beam at the RHIC. It consist of very narrow coherent peak on the top of the underlying revolution peak and two side band peaks due to particles betatron motions.

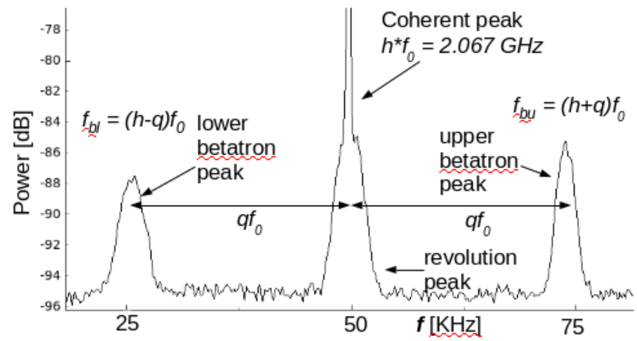

Figure 3: Schottky signal from the spectrum analyser.

The fractional part q of the tune is recovered from the positions of betatron peaks [3]:

$$q = \frac{f_{bu} - f_{bl}}{2 * f_0} \quad (1)$$

The chromaticity ξ is determined from the width asymmetry of the betatron peaks [3].

$$\xi = \eta \left(\frac{\Delta f_{bl} - \Delta f_{bu}}{\Delta f_{bl} + \Delta f_{bu}} h - q \right) \quad (2)$$

Here the η is a phase-slip factor of the accelerator.

The beam emittance is proportional to the rms beam size σ, which is determined from the power of the betatron peaks [3,4]:

$$P_{bu} = P_{bl} = \frac{1}{2} f_0^2 Q^2 N \sigma^2 \quad (3)$$

Where the N is the number of particles in the beam and the Q is the particle charge.

SIGNAL PROCESSING

Signals are changing rapidly during the ramp, the RF frequency is changing for ~8 harmonics in 30 seconds.

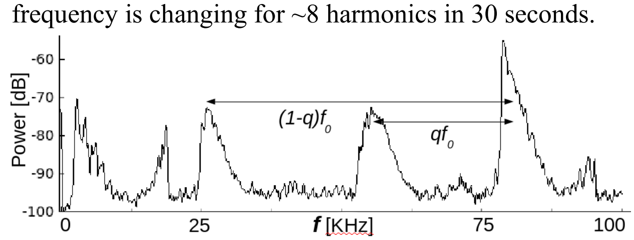

Figure 4: Schottky signal during the ramp.

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MACUP: A PROJECT FOCUSING ON DAQ HARDWARE ARCHITECTURE UPGRADES FOR SOLEIL

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Abstract

Since operation start-up more than 10 years ago, Synchrotron SOLEIL has chosen acquisition architectures that are mainly based on CompactPCI systems. The last few years there have however been an acceleration of obsolescence issues on the CPCI products and it has also been identified that this technology would shortly become a bottleneck in terms of performance for new projects. The MACUP (MAterial For data aCquisiton Upgrade) project was therefore created with two main objectives: maintaining the current facility operations by addressing the hardware obsolescence risks, all while searching for alternate high-performance solutions with better embedded processing capabilities to face new challenging requirements. One additional guideline for the project is to facilitate collaborative work for accelerator and beamline projects by evaluating and standardizing a limited set of technologies like the Xilinx ZYNQ SOC, VITA 57 FMC and µTCA standards. This paper describes the adopted methodologies and roadmap to drive this project.

CONTEXT

SOLEIL is a 2.75GeV 3rd generation synchrotron radiation source built in the early 2000s. Since 2006 SOLEIL is running continuously. Today 29 beamlines are open for users with a beam availability of more than 5000 hours a year.

Current Hardware Command/Control Architecture

The ECA (Electronique de Contrôle et Acquisitions) group is in charge of the electronic systems and the embedded software engineering dedicated for the control and acquisition of the accelerators, beamlines, and laboratory infrastructure devices. The group focuses on three main activities: Automation, Motion control, and Acquisition/Embedded processes.

The acquisition and embedded process activity is in charge of the fast analog/digital, instrumentation processes, and field bus. These processes are present in a wide range of applications on beamlines (beam imaging devices, beam-monitoring, attenuators, sample environment setups, detectors…) as well on the accelerators (diagnostics, power supplies, RF devices, Insertion devices…). This management is assured by two families of devices: the industrial standard CompactPCI (CPCI), custom in-house developments; all are remotely controlled over Ethernet in a Tango software command/control framework [1] (see Fig. 1).

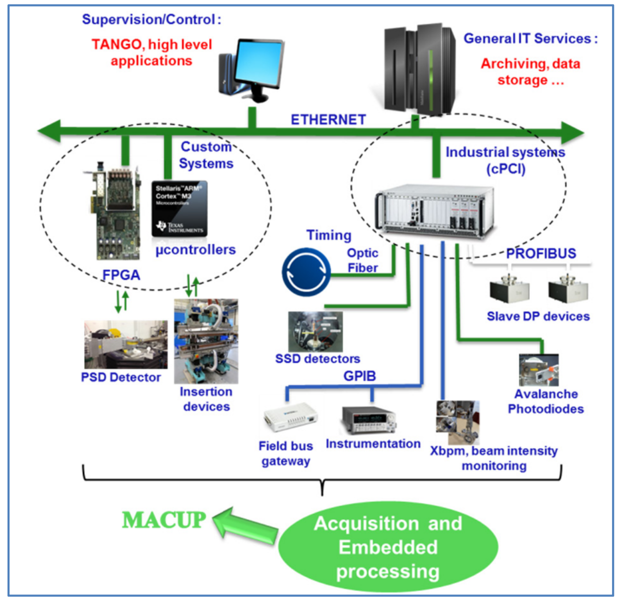

Figure 1: Acquisition and embedded process systems

Industrial COTS CompactPCI Systems

Based on a PC-type architecture but with a 19" chassis ruggedized form factor, SOLEIL has selected and standardized a large portfolio of CPCI COTS (Commercial Off-The-Shelf) analog and digital I/O cards targeting 90% of the applications for beamlines and accelerators. There are currently: 150 CPCI crates, 240 CPUs, and more than 750 peripheral I/Os boards (ADC, DAC, Video, Digital I/O, Counting, RS232, GPIB, TDC, Digitizers) in operation. The operating system mainly deploys Windows because the I/O board's drivers were mainly available for this operating system and functional in 2004.

Customized Systems

In-house systems have been developed (based on FPGA and µController solutions) to meet specific obsolescence needs or requirements not covered by COTS solutions. It is achieved by developing fully or partially customized hardware and firmware solutions (SPI platforms [2], SPEC platforms [3], FPGA CPCI boards).

THE MACUP PROJECT

Obsolescence issues, for all CPCI and custom systems, have been on an increase the last few years (obsolete components, end of life boards, drivers and operating systems out of date) which is normal after 10 years of using the same technology. In this context, the MACUP project was initiated in 2014. It is divided into 2 objectives for embedded acquisition and processing platforms:

- Ensure the operational continuity of the systems in production though MCO strategy (Maintenance in

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CEA IRFU EPICS ENVIRONMENT FOR THE SARAF-LINAC PROJECT

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Abstract

Our Institute CEA Saclay Irfu was in charge of providing the hardware and software for the EPICS based control system platform for the accelerator projects Spiral2 [1] at Ganil in Normandy and IFMIF/LIPAc at JAEA/Rokkasho (Japan). Our 3-year collaboration with ESS has given us the opportunity to use new COTS hardware. We have made our CEA Irfu control platform evolve by retaining relevant and evolutive ESS solutions. Currently, CEA Irfu is in charge of the design, construction and commissioning at SNRC(Israel) of the project SARAF-LINAC[2] (MEBT and Super Conducting Linac) including its control. This paper will present our proposition of architecture for the SARAF Linac control system using the new CEA Irfu hardware and software platforms.

INTRODUCTION

Involved in ESS[3][4] controls since 2014, our in-kind and collaborative work with ESS has provided us with new technology knowledge and helped our EPICS platform evolve. We have used the ESS IOxOS VME64X platform for the control of the ESS source at Catania and several ESS test stands at Saclay[5]. This gives us entire satisfaction. Therefore we are giving up the VME/ADAS platform used for Spiral2 and IFMIF/LIPAc for new projects. The IOxOS VME and MTCA solutions offer several seductive assets, the details of which will be provided further on in this paper. The evolution in the PLC domain will also be presented.

CEA is committed to delivering a Medium Energy Beam Transfer line (MEBT) and a Superconducting Linac (SCL) equipped with beam diagnostics (DIA) for supplementing the SARAF Linac accelerator in order to accelerate a 5 mA beam of protons from 1.3 MeV to 35 MeV or deuterons from 2.6 MeV to 40 MeV at the frequency of 176 MHz. CEA is in charge of SARAF-LINAC studies, constructions, tests, installation and commissioning. The new hardware and software platforms are used for the test stands and will be used for the MEBT and SCL controls.

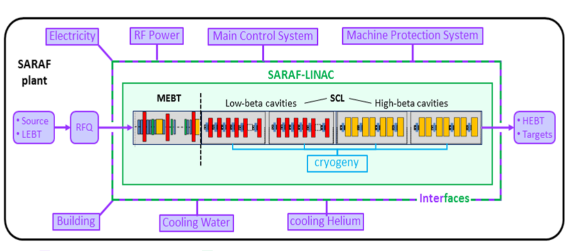

Figure 1: SARAF Linac schematic view.

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HARDWARE SOLUTIONS

EPICS Based Hardware

MEBT and SCL controls need fast and semi-fast acquisitions for beam diagnostics and RF signals acquisition. These 2 sets of sampling frequency are needed. The semi-fast sampling frequency is considered from 50KS/s up to 5 MS/s. The fast and semi-fast acquisitions are based on VME64X respectively with the FMC (FPGA Mezzanine Card) boards IOxOS ADC_3110/3111 and ADC_3117.

The CPU IFC_1210, currently used, Freescale PowerPC P2020 based intelligent FPGA controller, will be replaced by the more perennial CPU IFC_1211 that is becoming our standard CPU from late 2017. The IFC_1211 board will be tested on the SARAF test stands in the coming months.

Regarding the IFC_1211 key components, the lifetime is in the order of 15 years.

Long term availability is one of the main advantages of this board IFC_1211 and also the following improvements over the IFC_1210:

- T2081 processor up to 1.8 GHz featuring hardware FPU based on AltiVec for high demanding applications.
- Latest Xilinx FPGA generation (Artix-7 and Kintex UltraScale).
- PCI Express GEN3 direct connection between CPU and UltraScale device.
- FMC VITA57.1 multi-gigabit link up to 12.5 Gb/s with direct support of JESD204B interface.

Furthermore, the small European community of Laboratories using the CPUs of the IOxOS company is growing, which is a sound asset for the future.

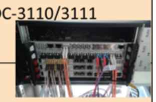
Requirements	Sampling/monitoring frequency range	COTS solutions
Fast acquisition	1 MS/s up to 250 MS/s	**VME64X & IOxOS CPU 1210/1211** IOxOS FMC ADC-3110/3111 
Semi-fast acquisition	50 KS/s up to 2 MS/s	IOxOS FMC ADC-3117
Remote I/Os control LAN or serial	100 ms up to 1s	Kontron Industrial PC  EtherCAT Beckhoff(Modbus/Tcp)
Process for vacuum and cryogenics & Remote I/Os & Interlock	100 ms up to 1s	Siemens PLC 1500 & I/O boards/  Fieldbus Profinet & remote I/Os

Figure 2: Choice of solutions.

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SLAC LCLS-II INJECTOR SOURCE CONTROLS AND EARLY INJECTOR COMMISSIONING*

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Abstract
LCLS-II is a superconducting upgrade to the existing Linear Coherent Light Source at SLAC with a continuous wave beam rate of up to 1 MHz. Construction is underway with first light planned for 2020. The LCLS-II Injector source is based on the LBNL Advanced Photo-Injector Experiment (APEX), and is being provided by LBNL. In 2015, responsibility for controls design and fabrication was transferred to SLAC from LBNL to promote commonality with the rest of the LCLS-II controls subsystems. Collaboration between the LBNL APEX community and SLAC LCSL-II EPICS controls teams proved vital in advancing the controls architecture toward standardized implementations integrated with the rest of LCLS-II. An added challenge was a decision to commission the injector in January 2018, approximately 1.5 years ahead of the rest of the machine. This early injector commissioning (EIC) is embraced as an opportunity to gain valuable experience with the majority of the LCLS-II controls, especially the 1MHz high performance subsystems (HPS), prior to LCLS-II first light, planned for August 2020. This paper discusses the LCLS-II GUNB Injector Source along with the early injector commissioning controls scope, approach, and advantages.

LCLS-II GUNB INJECTOR SOURCE

The SLAC LCLS-II injector section that comprises low energy (<1 MeV) from the gun up to the location of the first cryomodule is based on a subset of the LBNL Advanced Photo-Injector Experiment (APEX). The LBNL controls and LLRF systems for APEX were designed as stand-alone systems since APEX is intended to be a demonstration injector with no future connection to a larger accelerator system.

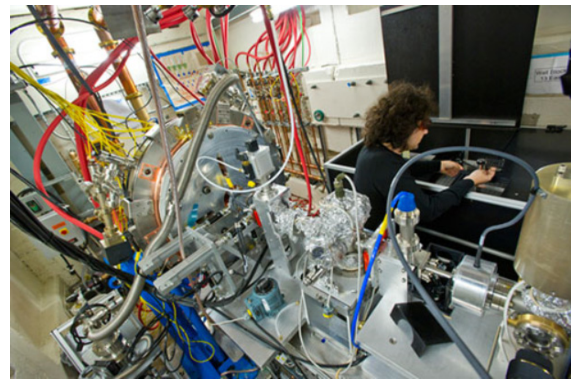

Figure 1: APEX “prototype” at LBNL.

LBNL is responsible for the Injector Source mechanical design, procurement, construction and commissioning support. LBNL has taken advantage of various performance and operational lessons learned from APEX in order to improve the design for use in LCLS-II. SLAC scope for the Injector Source includes the controls specification, procurement, and fabrication for the electronics plus associated control software, and will lead commissioning efforts.

The LCLS-II Injector Source, also known as GUNB, shown in Figure 2, includes the normal-conducting VHF RF gun, the buncher, the cathode vacuum load lock, the low energy beam line, including beam line components, and the VHF gun RF power supply and transmission lines.

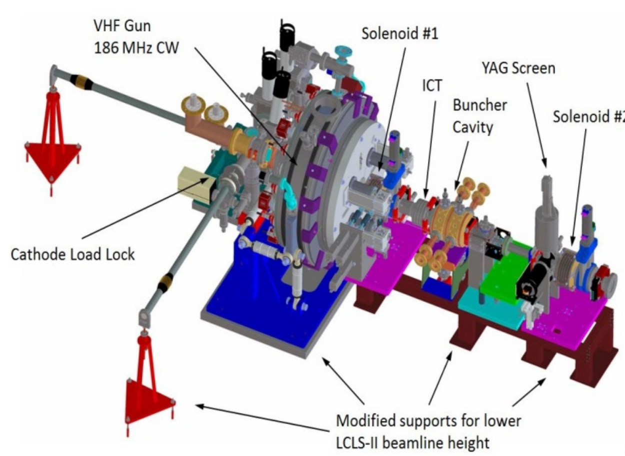

Figure 2: LCLS-II Injector Source.

In order to transfer GUNB controls from the responsibility of LBNL to SLAC, engagement between the two laboratories was essential. A web-based Smartsheet was shared between the two laboratories, which contains GUNB control element’s Z-position, description, major

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INSTALLATION AND HARDWARE COMMISSIONING OF THE EUROPEAN XFEL UNDULATOR SYSTEMS

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Abstract

This article describes in detail the steps of hardware installation and commissioning of components for undulator systems at European XFEL. In general, the work can be divided into 3 different steps: installation, alignment, and commissioning. During installation step, the following main components were rolled into the tunnel: - undulators with the control cabinets, intersection control cabinets, phase shifters, quadrupole movers, correction coils. They have been mounted according to the designed positions. Then all mentioned components have been aligned according to the specifications. Finally, the cabling has been done and basic tests were performed. As part of the commissioning, the calibration of the temperature sensors, as well as the measurements of the quadrupole mover travel distance has been done in the tunnel. Afterwards, the undulator limit switches and hard stops were adjusted to secure the vacuum chamber by closing the undulator gap up to 10mm. Eventually, the system was handed over to the global control system in order to perform all functional tests. The main focus is given to the components which are controlled or monitored by the undulator local control system [1].

INTRODUCTION

The European X-ray Free-Electron Laser (XFEL) will be operated by using tree undulator systems based in total on 91 variable gap undulators. The SASE1 system is commissioned, it is in operation and delivering the photon beam to the experimental hall with the following parameters: 300muJ, 9.3keV up to 30 bunches, for the FXE (Femtosecond X-Ray Experiments) and the SPB/SFX (Single Particles, Clusters, and Biomolecules and Serial Femtosecond Crystallography) instruments. The first lasing has been achieved in May 2017. The SASE3 undulator system is commissioned and ready for the operation which will start in October 2017. The last SASE2 system is currently installed in the tunnel and will be commissioned by the end of the year 2017. All three systems are designed in the same fashion, and installation sequence of actions is identical for all three undulator systems: SASE1 (Self-Amplified Spontaneous Emission), SASE2 and SASE3. The description of SASE1 system is presented.

INSTALLATION ACTIVITIES

Before being installed in the tunnel all hardware components have been commissioned and validated in the laboratory by performing the number of tests. The SASE1 undulator system contains of 37 sections, so called cells. Each typical cell includes an undulator and an intersection. Only first two cells are not equipped with the undulators. This scheme has been realized for the future evolution of the SASE system by implementing the self-seeding feature. Each intersection is including a number of hardware components: vacuum chamber absorber, beam position monitor, beam loss monitor, quadrupole lens installed on the quadrupole mover and phase shifter. The phase shifter and quadrupole mover are part of the undulator local control system.

After equipping the tunnel with all necessary basic infrastructure such as light, power lines, water supply pipes, main air flow system and reaching the acceptable temperature and humidity conditions, undulator control racks (UCR), intersection control racks (ICR), intersection control nodes (ICN), and media convertor racks (MCR) have been installed. All mentioned racks are the parts of the undulator control system, which is based on the real time Beckhoff automation technology. The PLC program is implemented in the TwinCAT system [2] and running on the Industrial PC (IPC's) installed in the UCR's. The undulator cell is shown in Figure 1.

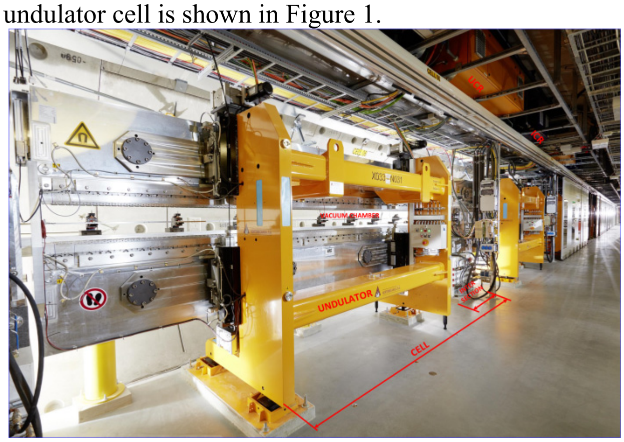

Figure 1: The view of SASE1 cell, equipped with the undulator system components: vacuum chamber, undulator, intersection, UCR and ICR.

As a part of the water supply system the 3-way valves which are modulating control valves with magnetic actuators (Siemens MXG461B) have been installed on each cell, for the vacuum chamber temperature stabilization system.

Vacuum Chamber Temperature Stabilization System and Two Wire Correction System

The temperature of the vacuum chamber in the undulator gap needs to be identical to the temperature of the magnetic structure to avoid the girder deformation due to the transverse heat flux, which occurs if the vacuum chamber is at a different temperature than the magnet girder. This is done with a vacuum chamber water cooling system. For efficient operation of the water cooling sys-

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INTEGRATION CHALLENGES AND SOLUTIONS FOR LOW LEVEL CONTROLS SYSTEMS AT THE FRIB*

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Abstract

The FRIB, is a new heavy ion accelerator facility currently under construction at Michigan State University. It is being built to provide intense beams of rare isotopes. The low level controls system integrates a wide variety of hardware into an EPICS/PLC based control system. This paper will present the challenges encountered with resulting hardware interfaces, and lessons learned that can be applied to future projects. These challenges include both technical design and project management challenges that are encountered when integrating hardware from other departments.

INTRODUCTION

FRIB is designed to accelerate all the stable isotopes from hydrogen through uranium to energies greater than 200 MeV/u with beam power up to 400 kW. It is comprised of two ion sources, an RFQ, 46 superconducting RF (SRF) cryomodules comprising the accelerator portion of the machine, a cryoplant, a target facility utilizing superconducting magnets, and will connect into the existing National Superconducting Cyclotron experimental beamlines, (see Fig. 1). This new higher power accelerator has presented a number of new control challenges over the existing cyclotron systems and experiences; a few of those are documented here.

CONTROL PROCESS IMPROVEMENTS

The FRIB Cryoplant Control System

The FRIB cryoplant presents special challenges and constraints on the control system due to its nature as a continuous process plant providing a vital utility to the accelerator. The cryoplant control system must be designed to have the maximum possible uptime due to the fact that the helium inventory must be maintained even when the accelerator is off. The cryoplant controls are largely analog in nature and are comprised of a complex series of feedback loops for temperature and pressure regulations, as well as control of rotating machines such as screw compressors and turbo expanders.

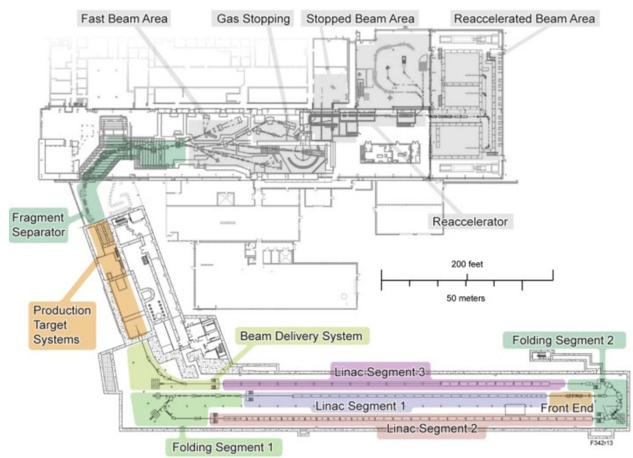

Figure 1: Schematic layout of the FRIB (colored areas) and existing infrastructure (gray).

The Cryoplant is controlled entirely by Allen Bradley ControlLogix PLCs utilizing the enhanced PID (PIDE) version of the ControlLogix PID instruction. This system utilizes the velocity form of the PID control equation with independent gains and many tuneable parameters.

The control algorithm of the PIDE instruction operates on percent error rather than absolute error providing a couple of benefits. Process values may be chosen with a wide variety of ranges during runtime. Gains are always applied against a known scaling (0 to 100% input) so the

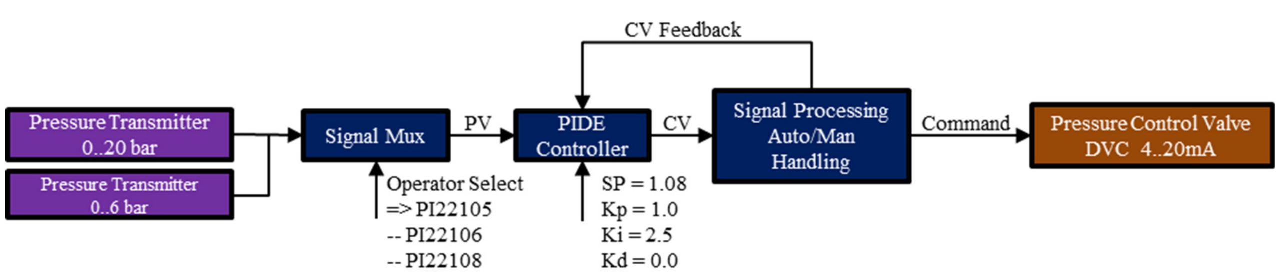

Figure 2: Example PIDE implementation for FRIB cryoplant.

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A HOMOGENOUS APPROACH TO CERN/VENDOR COLLABORATION PROJECTS FOR BUILDING OPC-UA SERVERS

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Abstract

Industrial power supplies deliver high and low voltage to a wide range of CERN's detector and accelerator components. These power supplies, sourced from external companies, are integrated into control systems via industry standard OPC servers. The servers are now being modernized. A key lesson learnt from running the previous generation of OPC servers is that vendor specific, black-box implementations can be costly in terms of support effort, particularly in diagnosing problems in large production-site deployments. This paper presents the projects producing the next generation of OPC servers; following an open, collaborative approach and a high degree of homogenization across the independent partners. The goal is to streamline development and support costs via code re-use and a template architecture. The collaborations aim to optimally combine CERN's OPC and production operations knowledge with each company's experience in integrating their hardware. This paper describes the considerations and constraints taken into account, including legal aspects, product commercialization and technical requirements to define a common collaborative approach across three hardware manufacturers.

PROJECT OUTLINE

The accelerator chain and experiments at CERN require a feed of consistent, stable and controllable high and low voltage. Where applicable, this requirement has been satisfied, by purchasing industrial power supply units from commercial companies. CERN has an incumbent investment of tens of millions of Swiss francs in a range of equipment from three Member States vendors: CAEN, ISEG and Wiener (ordered alphabetically). Each company designs, builds, sells and maintains their own models of industrial power supplies. This inhomogeneous mix of hardware is currently integrated in to CERN control systems via a middleware layer based on the industry standard OPC-DA [1] (DA stands for Data Access) protocol.

Due to obsolescence of the OPC-DA protocol (also latterly known as OPC Classic), this middleware layer is undergoing a significant migration, fromthe old COM based, MS Windows only, OPC-DA standard to the modern, platform agnostic OPC-UA [2] (UA stands for Unified Architecture) standard.

This paper outlines the process of collaborating with these three independent commercial suppliers, with assistance from CERN's Knowledge Transfer group (henceforth KT), to ensure that:

- Post-migration, the equipment installations at CERN continue to fulfil the required function in the laboratory.
- Opportunities for increasing homogeneity in the middleware integration software components and the procedures by which they are built are identified and acted upon.
- Maximum benefit is taken from the collective expertise of both CERN and the hardware providers: from CERN's side this includes experience of operational requirements, standards support and software engineering; from the commercial partners' sides this includes deep knowledge of their hardware and firmware and their systems integration experience.

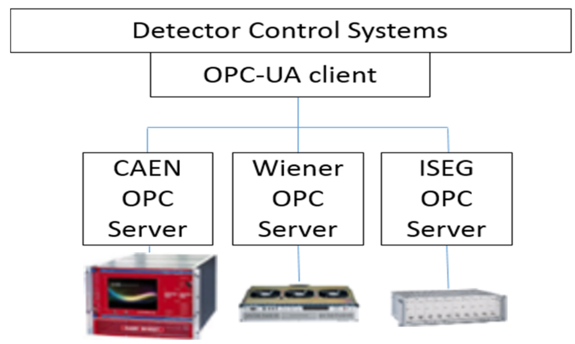

Figure 1: Hardware Controlled via OPC Middleware.

OPC-DA SERVER OPERATION: LESSONS LEARNED

Despite the similarity in names, OPC-UA is a fundamentally different protocol [3] from OPC-DA. This modernisation, moving from OPC-DA to OPC-UA, requires a complete rewrite of the OPC layer. This presents an opportunity to reflect on the development process and past 10 years of operation with the incumbent OPC-DA servers and apply the lessons learned to improving the development and operation of the forthcoming OPC-UA servers.

The development model followed previously for OPC-DA was for CERN to provide a requirements specification to each vendor who autonomously implemented and delivered a complete OPC-DA server component. Although this approach had the desired effect of incorporating expert hardware knowledge into the development process, it had the consequence of delivering three very different software components to CERN's control system chains, each component exposing its own unique behaviour for end-user installation, configuration and runtime operation. This inhomogeneity proved a costly model in terms of support.

An additional consequence of this approach was that each company delivered, initially anyway, black-box components whereby CERN had no access to the internal implementation code. In general, the CERN production environments contain large numbers of devices and, during data taking operations, these devices must all be controlled

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UPGRADE THE CONTROL SYSTEM OF HIRFL-CSR BASED-ON EPICS

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Abstract

Control system of HIRFL-CSR accelerator is now upgrading to new architecture based on Experimental Physics and Industrial Control System (EPICS). Design and implement power supply subsystem, data distribution subsystem, data acquisition subsystem, etc. This paper describes the design and implementation of the control system and introduce the next work for upgrading synchronization subsystem and middle/high level applications.

INTRODUCTION

The Cooler-Storage-Ring (CSR) is the post-acceleration system of the Heavy Ion Research Facility in Lanzhou (HIRFL) [1]. The HIRFL-CSR consists of two cooler-storage-ring, heavy ions will be accumulated and accelerated in main cooler-storage-ring (CSRm) and extracted to experimental ring (CSRe) or other target experiments [2]. The control system of HIRFL-CSR consists of many sub systems such as power supply control system, timing system, Low Level RF system, beam monitor system and so on. The structure of original HIRFL-CSR control system is shown in Figure 1.

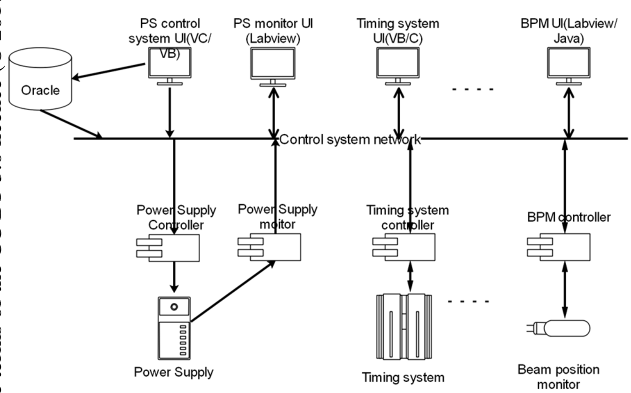

Figure 1: Structure of original HIRFL-CSR control system.

The original structure was not build on a uniform standard and created by different development tools. So, the different subsystem cannot communicate with each other, and very difficult to maintain. Also, developers who belong to different subsystems could not collaborate to build the whole control system.

EPICS is a set of Open Source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as a particle accelerators, telescopes and other large scientific experiments [3]. EPICS defined a standard interface (Channel Access) for different subsystem and different hardware.

DESCRIPTIONS

This part wills description the structure of the new control system, also description a new modular development platform. Descriptions include two sections and each section is introduced in detail as following. The structure of the new control system is shown in Figure 2.

Structure of the New Control System

Upgrading the control system of HIRFL-CSR based-on EPICS since 2016. Redesign the whole structure of control system and implement kinds of Input Output Controllers (IOC) for the power supply subsystem, timing subsystem, database subsystem, beam monitor subsystem etc. Most of the IOC running on the CentOS at 1U industry PC via the Ethernet, serial port or PXIe interface. There is also small part of IOC running on the embedded Linux (FPGA SOC) and Windows.

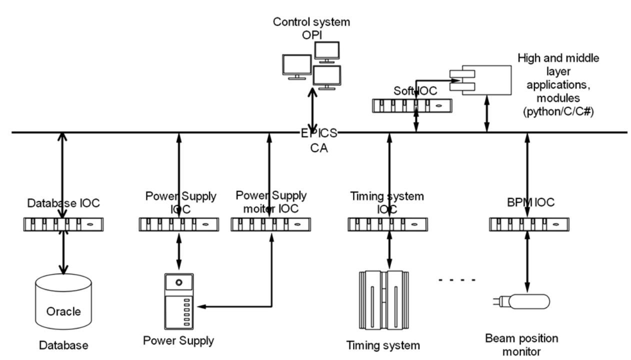

Figure 2: Structure of the new control system.

On the top level, use Control System Studio (CSS) [4] to implement Operator Interface (OPI) of the whole control system. The unified interface become more productivity and easier to use for the operator of accelerator. Figure 3 shows a screenshot of the OPI.

Up to now, there are over 1000 PVs running on the HIRFL-CSR (CSRm and CSRe). The main part of the new control system has been finished.

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UPGRADE OF VACUUM CONTROL SYSTEM FOR KOMAC LINAC AND BEAMLINES

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Abstract

At Korea Multi-purpose Accelerator Complex (KOMAC), we have been operating a proton linac since 2013 [1]. It consists of a 100 MeV accelerator and 5 operational target rooms. Beam operation at KOMAC is carried out by a home-grown control system with a machine protection system which affects the accelerator the least when the machine suddenly fails. Our work is mainly concentrated on interlock sequence of vacuum related equipments based on a programmable logic controller (PCL). PCLs monitor vacuum status and control vacuum pumps and gate valves. By applying interlock sequence to PCLs connected to the vacuum equipments, we close gate valves to isolate a failed part so the the rest of the accelerator remains under vacuum, and safely shut down the vacuum pumps. Then the MPS receives a signal to safely stop the beam operation to protect the accelerator. We describe in this paper architecture of our PLC on interlock sequence of vacuum related equipment and its implementation.

INTRODUCTION

A 100 MeV accelerator comprises of an ion source, a radio-frequency quadrupole (RFQ) and 11 drift tube linacs (DTLs). We have beam lines to transport proton beam from the accelerator to 5 target rooms. The entire accelerator and beam lines are under vacuum and it is important to keept a certain appropriate vacuum level for a reliable beam operation. For this, we chose Programmable Logic Controllers (PLCs) and EPICS Input and Output Controller (IOC) for reliability of the vacuum system [2].

As we have been constructing additional beam lines and target rooms to..., correspondingly increasing vacuum system and related control system need to be installed, and to be linked.... We have designed an architecture for the required vacuum control system and implemented it for all the beam lines and operational target rooms. In this paper, we present upgradation of our vacuum control system for a safe operation of our 100 MeV proton accelerator at KOMAC.

VACUUM CONTROL SYSTEM

KOMAC Control System

KOMAC has developed EPICS based control system for a 100 MeV proton linac. The control system is largely divided into three types: DLINAC Control system to control and to monitor linac state; Timing system for synchronizing all devices; and Data Management system for archiving and analysing acquired data. Following Figure 1 shows the block diagram of KOMAC control system.

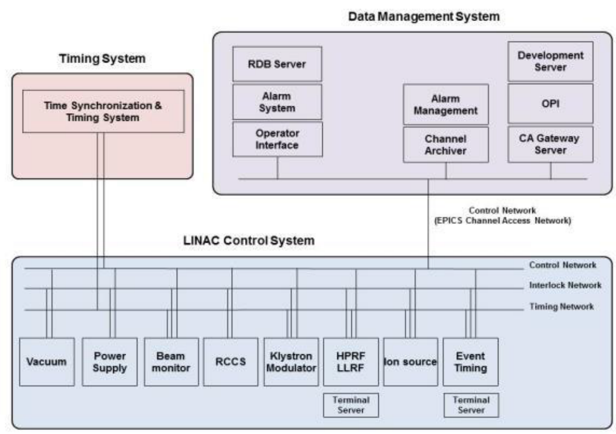

Figure 1: Block diagram of KOMAC control system.

Vacuum System

The vacuum system comprises scroll pumps, turbo-molecular pumps, ion pumps, gate valves and vacuum gauges. Figure 2 shows the vacuum system for a KOMAC 100 MeV linac.

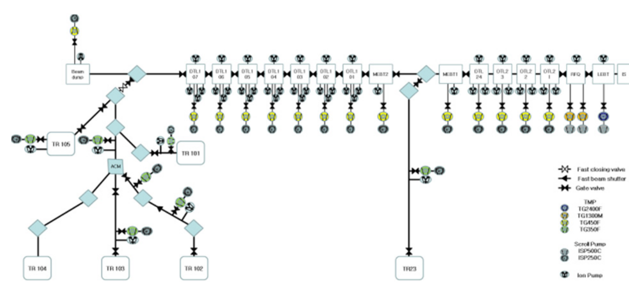

Figure 2: Block diagram of KOMAC vacuum system.

PLCs and Controllers for control those components are installed on the second floor named Klystron gallery. Allen-Bradely ContorlLogix PLC is adopted for KOMAC vacuum system. PLCs control and monitor scroll pumps and gate valves. There are two EPICS IOC for vacuum control system; an EPICS IOC for controlling or monitoring PLC using EPICS Ether/IP modules the other EPICS IOC for vacuum gauge controllers and TMP controllers using EPICS ASYN module and STREAM module. Sequencer driver is used to prevent entering undesired state and send interlock signals and alarm to other subsystems via Channel Access (CA) protocol.

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CONTROL SYSTEM PROJECTS AT THE ELECTRON STORAGE RING DELTA

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Abstract

Data logging and archiving is an important task to identify and investigate malfunctions during storage ring operation. In order to enable a high-performance fault analysis, large amounts of data must be processed effectively. For this purpose a fundamental redesign of the present SQL database was necessary.

The VME/VxWorks-driven CAN bus has been used for many years as the main field bus of the DELTA control system. Unfortunately, the corresponding CAN bus I/O-modules were discontinued by the manufacturer. Thus, the CAN field bus is currently being replaced gradually by a more up-to-date Modbus/TCP-IP communication (WAGO), which largely supersedes the VME/VxWorks layer. After hard- and software integration into the EPICS environment, several projects have been realized using this powerful field bus communication.

The server migration to a 64-bit architecture was already carried out in the past. By now, all client programs and software tools have also been converted to 64-bit versions.

In addition, the fast orbit feedback system project, using a in-house FPGA-based hardware, has been resumed.

This report provides an overview of the developments and results of each project.

INTRODUCTION

DELTA is a 1.5-GeV electron storage ring operated as a synchrotron light source by the TU Dortmund University [1]. Since 2011, a short-pulse facility for coherent sub-picosecond light pulses in the vacuum-ultraviolet (VUV) and Terahertz (THz) regimes has been established [2], [3]. In order to reach shorter wavelengths, an upgrade applying the so-called echo-enabled harmonic generation (EEHG) scheme is under preparation [4], [5]. Further upcoming upgrades like the installation of a new superconducting wiggler magnet (SCW) as well as the associated expansion of the storage ring RF-System (integration of a EU-type-cavity [6]) increase the need for a number of control system hardware and software innovations.

REDESIGN OF THE EPICS-LOG DATABASE

All important actual machine data is stored in EPICS records, collected by a logger daemon (linux systemd service) and archived in the open-source object-relational database management system (ORDBMS) PostgreSQL [7].

Usually, typical data logging tables become quite extensive over time, compared to the working memory (RAM) of DB servers. To improve query performance in such large tables the basic table partitioning functionality of PostgreSQL is used [8]. Partitioning refers to splitting what is logically one large table into smaller physical pieces. PostgreSQL supports partitioning via table inheritance (see Fig. 1).

For each month (*mXX*) of yearly (*yXXXX*) logged data, there is a separate data table (*log_yXXXX_mXX*) that inherits from the base table *log* (see Fig. 1, blue arrows). A *sql-SELECT* command on the base table automatically accesses all the monthly tables. Only the tables that are in the time slot of the *sql-WHERE* condition are searched which significantly accelerates data access.

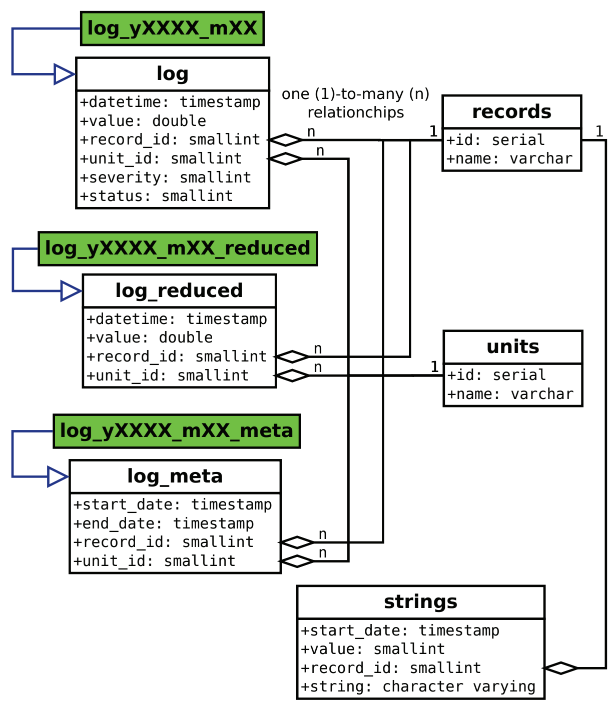

Figure 1: Epics-Log DB inheritance scheme (class diagram in UML notation [9]).

In the intermediate tables *log_yXXXX_mXX_reduced* (green), which inherit from *log_reduced*, the values of the records of the associated monthly table are averaged over one minute intervals. This is useful for evaluating larger time periods. In the intermediate tables which inherit from table *log_meta*, the time intervals of the associated monthly table are stored in which a record has a specific unit (e.g. mm, mA, V, etc.). The *strings* table stores the mapping of ENUM values to record values for individual EPICS records

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EVOLUTION IN THE DEVELOPMENT OF THE ITALIAN SINGLE-DISH CONTROL SYSTEM (DISCOS)

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Abstract

DISCOS [1] is a control system developed by the Italian National Institute for Astrophysics (INAF) and currently in use at three radio telescope facilities of Medicina, Noto and the Sardinia Radio Telescope (SRT) [2]. DISCOS development is based on the adoption of the ALMA Common Software (ACS) [3] framework. During the last two years, besides assisting the astronomical commissioning of the newly-built SRT and enabling its early science program, the control system has undergone some major upgrades. The long-awaited transition to a recent ACS version was performed, migrating the whole code base to 64 bit operative system and compilers, addressing the obsolescence problem that was causing a major technical debt to the project. This opportunity allowed us to perform some refactoring, in order to implement improved logging and resource management. During this transition the code management platform was migrated to a git-based versioning system and the continuous integration platform was modified to accommodate these changes. Further upgrades included the system completion at Noto and the expansion to handle new digital backends.

INTRODUCTION

The SRT just went through 5 months of no-operations during which a complete refurbishment of the Active Surface System (SSA), including the repainting of primary mirror panels, was completed. In parallel the Data Center (included the control system workstations) has been moved from the original location to a shielded room. Exploiting this idle period the DISCOS staff, working at the SRT, heavily focused on the porting of our codebase to a newer ACS version and to put in place an even better automatic provisioning system in order to improve the quality of our testing process and the stability of our products. Similarly, in the pursuit of creating a good testing environment, some simulators of the telescope devices have been developed: currently the Active Surface, the Antenna Control Unit and Minor Servo System Unit can be simulated and the core of the DISCOS control software tests can be executed without accessing the telescope's hardware. This idle period was also exploited by the project's staff to update the production system on Medicina and Noto telescopes.

In the following chapters the major activities and areas of upgrade related to the DISCOS framework are described in greater detail. A whole chapter is dedicated to core upgrades in the control system. Another major activity has been the upgrade of the IT infrastructures supporting code development and code documentation. The two final chapters are dedicated to the description of how Medicina and Noto radio telescopes could benefit from the development done for the SRT and finally got upgraded version of the control system installed on site, enabling better performance and further capabilities.

DISCOS

The control system has gone through some maintenance and some major upgrades in this period of time.

Upgrade of ACS Version

As the previous development of DISCOS was based on a legacy version of the Alma Common Software framework this was causing major issues, mainly regarding the obsolescence of the whole system. Being tied to an old product not only means being unable to incorporate new ACS features and fixes, but the consequences are spread all over the control environment: the main one being the inability to upgrade operative systems to recent versions and the consequent maintenance of old products.

This was causing security issues and was also slowing doen the adoption of modern libraries and tools in the development of all the accessory software outside of the control system.

The main issues encountered in the porting activity are related to the different version of C++ compiler, c libraries and external libraries such as boost. Several unresolved symbol in the linking phase required to be addressed to the point that our make files are now completed changed. On the IDL side, we encountered some naming clash between types defined in our code base and types defined in the new versions of the language, but this required minor changes.

We were expecting troubles related to the migration to a 64 bit architecture, but none of those emerged so far.

Refactoring

The upgrade to a modern OS and the related activity was the first step for a full review of the code base. A large portion of the code based in fact was not exploiting recent additions made to the control system libraries for the standardization of logging behaviours and internal resource handling. This is being incorporated as part of the porting activity and is reducing the percentage of duplicated code, easing future maintenance.

As code is being ported to the new platform, and thus completely reviewed just to eliminate compile warnings

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THE UNICOS-CPC VACUUM CONTROLS PACKAGE

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Abstract

The vacuum control of the Large Hadron Collider and its injectors is based on PLC and SCADA off-the-shelf components. Since late '90s, CERN's vacuum group has developed a dedicated control framework to drive, monitor and log the more than 10 000 vacuum instruments. Also, in 1998, CERN's industrial controls group developed the UNICOS framework (UNified Industrial Control System), becoming a de facto standard of industrial control systems and gradually deployed in different domains at CERN (e.g. Cryogenics, HVAC...). After an initial prototype applying the UNICOS-CPC (Continuous Process Control) framework to the controls of some vacuum installations, both teams have been working on the development of vacuum-specific objects and their integration, together with new features, into the UNICOS framework. Such convergence will allow this generic framework to better fit the vacuum systems, while offering the advantages of using a widespread and well-supported framework. This paper reports on the experience acquired in the development and deployment of vacuum specific objects in running installations, as a prototype for the vacuum controls convergence with UNICOS.

INTRODUCTION

At CERN, the European Organization for Nuclear Research, industrial control systems have been developed and deployed to operate accelerator systems such as cryogenics, gas flows, vacuum… Most of these control systems have the same type of top level architecture based on Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA), i.e. WinCC-OA™ application.

The cryogenics control team developed a software framework (first version of UNICOS framework) based on generic I/O field objects [1]. The vacuum control team developed a software framework dedicated to vacuum instruments [2]. The vacuum control framework is used in all the CERN accelerators except the ISOLDE complex. UNICOS is not only used in cryogenics but also for the control system of LHC Collimators interlocks, Cooling&Ventilation, Experiments gas flows, Detector cooling… UNICOS has become the CERN standard framework for industrial controls.

In 2011, the vacuum control system in ISOLDE had been completely refurbished [3]. The old control system was not using the vacuum framework and was totally outdated. For this renovation, it was decided to use UNICOS-CPC framework [1] and not the vacuum framework. Later, was raised the question of migrating other vacuum installations to UNICOS. The advantages would be:

- standardisation of vacuum controls to CERN industrial controls. Also GSI institute is using UNICOS framework for the vacuum control of the FAIR facility.
- global reduction of effort for maintaining code.
- central Support from the CERN industrial controls.

These are major advantages but on the other hand the vacuum framework already offers a high level of process control, supervision and diagnostics:

- PLC code is dedicated to vacuum instruments, simple and much optimized (a small PLC can control a large number of instruments).
- Supervisory application has dedicated widgets for vacuum instruments and a large number of user friendly features.
- SCADA instance data files and PLC instance data blocks are generated from a vacuum ORACLE database. The database has high level of interaction with CERN layout database and asset management database.

The migration of vacuum control system to UNICOS must be very smooth to vacuum control users and shall not depreciate any functionalities offered by the current vacuum framework.

At the end of 2016, the vacuum control team, in collaboration with UNICOS team, has started to develop a set of new UNICOS components, dedicated to vacuum application called “unVacuum”. The goal of this package is to preserve the level of services from vacuum framework to UNICOS framework. The unVacuum package focus on CPC objects development and SCADA features.

VACUUM CPC OBJECTS

Why Do Vacuum Applications Require Specific Objects?

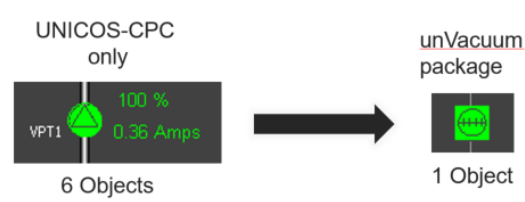

Figure 1: Turbomolecular pump widget without and with the vacuum package.

UNICOS-CPC framework is very flexible because it manages I/O generic field objects. These objects combined together are able to control most of the instruments

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UPGRADE OF CONTROL SYSTEM OF ALBA MAIN BOOSTER POWER SUPPLIES

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Abstract

This article introduce a project for upgrading the control system of the main booster power supplies of ALBA synchrotron. A brief description of the booster power supplies and the motivation for this upgrade is given. The several options for the upgrade that are being evaluated are discussed. Different possible architectures are also presented. Finally, conclusions about how to face this kind of project are given.

INTRODUCTION

ALBA is a 3 GeV third generation synchrotron light source operating with users since 2012. The injection system is composed of a 100 MeV Linac as pre-injector followed by a full energy booster synchrotron. The booster requires AC power converters (PC) operating at 3.125 Hz with a sinusoidal-like current waveform.

Main Booster Power Supplies

The Main booster power supplies are power supplies that feed the main magnets of the booster accelerator. The main magnets perform the tasks of bending and focusing the electron beam in the booster accelerator. The correction magnets are excluded from this group. Five different groups of magnets are supplied by the main booster power supplies. One group is formed by the bending magnets and the other four group are formed by quadrupole magnets [1]. All the magnets within a group are in series connection. Some of the specification and loads of the main booster power supplies are summarized in Table 1.

Table 1: Summary of Main Booster Power Supplies Specifications and Loads

PS type	**Bend**	**QS180**	**QS340**	**QC340**
# ps	2	2	1	1
I_{peak} $[A]$	750	180	180	180
V_{peak} $[V]$	1000	120	200	750
R_{Load} $[m\Omega]$	710	440	610	2360
L_{Load} $[mHy]$	200	27.2	48	216
Resolution $[ppm]$	5	5	5	5
Stability $[ppm]$	15	15	15	15
Reproducibility $[ppm]$	50	50	50	50

UPGRADE MOTIVATION

The main reason for the upgrade of the control system for the main booster power supplies is the obsolescence of some components. This makes very expensive the maintenance of them. The control system is a full-custom development from a specific manufacturer and is not longer used for new developments.

Other reason for the upgrade is the lack of flexibility to implement new features in the present control systems. After some year of operation, there are new requirements to the main booster power supplies. This new requirements cannot be satisfied by the present control system. The new requirements are related to the increment of the reliability of the power supplies and with the ramp to ramp repeatability of the output current.

SYSTEM DESCRIPTION

A brief description of the control system is given in this section. Firstly a description of the power supply control key features is given. Then, some of the new requested features of the new control system are listed.

Key Features

Ramping Main Booster power supplies work in what is called ramping mode. The output current of the power supplies is a raised co-sinusoidal waveform which follow the energy increment of the electrons in the booster accelerator.

Tracking Between Power Supplies The tracking between different power supplies is the ratio between the difference on the output currents and the value of one output.

$$NTE = \frac{I_{ps_1}(t) - I_{ps_2}(t)}{I_{ps_1}(t)} \quad (1)$$

When the tracking is between power supplies with different output peak values, the tracking error is defined as:

$$NTE = \frac{I_{ps_1}(t) - K \quad I_{ps_2}(t)}{I_{ps_1}(t)} \quad (2)$$

Figure 1: Main Booster Power Supplies during commissioning

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CONTROL SYSTEM EVOLUTION ON THE ISIS SPALLATION NEUTRON SOURCE

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Abstract

The ISIS spallation neutron source has been a production facility for over 30 years, with a second target station commissioned in 2008. Over that time, the control system has had to incorporate several generations of computer and embedded systems, and interface with an increasingly diverse range of equipment. We discuss some of the challenges involved in maintaining and developing such a long lifetime facility.

ORIGINAL DESIGN

The original control system for ISIS was based on GEC 4000 series minicomputers. Hardware interfacing was via CAMAC controller, branching out to a General Purpose MPX system (as used on the CERN SPS). Software was developed using a high level assembly language called BABBAGE as a systems language, and an interpreted language called GRACES for user programs. As at CERN, touch screen displays were used to provide menu driven systems.

TRANSITION TO VSYSTEM

By the early 1990's, it became clear that the existing control system had to be replaced. Vista Control Systems product Vsystem[1], which grew out of work at Los Alamos National Laboratory, was chosen as the replacement system. By that time, ISIS was well established as a production neutron facility, which severely restricted the downtime available to progress the migration. A new system would thus have to run in parallel for some time.

The ability of CAMAC to support multiple controllers was extremely useful in that it provided a means for Vsystem to have direct access to all the existing MPX hardware. Hytec ECC 1365 controllers were installed to allow Vsystem to access the CAMAC over the growing Ethernet network.

C was used as a low level language, replacing BABBAGE. BASIC was chosen as a simple language to port user's GRACES programs to. A simple menu toolkit was developed to map the old touchscreen interface, and also a graphics toolkit emulating the limited graphics previously available.

The two systems ran in parallel for several years, as the functions of the original GEC software were gradually migrated to Vsystem. The original touch screen based design still influences the navigation of the control screens, and the operation of some of the utilities.

FRONT END SYSTEMS – STEBUS

As the number of systems monitored increased, it became necessary to offload the interface work to more intelligent I/O processors. Initially these were based on the STEbus standard[2]. These included an Intel 80188 processor, an Ethernet card, and one or more I/O cards. The latter are a mix of commercial off-the-shelf cards (e.g. for GPIB and RS422 interfaces) and ISIS designed ones (e.g. timing and function generators).

The software on these systems is stored on an EPROM: device handlers for various hardware devices are built into the image. This allows them to encode and decode read/write operations as (for example) query strings to send over local bus connections such as RS422 or GPIB. A simple polling loop regularly reads and caches equipment values, and listens for read/write requests from the network.

An important feature of the design is that the software configuration is downloaded over the Ethernet at boot time. This means that the hardware is interchangeable: so, despite the local intelligence, any faulty component can be readily replaced.

FRONT END SYSTEMS - COMPACTPCI

STEbus systems proved to be a dependable workhorse throughout the 1990's, supplementing, and in some cases replacing, existing MPX equipment. After some investigation of alternatives, the decision was made to base the next generation front end system on CompactPCI hardware. Windows XP Embedded was used as the operating system.

Like the STEbus systems, their configuration is downloaded at boot time to keep the hardware as interchangeable as possible. The main boot image is also loaded over the network, which makes it easier to manage updates centrally.

Much of the design of the STEbus systems carried over to the CompactPCI systems, although there were some subtleties in the implementation of exactly what happened at initialization that were missed and had to be added later. The original STEbus design was also single threaded, with mainly synchronous I/O. With the speed of the newer hardware, it became clear that this design was a serious bottleneck when addressing multiple slow devices, and read parallelization had to be retrofitted onto the code.

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LCLS-II UNDULATOR MOTION CONTROL

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Abstract

At the heart of the LCLS-II are two undulator lines: the hard x-ray (HXR) line and the soft x-ray line (SXR). The SXR line is comprised of 21 variable gap undulator segments separated by an interspace stands with a cam positioning system capable of positioning in 5 degrees of freedom (DOF). The undulator segment motion control utilizes the Aerotech Ensemble motion controller through an EPICS Soft IOC (input-output controller). Its drive system consists of a Harmonic Drive servo system with feedback from two absolute full-gap encoders. Additional Aerotech motion controllers are used to control the cam-positioning system and phase shifters of the interspace stand. The HXR line is comprised of 32 undulator segments each including an integrated interspace assembly. The segment girder is placed on two stands with a similar cam-positioning system as in the SXR line allowing for movement in 5 DOF. As one of the design goals of the HXR line was to reuse the original LCLS girder positioning system, the motion control system is an upgraded version of that original system, using RTEMS on VME with Animatics SmartMotors.

OVERVIEW

This paper introduces the motion control design for the two LCLS-II undulator lines, the soft x-ray line (SXR) and the hard x-ray line (HXR). The motion control requirements of which are summarized in Table 1.

Table 1: LCLS-II Undulator Motion Control Requirements for both undulator lines.

Requirement	HXR	SXR	Unit
Minimum Undulator Gap	7.2	7.2	mm
Minimum Full Open Undulator Gap	120	200	mm
Taper Accuracy	±1.5	±2	µrad
Gap Repeatability	<1.5	<5	µm
Long term gap stability (24 hours)	±1	±1	µm
Maximum available full gap speed	1.0	1.0	mm/s

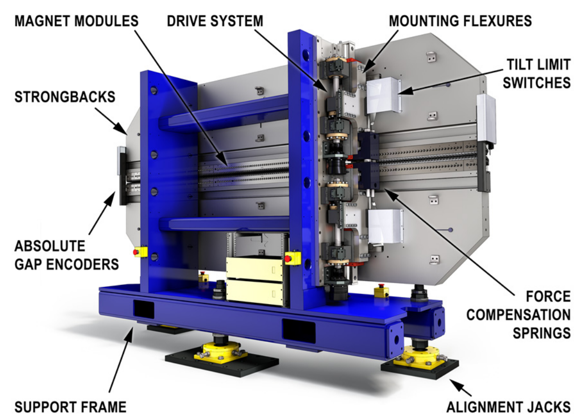

Figure 1: An LCLS-II Soft X-ray Undulator segment.

SXR LINE

The SXR line is comprised of 21 undulator segments separated by break sections, where each segment is a variable-gap permanent-magnet device with a minimum gap-height of 7.2 mm and a total segment length of 3.40 m [1, 2]. A single SXR undulator segment is shown in Figure 1. The gap drive system consists of four Harmonic Drive servo motors with feedback from internal rotary encoders and two full-gap encoders attached at each end of the undulator segment. Precise motion is achieved through the zero-backlash 51:1 strain wave gearing mechanism and is held in position with per-motor integrated brakes. Each break section in the SXR line consists of an interspace stand with a cam positioning system. Emergency stop circuits are intertwined between neighboring undulator sections and interspaces, such that the nearest emergency stop button can be used.

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LARGE-SCALE UPGRADE CAMPAIGNS OF SCADA SYSTEMS AT CERN - ORGANISATION, TOOLS AND LESSONS LEARNED

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Abstract

The paper describes planning and execution of large-scale maintenance campaigns of SCADA systems for CERN's accelerator and technical infrastructure. These activities, required to keep up with the pace of development of the controlled systems and rapid evolution of software, are constrained by many factors, such as availability for operation and planned interventions on equipment. Experience gathered throughout the past ten years of maintenance campaigns for the SCADA Applications Service at CERN, covering over 230 systems distributed across almost 120 servers, is presented. Further improvements for the procedures and tools are proposed to adapt to the increasing number of applications in the service and reduce maintenance effort and required downtime.

INTRODUCTION

SCADA systems today have to accommodate many requirements that transcend basic functionality expected from them ten years ago. Apart from providing a view on the state of the controlled plant and archiving values of acquired signals, SCADA applications are becoming increasingly connected to other enterprise software, including ERP (Enterprise Resource Planning) and MES (Manufacturing Execution System) solutions and data analytics tools. Those trends increase the frequency at which industrial supervision systems should be updated in order to remain secure and compatible with other software and technologies.

On the other hand, the effort of preparing an upgrade of a supervision application can be high due to required testing, incurred downtime and re-commissioning needed in some cases. Consequences of errors or introducing regressions during the intervention can also be very severe. Because of that, upgrades are often only performed when there is a problem with the SCADA system that poses an immediate risk for operation. This reactive approach is not feasible in case of larger systems, where upgrades require extensive planning and coordination between multiple teams and users need to be notified well before the planned interventions.

The SCADA Applications Service (SAS) is provided by the Industrial Controls and Safety systems group at CERN. It is responsible for managing the full lifetime of SCADA applications for many equipment domains at CERN. This includes systems critical for the CERN accelerator complex and experiments, like machine protection equipment, cryogenics, cooling and ventilation, vacuum and magnet control. All applications in the SAS are based on WinCC OA [1], which is the most widely used solution for building SCADA applications at CERN. The scale of the service and the variety of systems pose many challenges, on both technical and management levels, especially considering the modest size of the team responsible for it.

Keeping applications in the SAS up-to-date is critical for their reliability and interoperability with other systems at CERN. This includes not only the versions of WinCC OA and components developed on top of it, but also the operating system and other software. Due to the number of applications in the service, it is important to use only supported versions of the software and to keep them as uniform as possible to facilitate support. Complex dependencies need to be taken into account, as many applications in the service exchange data with other systems. All those factors result in scarcity of time windows for upgrades, further aggravated by the fact that some applications are most intensively used during technical stops of the accelerator complex. Moreover, for certain critical application no downtime is accepted, which requires significant changes to the baseline procedure and further increases the workload on the team performing the upgrade.

In this paper we present the methodology used to plan and execute upgrades of the SCADA applications in the SCADA Applications Service. We start by introducing the scope of the service, maintained application domains and some most important statistics. Key steps in the evolution of handling of upgrades are described, together with modifications used for critical applications. The paper is concluded with a discussion of limitations of the current solution and planned improvements for future upgrade campaigns.

SCADA APPLICATIONS SERVICE

In an environment with many supervision applications for different plants, yet based on the same SCADA solution, it is important to minimize the duplication of work across different teams, both in software development and operations and maintenance.

JCOP [2] and UNICOS [3] are two frameworks developed at CERN, which provide a common base for WinCC OA applications. JCOP is mainly a set of programming interfaces, meant to be used by software engineers and it is widely used at the LHC experiments. UNICOS makes use of some components from JCOP and enables control engineers to create supervision applications without writing any code.

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ROADMAP FOR SLAC EPICS-BASED SOFTWARE TOOLKIT FOR THE LCLS-I/II COMPLEX*

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Abstract

With the advent of LCLS-II, SLAC must effectively and collectively plan for operation of its premiere scientific production facility. LCLS-II presents unique new challenges for SLAC, with its electron beam rate of up to 1MHz, complex bunch patterns, and multiple beam destinations. These machine advancements, along with long-term goals for automated tuning, model dependent and independent analysis, and machine learning provide strong motivation to enhance the SLAC software toolkit based on EPICS V3 to take full advantage of EPICS 7[1], which supports structured data and facilitates a language-agnostic middle-ware service layer. This paper provides an overview of a few main goals for the software platform upgrade path in support of controls, online physics and experimental facilities for the LCLS-I/II complex.

SLAC SOFTWARE WORKING GROUP

An inter-departmental SLAC Software Working Group was assembled in 2017 to review the existing status of controls and physics software at SLAC. Going forward, the working group will share plans, priorities, and set common practices for software toolkits and standard implementations to service their accelerators and photon beamlines. A roadmap was formed[2], with emphasis on the near-term timeframe (2017-2020) which includes: 1a) establishment of a SLAC-wide common EPICS version 3.15.5, 1b) migrating EPICS to git version control, along with establishment of a centralized git repository, 2) adapting a new python/QT based Display Manager, 3) leveraging the existing suite of High Level Applications (HLAs), 4) add to the existing EPICS 7 middle services layer, and finally, 5) start integrating EPICS 7 components for handling of structured data. To accomplish further EPICS 7 development and integration, SLAC is committed to strengthening its engagement with the EPICS Collaboration and to allocating resources.

SOURCE CONFIGURATION MANAGEMENT

Lab-wide at SLAC there are multiple controls groups, multiple EPICS repositories, and multiple version control tools in use, with CVS and SVN historically being the tools of choice. An effort is in place to unite the EPICS source configuration management using Git[3], a modern distributed revision control system aimed at speed, data integrity, support for distributed, non-linear workflows, and provision of superior web-based graphical user interface tools. The plan for EPICS source management includes:

- Shared SLAC Git repos with SLAC department specific branches as needed
- Upgrading to EPICS base version 3.15.5, with department specific releases for each target architecture
- Upgraded EPICS 3.15.5 modules will be shared across base releases and departments.

It is anticipated that this plan will reduce duplication of core software maintenance effort and facilitate SLAC-wide collaboration.

DISPLAY MANAGER

The Extensible Display Manager (EDM), which has been in heavy use for all SLAC accelerators and beamlines for the past decade, is nearing end-of-life, is no longer actively supported, and has no EPICS 7 upgrade path. PyDM, a python and QT based display manager presently being developed at SLAC, has been chosen as the EDM upgrade path. There are currently PyDM displays being introduced for LCLS; the intention is to use PyDM for new displays for new machines (LCLS-II, FACET-II).

Python was chosen as the basis for our display manager because it is widely used by SLAC developers and users, has strong community support, and has a large ecosystem of libraries (particularly in the scientific and numerical domains). By building the entire PyDM system in Python, it is easy to extend with new widgets, and create customised versions of existing widgets for special purposes, which encourages code re-use. The ease of development in Python and the extensibility of PyDM, are a significant advantage over other EPICS GUI systems.

PyDM includes a scripting system that lets developers add code to displays. One way this code can be used is to make dynamic displays that generate themselves from middleware services. For displays like magnet control panels, this eliminates a very large amount of work; currently, LCLS-I requires about 75 EDM files just to list the various magnets in each accelerator region. By building a generic PyDM 'magnet list' display that can retrieve a list of magnets for a region (from the directory service) and populate itself with user interface elements, the same magnet interface can be provided by a single file.

As shown in Figure 1, this Python and PyDM capacity for both display generation and code is the basis for new

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SLAC KLYSTRON TEST LAB BAKE STATION UPGRADE

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Abstract

The Klystron Bake Station at SLAC is a facility for baking out klystron tubes (high power RF amplifiers) among other large equipment in preparation for installation in the linac. The scope of this project was to upgrade the 30-year-old controls (based on VMS and CAMAC) to utilize PLC automation and an EPICS high-level user interface.

The new system allows for flexible configuration of the bake out schedule that can be saved to files or edited real time both through an EPICS soft IOC as well as a local touch panel HMI. Other improvements include active long term archiving of all data, COTS hardware (replacing custom-built CAMAC cards), email notification of fault states, and graphical user interfaces (old system was command line only). This paper discusses the improvements made and problems encountered in performing the upgrade.

BACKGROUND

Figure 1: Bake station 5 with oven shell removed (device in center is klystron tube awaiting bake-out).

Production and fabrication of most chambers and in-vacuum devices naturally leads to many undesirable contaminants building up on and in their surface. Such contaminants such as hydrocarbons will lead to outgassing under very low pressures, which makes pumping down a high vacuum system very difficult if not impossible. Additionally, such contaminants in high voltage gradient devices such as klystrons can lead to arcing once voltage is applied which can damage the hardware. In order to remove these contaminants, a combination of high heat and vacuum pumping needs to applied under highly controlled conditions over a long period of time (up to a week or more).

The klystron bake stations (Figure 1) at SLAC were originally built over 30 years ago and whereas some minor elements have been upgraded over the years, the hardware and controls have largely remained unchanged. Control of the heaters and pumps were all handled through FORTRAN scripts running on a VMS operating system that in turn communicated with a CAMAC crate loaded with custom SLAC-designed I/O modules. Interlocks were handled entirely through hard-wired relay circuits that also read back through CAMAC modules.

Not only was much of the hardware for the heater and vacuum systems much in need of modern replacements, the CAMAC and VMS systems are no longer being supported at SLAC and therefor a full upgrade was necessary.

REQUIREMENTS

Upgraded stations provided must be robust, stable, reliable, and serviceable. Mechanical and electromechanical hardware shall have a service life of 10-20 years. Electronic hardware shall have a service life of 20 years. After a power outage, the system shall default to a predefined safe condition upon reset or restart.

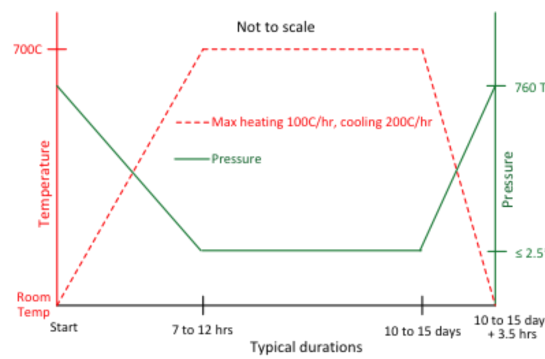

Figure 2: Example vessel temperature and pressure vs. time profile (not measured data).

In order to prepare new klystrons and chambers ready for use in High Vacuum, the Vacuum Microwave Devices Department (VMDD) at SLAC needs to be able to pump down the oven vessel, klystron tube, and RF window to at least the 2.5x10-5 Torr range while simultaneously raising their temperatures to as much as 700°C [1]. Temperatures for these regions are ramped up and down via heat tape according to predetermined profiles created by the expert users. These profiles (Figure 2) can be saved and loaded both directly via the PLC interface as well as remotely for offline filing and log reports.

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LCLS-II INJECTOR LASER SYSTEM

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Abstract

The Linac Coherent Light Source II (LCLS-II) is a new Free Electron Laser (FEL) facility being built as an upgrade to the existing LCLS-I and is planned for early commissioning this year (2017) and full operation in 2020. The injector laser, which hits the cathode to produce the electrons for this FEL source, is conceptually similar to LCLS-I but will utilize an upgraded controls architecture in order to be compatible with the faster repetition rate (1 MHz) of the beam. This includes moving to industrial PCs from VME and utilizing SLAC designed PCIe timing cards and camera framegrabbers.

BACKGROUND

The Linac Coherent Light Source II (Figure 1) at SLAC National Accelerator Laboratory is a high intensity, extremely tunable X-Ray Free Electron Laser (XFEL) facility. The light this facility uses for experiments is generated by a 1 km superconducting electron accelerator with a photocathode source [1].

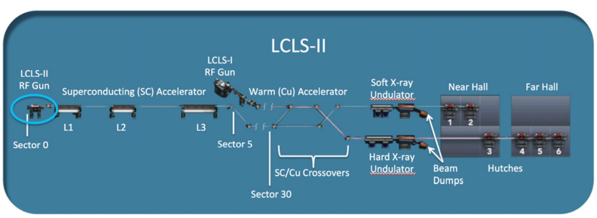

Figure 1: LCLS-II Full Beamline Schematic (Injector circled).

In order to generate these intense X-Rays, LCLS-II actually uses two different laser systems (Figure 2). For the first or these, high power 257 nm wavelength (UV) laser light (hereon referred to as the Drive Laser) is pulsed at up to 1 MHz onto a semi-conductor cathode to emit electrons that are then accelerated by RF through a series of superconducting cavities.

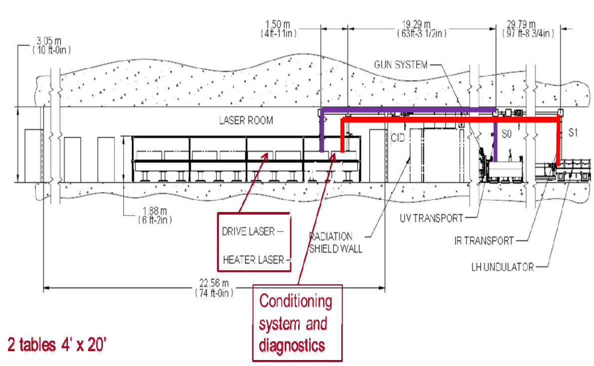

Figure 2: Laser Transport Lines.

Once these electrons are sent down the accelerator however, micro-bunching instabilities can develop which adversely affect the quality of the X-Ray beam generated further on. To counteract these instabilities there is a second 1030 nm (IR) laser (called the Heater Laser) that is aligned to co-propagate with the electron bunch through a small wiggler magnet in the center of a magnetic chicane. This laser is capable of running at 1 MHz as well and will be timed to overlap with the travel time of the electrons to the chicane.

REQUIREMENTS

Each of the two laser systems described above will be designed to function entirely independently [2]. They will each be generated from separate sources and synchronized with independent oscillators and feedbacks. This is a departure from LCLS-I where the Heater Laser was generated from the unconverted light left over after the UV conversion process for the Drive Laser. This allows for far more flexibility for using these systems as well as the ability for the laser physicists to manually reconfigure the Heater Laser to act as a hot spare for the Drive Laser in the case of a major failure (dedicated spare lasers are planned for both the Heater and Drive, but they will come at a later date).

Additionally, both lasers will have dual shutoff paths tied to the Machine Protection System (MPS) in the case of an interlock fault which endangers a piece of beamline equipment as well as the Beam Containment System (BCS) which will fault the Drive Laser in the event of a fault where the beam may cause a potential risk to personnel. The first of these shutoff paths comes in the form of the Acousto-Optic Modulator (AOM) that acts as a fast switch and rate selector for the lasers. The second is a slower mechanical shutter that will block the lasers just before they enter the electron beamline. When a fault occurs, the AOM will divert the lasers into a beam dump until the mechanical shutter has had time to close. Once the shutter is fully inserted, the AOM will be allowed to send beam down so that the beam can be diagnosed and aligned if need be.

In order to stably deliver the laser pulses to their respective destinations, there will be several automated steering feedbacks that will maintain the beam centroid calculated from camera data by tilting upstream mirrors in the horizontal and vertical planes. Most of these feedbacks will be capable of maintaining both position and angle of the beam trajectory, but due to space constraints there will be some that are only able maintain position.

Finally, there will be a variety of other beam diagnostics for remotely tracking the properties of the lasers along their transport. Cameras, powermeters,

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CONTROL SYSTEM DEVELOPMENT FOR THE TLS

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Abstract

Control system of the 1.5 GeV Taiwan Light Source (TLS) was working near 25 years. The original control system for TLS is a proprietary design. Limited resource prevent major revised possible. Several minor upgrades during last two decade to avoid obsolete of some system components and keep up-to-date since its delivery in early 1990. These update are also necessary to support the development of the accelerator system. The control system of the new 3 GeV Taiwan Photon Source (TPS) which start service in 2016 is based upon the EPICS framework. To save resources for TLS control system maintenance and development, adopt EPICS for new developed and rejuvenated subsystems for some of the TLS control interfaces includes BPM system, insertion devices, bunch-by-bunch feedbacks, quadrupoles power supplies control, booster to storage ring transport line control, electronics instruments interface and so on. These efforts allow new devices installed, obsoleted parts replacement, add new software components and functionality. EPICS related applications developed continually accompany with the TLS control consoles environment normally. Control system allowed two kinds of control environments working together seamlessly. Strategic and efforts will summary in this report.

INTRODUCTION

The TLS is a third generation of synchrotron light source built at the National Synchrotron Radiation Research Center (NSRRC) campus in Taiwan in early 1990's. The machine dedicated in 1993. The TLS consists of a 50 MeV electron Linac, a 1.5 GeV booster synchrotron, and a storage ring with 360 mA top-up injection. The TLS Control system is a proprietary design [1] which consists of console level workstations as operation interface and VME based intelligent local controller (ILC) to interface with subsystems. Several minor upgrades had been performed to avoid obsolete during last two decades. Hardware and software on console level workstation change several times due to evolution of fast evolution of computer technology. PC running Linux is the current configuration. Hardware and software on VME layer change several times also to avoid obsolesce of parts. Well design of the original control software structure, port to new platforms without difficult.

The EPICS (Experimental Physics and Industrial Control System) is a set of open source software toolkits used to create distributed soft real-time control systems for scientific facility such as the particle accelerators and large scientific experiments [2]. Many resources and supports are available as well as numerous applications for accelerator have been developed.

To meet user requirements, a new low emittance light source was initiated and discussed around 2005 and finally conclude the TPS of 3 GeV synchrotron light source [3, 4] which was delivered in 2015 and start to provide user service in 2016. The EPICS toolkits were chosen as control system framework for the TPS project. Due to limited resources available, it was decide to fuse the original architecture of the TLS control system with the EPICS environment and run two control environments together at the same platform rather than to convert whole control system into EPICS or use gateway to bridge two different control environments. For the new installed or rebuild subsystems runs EPICS control environment to reduce working load and use the same expertise of manpower.

In the TLS, the control console operate on the existing control system environment and fuse with the EPICS is the approach for TLS control system maintenance strategic.

TLS CONTROL SYSTEM AT BEGINNING

The control system of the TLS is a distributed-type system and follows the concept of "Standard Model" control system for experimental physics. It's a two-level hierarchical system providing good real-time performance with a system update rate of 10 Hz. The overall architecture is simple, scalable, and easy in maintenance. Process computers and workstations at the upper -level control system provide graphical user control interfaces, data storage, the necessary computing power for machine modeling, …etc. The VMEbus based ILC are hearts of the lower-level control system that handles real -time device access and closed loop control. The two levels are connected by Ethernet network using IEEE 802.3 standard and TCP/IP protocol. The software used on the upper-level computers includes database server, network server, simulation programs, various applications, and X-window based graphical user interfaces. Device drivers, application programs for devices control, and communication programs are the major software components on the ILC level. The central parts of the console level software and ILC layer software called as "TLS console core" and "TLS ILC core" respectively. The hardware configuration of the control system is shown in Fig. 1.

The console level computers, comprising a process computer and several workstations, handle the system-wide device control functions and provide a friendly operator interface. The process computer is a VAX 4500. The workstation consoles serves as the platform to run graphical and control applications as well as the operator control console. The X-Window and OSF/Motif systems are used to develop the friendly, dedicated graphic user interface for facility operation. A graphical editor was

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IMPROVEMENTS OF THE ELBE CONTROL SYSTEM INFRASTRUCTURE AND SCADA ENVIRONMENT

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Abstract

The ELBE Center for High-Power Radiation Sources is driven by a 35 MeV C.W. electron linear accelerator, driving diverse secondary beams, both electromagnetic radiation and particles. Its control system is based on PLCs, fast data acquisition systems and the industrial SCADA system WinCC. In the past five years, requirements for availability and reliability increased, while at the same time many changes of the machine configuration and instrumentation needed to be handled. Improvements of the control system infrastructure concerning power supply, IT and systems monitoring have been realized and are still under way. Along with the latest WinCC upgrade, we implemented a more redundant SCADA infrastructure and continuously improved our standards for software development.

ELBE CONTROL SYSTEM OVERVIEW

The ELBE [1] control system has been using commercial and Windows based control system components right from start [2]. This decision was made due to the available expertise, manpower and time budget. Design started in the late 1990s, so it became a textbook example for IEC62242 automation system structure during its first decade that still dominates. The ELBE CS uses interconnected Siemens S7-300/400 PLCs [3] with distributed I/O-stations for basic level equipment control and machine protection, grouped by their technological tasks like vacuum, auxiliary media, PSS, MPS or beam control, see figure 1). WinCC V7.3 by Siemens [4] serves as SCADA system in a server-client architecture. Fast data acquisition (DAQ) systems use National Instruments (NI) hardware and LabView applications [5], usually combining a real time DAQ system with a Windows GUI via shared network variables and, if necessary, with the PLC system using OPC DA [6]. A variety of in-house built hardware for i.e. beam diagnostics, MPS, low level RF has been integrated by hardwired I/O, field bus interfaces or LabView applications. Critical MPS functions are covered by hardware based systems which are PLC-configured according to the actual beam mode and path [7].

PLC AND WINCC SOFTWARE IMPROVEMENTS

Although available, object oriented PLC programming options were rarely used during the first commissioning steps of ELBE. With its latest larger facility upgrade from 2012 on, we made the paradigm shift in this field. Standard components, hardware or virtual, are represented using structural PLC data types, see figure 2. The PLC code is a set of functions using these data instances as input/output parameters. The PLC data types are used almost one-by-one in WinCC, too.

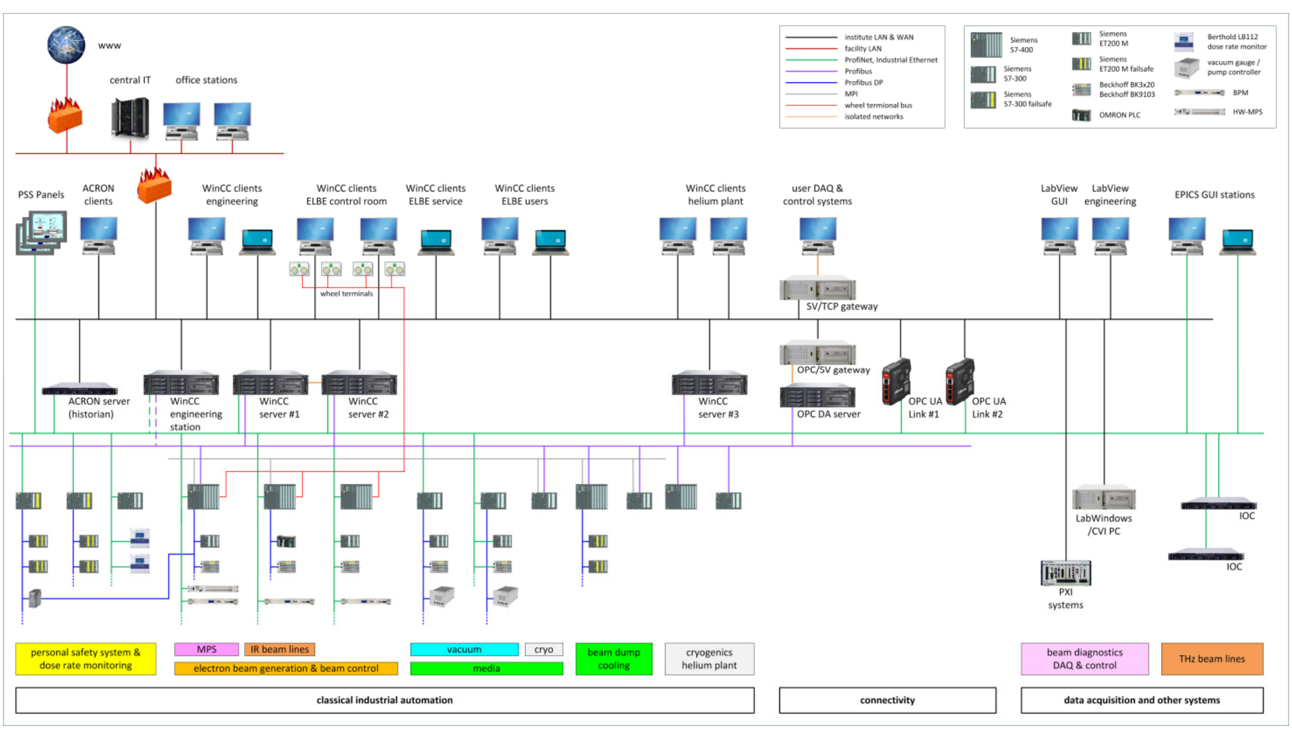

Figure 1: Overview of the ELBE control system.

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STATUS UPDATE FOR THE HIT ACCELERATOR CONTROL SYSTEM

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Abstract

Changes in the accelerator beamline of the Heidelberg Ionbeam Therapy-Center (HIT) and in virtualization hardware and software as well as demands for more redundancy and performance prompted an overhaul of the accelerator control system (ACS) and a new approach to the hardware base.

The addition of a third ion source necessitated an expansion of the Virtual Accelerator (VAcc) structure both in the database and the Device Control Units (DCU) software. To increase redundancy and system performance, new virtualization servers and storage systems were used and the ACS database needed to be revised. To take advantage of newer hardware and operating systems, all server programs and GUIs were converted to a 64 bit base. As a quality of life and security improvement, the download and flash functionality of the ACS were updated to enhance performance and security checks.

The new virtualization host server and infrastructure hardware in conjunction with the 64 bit update and ensuing efficiency increases have resulted in a safer and significantly faster ACS with higher redundancy in case of hardware failure.

INTRODUCTION

The Heidelberg Ion Therapy Centre (HIT) is a dedicated hadron accelerator facility for radio-therapeutical treatment of tumour patients. The two horizontally fixed treatment places, the 360° gantry, as well as the experimental area can be served with proton and carbon beams with qualified beam parameters (MEFI – seeTable 1), helium is available for the experimental area and oxygen is being tested.

The achieved energy range of 88-430 MeV/u for carbon ions and 48-221 MeV/u for protons and helium is sufficient to reach a penetration depth of 20-300 mm in water.

Table 1: MEFI Beam Parameters for Main Ion Types

Parameter	Steps	Protons	Carbon	Helium
Energy	255	48 – 221 MeV/u	88 - 430 MeV/u	50 - 220 MeV/u
Focus	4 (6)	8 - 20 mm	4 - 12 mm	2 - 9 mm
Intensity	10 (15)	$4 \cdot 10^8$ – $1 \cdot 10^{10}$ 1/s	$1 \cdot 10^7$ – $1 \cdot 10^8$ 1/s	$1 \cdot 10^7 - 1 \cdot 10^9$ 1/s

CHANGES IN THE ACCELERATOR

In 2015 a third ion source was constructed and integrated into the beamline [1]. This ion source is used to supply helium ions into the accelerator and necessitated an addition of five new therapy Vaccs (see Figs. 1 and 2). This in turn changed the data structure for therapy data in the device control units (DCU) and in the database.

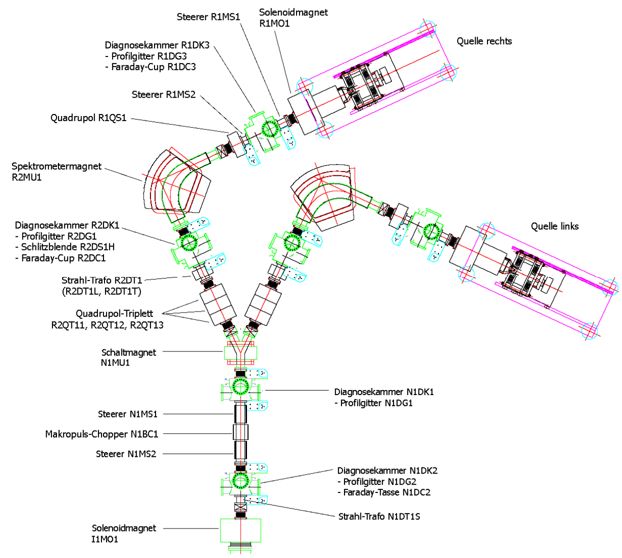

Figure 1: Former LEBT with two ion sources.

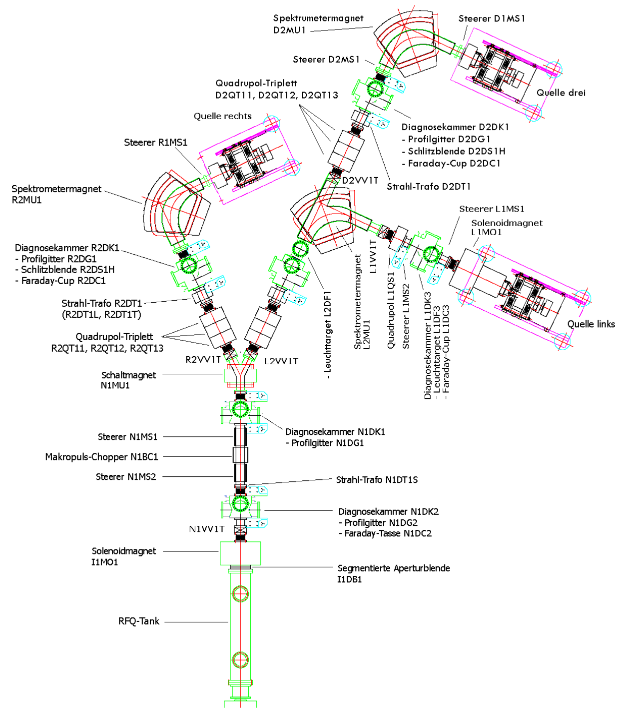

Figure 2: New LEBT with three ion sources.

Changes in Therapy VAccs and MEFI Data

A "virtual accelerator" or VAcc defines a beamline from one of the ion sources to one of the target rooms. It contains

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ONLINE ANALYSIS FOR ANTICIPATED FAILURE DIAGNOSTICS OF THE CERN CRYOGENIC SYSTEMS

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Abstract

The cryogenic system is one of the most critical component of the CERN Large Hadron Collider (LHC) and its associated experiments ATLAS and CMS. In the past years, the cryogenic team has improved the maintenance plan and the operation procedures and achieved a very high reliability. However, as the recovery time after failure remains the major issue for the cryogenic availability new developments must take place.

A new online diagnostic tool is developed to identify and anticipate failures of cryogenics field equipment, based on the acquired knowledge on dynamic simulation for the cryogenic equipment and on previous data analytic studies. After having identified the most critical components, we will develop their associated models together with the signature of their failure modes. The proposed tools will detect deviation between the actual systems and their model or identify preliminary failure signatures. This information will allow the operation team to take early mitigating actions before the failure occurrence. This contribution will present the overall architecture of the proposed tool, the methods used to identify critical components, the characteristic failure model to recognize together with the implementation plan and the achieved results.

THE CERN CRYOGENIC SYSTEM AND THE INTEREST OF ONLINE DIAGNOSTICS

The CERN cryogenic system for the LHC and its associated detectors is distributed around the 27 km of the LHC accelerator.

This system uses industrial actuators such as motors compressors, pumps, turbines, heater, and sensors for speed, pressure, temperature and level measurements. The interface to the control system counts more 60000 I/O and uses both field buses and 4-20 mA classical interfaces. The system is fully automated and controlled by a large and distributed set (>80) of programmable logic controllers (PLC) and Front End Computers (FEC) connected to a cluster of industrial Supervisory Control and Data Acquisition (SCADA) servers for the supervision and monitoring. The control system is using the CERN UNified Industrial COntrol System (UNICOS) framework [1].

Since the operation of the cryogenic system is fully automated, the normal duty of the operation crew is to monitor, improve the settings, start sequences when new operating conditions are requested and intervene in case of failure or degradation of the performances.

It is important to note that the recovery time of large cryogenic systems after a failure or a performance degradation is a major concern for the LHC as it amplifies the downtimes and leads to large reductions of the total availability of the accelerator and the overall luminosity.

To cope with this issue, the UNICOS based control system has been developed to allow the operators to take over the control of the process and operate the facilities in degraded conditions, treating failures, recovering from perturbations, and re-establishing nominal conditions.

To detect faults and perturbations that need to be treated, the control and supervision systems include classical trending facilities and alarm systems. These features, that have been setup and tuned since the beginning of the project, are giving excellent results to identify and detect interlocks, alert threshold crossings, equipment failures and typically all significant and rapid perturbations.

However, slow deviation or perturbations resulting of complex process evolutions are difficult to detect as they are often hidden in a large volume of information and their signature is at the limit of detectability.

Our proposal is to observe these phenomena in real time, comparing them with an equivalent dynamic model that will detect non-conformities and, in a second phase, we will implement the developed tool within the supervision system in order to inform the operation crew allowing them to treat the issue anticipating the failure and reducing thus the downtime of the facility.

AUTOMATED ONLINE DIAGNOSTICS STRATEGIES

There are different approaches and techniques to perform online diagnostic to detect malfunctions in real time. Two main approaches can be considered for the cryogenic system, the data driven and the model driven method:

Data Driven Methods

In this type of technique, the experimental data extracted from the actual system are compared by means of analytical tools with a 'database' of known faults, or known fault signatures, and alert the operators in case of positive matching. They have already been applied at CERN for:

- Root cause alarm identification with alarm list analysis [2].
- Field devices fault pattern recognition [3] such as oscillations, or defective behaviour for a device out of a set were evolutions are supposed to be coherent.

An example of this technique treating the detection of poorly tuned PID is presented in this conference [4].

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FAST IMAGE ANALYSIS FOR BEAM PROFILE MEASUREMENT AT THE EUROPEAN XFEL

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Abstract

At the European XFEL, images of scintillator screens are processed at a rate of 10 Hz. Dedicated image analysis servers are used for transversal beam profile analysis as well as for longitudinal profile and slice emittance measurement. This contribution describes the setup and the algorithms used for image analysis.

INTRODUCTION

The European X-Ray Free Electron Laser Facility (XFEL) consists of a 2.1 km long, superconducting linear accelerator which accelerates particles up to 17.5 GeV, followed by three undulator sections into which portions of the beam are distributed. Behind each undulator section, the photon beam is divided into multiple beamlines.

The electron beam onsists of trains with up to 2700 bunches at a repetition rate of 10 Hz. With an inter-bunch repetition rate of 4.5 MHz, each bunch train is up to 600 µs long [1].

Emittance Measurements

For beam size measurements, scintillator screens and wire scanners are available [2]. Different methods are applied for screen-based emittance measurements [3, 4]:

- On-axis measurement: Four screens are moved into and out of the beam one by one. This method has been well established at the FLASH linac [5], but is destructive and takes considerable time (several minutes).
- Off-axis measurement: Single bunches are extracted from the pulse train by fast kickers onto four off-axis screens. This measurement can be performed during the FEL operation and takes less than 10 seconds (including statistics over multiple images taken at 10Hz).
- Multi-quadrupole scans: The beam size is measured on a single screen, dependent on the strengths of multiple quadrupoles. This makes it possible to measure with a higher precision since more measuring points are available, and the beam size can be magnified. The duration of a measurement is several minutes.
- Slice emittance measurement: By a transverse deflecting structure (TDS) , a bunch is streaked in one transversal direction and then deflected by a fast kicker onto an off-axis screen [6]. The longitudinal profile can then be measured in the streaked plane, while slices can be analyzed in the perpendicular plane.

Camera Servers

Cameras are controlled by DOOCS servers [7] which expose camera and processing parameters to control system clients. Client programs also read the produced images via DOOCS over the network. The camera images have a resolution of max. 1750x2330 with a 12 bit depth, resulting in 16 bit grayscale images. Each camera server runs on a µTCA crate with 4 hyper-threaded CPUs and up to 6 cameras attached.

FAST IMAGE ANALYSIS

Traditional implementations of transversal beam profile measurement as used in FLASH operated as central servers which read images from the distributed camera servers. Off-Axis measurement at the XFEL requires to process up to 4 different screens simultaneously. With a rate of 10 Hz and an image size of 8 MB, even a single camera would already use up the available network bandwidth. Besides that, the analysis of such big images is quite CPU intensive. This situation suggests to consider local processing directly on the µTCA crates in order to eliminate network traffic, and to look for optimized algorithms which reduce the CPU utilization.

Image Analysis Server

The image analysis server is implemented in C++ as a DOOCS server. It runs directly the on the µTCA crates and supplements the camera server. Image data are exchanged asynchronously through ZeroMQ [8] channels. Each image is processed in a separate thread. Fig. 1 illustrates the setup.

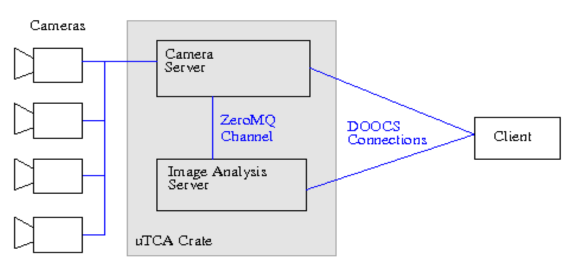

Figure 1: Setup of camera and image analysis servers.

Performance Improvements

The analysis needs to be fast and reliable. It is performed entirely on x and y axis projections in order to make the processing as fast as possible. It mainly consists of Gaussian fits and RMS calculations, making use of the OpenCV [9], GSL [10], and armadillo [11] libraries.

An obvious question is how image size reduction could improve the performance and how this would affect the accuracy of the results.

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EPICS AND OPEN SOURCE DATA ANALYTICS PLATFORMS

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Abstract

SKA scale distributed control and monitoring systems present challenges in hardware sensor monitoring, archiving, hardware fault detection and fault prediction. The size and scale of hardware involved and telescope high availability requirements suggest that machine learning and other automated methods will be required for fault finding and fault prediction of hardware components. Modern tools are needed leveraging open source time series database & data analytic platforms. We describe DiaMoniCA for The Australian SKA Pathfinder Radio Telescope which integrates EPICS, our own monitoring archiver MoniCA, with an open source time series database and web based data visualisation and analytic platform.

INTRODUCTION

The Australia Square Kilometre Array Pathfinder (ASKAP) Radio Telescope has been in operation for several years while dishes and associated digital systems for each of its 36 antennas are commissioned. During this time, the in-house developed MoniCA data archiver platform [1] has been in use. As the ASKAP Telescope Operating System (TOS) uses the Experimental Physics and Industrial Control System (EPICS) framework for monitoring & control, an EPICS Channel Access archiver plugin was developed for use with MoniCA.

The MoniCA Server and MoniCA data visualisation client (MoniCA Client) are used across all CASS Radio Telescopes, providing some continuity to the otherwise very different instruments. However, the MoniCA platform is aging and the scalability requirements of ASKAP and beyond require new solutions. Migration to web-based solutions are seen as essential for ease of deployment and maintainability over the life of ASKAP. By adopting solutions from the wider DevOps community, we can take advantage of the latest technology trends, gain scalability and draw from a much larger pool of open source contributions.

DiaMoniCA is a CASS platform that encompasses all aspects of monitoring, visualisation and data mining for ASKAP and other CASS instruments. It brings together a collection of open source technologies and in house developed modules to integrate off the shelf data archiving & visualisation tools with EPICS monitoring and control.

Figure 1 shows the main components of DiaMoniCA. The platform is centred around a Commercial Open Source time series database and a data visualisation platform, together with in-house developed modules for data ingest and data extraction. Ancillary services such as alerting are provided as standard components of the open source platforms.

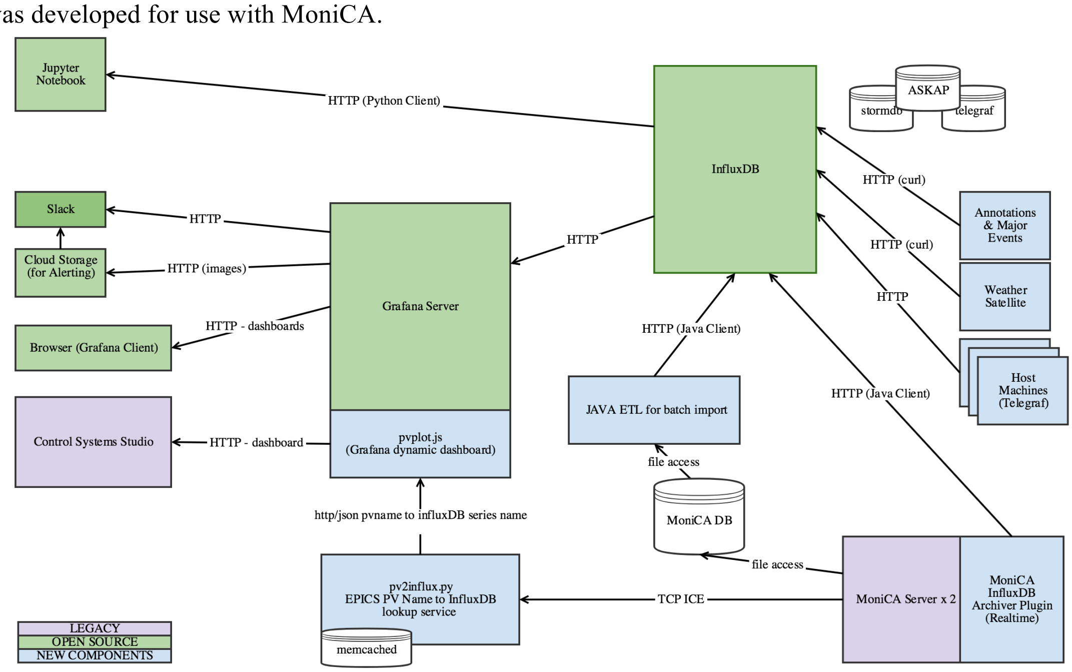

Figure 1: The DiaMoniCA platform in ASKAP.

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DEVELOPMENT OF STATUS ANALYSIS SYSTEM BASED ON ELK STACK AT J-PARC MLF

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Abstract

In recent neutron scattering experiments, large quantities of various types of data, including raw data, metadata, logs and metrics have been generated by the system, apparatus and devices. At J-PARC MLF, it is possible to conduct many experiments under various conditions within short time by using high-intensity neutron beams, high-performance neutron instruments, and various sample environments. In this experimental environment, it is essential to perform efficient and effective data analysis. Additionally, since it has been almost nine years from the start of operation in MLF, the rate of occurrence of failures is rising due to ageing of devices. Given that such failure can lead to loss of precious beam time, failure or its signs should be detected early. The MLF status analysis system based on Elasticsearh, Logstash, and Kibana (ELK) Stack, which is one of the web-based framework that is being rapidly adopted for big data analysis, collects various data from neutron instruments. It offers insight to decision-makers in terms of data analysis and experimentation as well as instrument maintenance, by facilitating flexible user-based analysis and visualization. In this paper, we present an overview and the development status of our status analysis system.

INTRODUCTION

J-PARC MLF

The Materials and Life Science Experimental Facility (MLF) at the Japan Proton Accelerator Research Complex (J-PARC) is an experimental facility for neutron scattering, providing domestic and international users from a wide variety of research fields with one of the highest intensity pulsed neutron beam in the world since 2008. Currently 21 neutron instruments are operational in this facility. Each instrument is equipped with a large-area neutron detectors and a wide variety of purpose-built sample environment equipment.

Status Analysis with Log Information

Since neutron instruments include a wide variety of systems, apparatus, and devices, large amounts of diverse data, including raw data, metadata, logs, and server metrics, are generated. These data contain useful information from the viewpoint of instrument operation and data analysis, such as operating state, physical values, and neutron detection. However, there is not much opportunity to positively utilize these logs. This is because these logs are usually generated and stored in different system and have different data structure. Moreover, there is no convenient tool to analyze these logs. Therefore, there is a need for as tool that can provide useful insights into actions required to prevent failure of system and devices, as well as for performing data analysis, especially, since it has been almost nine years from the start of operation of MLF, and system and device failures occur frequently owing to age-related degradation. It has been challenging to develop such a tool until now. However, the rapid growth of big data analysis frameworks of late has made it possible to develop such a tool.

Big Data Approach

Figure 1 shows an overview of our status analysis system. We employed the ELK Stack [1], an open-source software framework developed by Elastic Inc. for big data analysis, to develop the system. This system collects log information with a wide variety of structures from various types of systems and devices installed in the neutron instruments in real-time. Moreover, it can be used to flexibly and easily analyze and visualize log information via a web-based interface. Furthermore, we plan to combine the system with a machine learning scheme to facilitate anomaly detection and advanced status analysis.

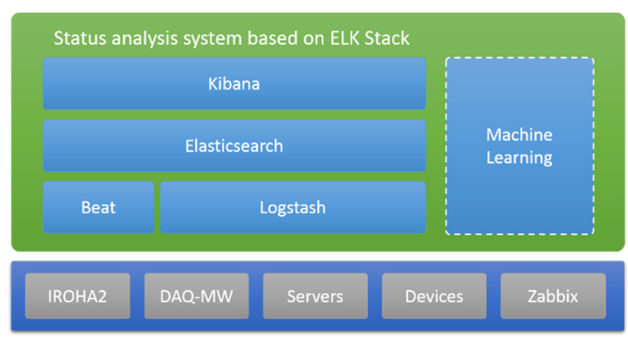

Figure 1: Overview of the status analysis system.

ELK STACK

The ELK Stack consists of three main components, namely, Elasticsearch, Logstash, and Kibana, and a subcomponent called Beat. Figure 2 shows the architecture of ELK Stack.

Elasticsearch

Elasticsearch is a document store based on a distributed document-oriented database with a full-text search engine

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THE STUDY OF BIG DATA TOOLS USAGES IN SYNCHROTRONS

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Abstract

In today's world, there is plenty of data being generated from various sources in different areas across economics, engineering and science. For instance, accelerators are able to generate 3 PB data just in one experiment. Synchrotrons industry is an example of the volume and velocity of data which data is too big to be analyzed at once. While some light sources can deal with 11 PB, they confront with data problems. The explosion of data become an important and serious issue in today's synchrotrons world. Totally, these data problems pose in different fields like storage, analytics, visualisation, monitoring and controlling. To override these problems, they prefer HDF5, grid computing, cloud computing and Hadoop/Hbase and NoSQL. Recently, bigdata takes a lot of attention from academic and industry places. We are looking for an appropriate and feasible solution for data issues in ILSF basically. Contemplating on Hadoop and other up-to-date tools and components is not out of mind as a stable solution.

INTRODUCTION

The world's most valuable resource is not oil anymore, it is "Data", the oil of digital age. Nowadays there is a plenty of data being generated from various sources in different areas such as economy, engineering, science, etc. 5 companies (Google, Amazon, Apple, Facebook and Microsoft) are the most well-known companies in the world and the reason is "data" [1]. How useful could be this amount of data? Have you ever thought about this? Ending world hunger, reducing crime, halting deadly outbreaks of diseases are a small advantage of using data to solve problems. For instance, $300 billion to $450 billion could be saved by using data for a better outbreak prediction just in the United States [2][3]. The five companies named above have earned totally $25 billion profit in the first quarter of 2017 [1]. Although data innovation itself isn't the solution in most cases, it could present an extremely fundamental piece of information to unlock the doors to the new answers. Todays, the sheer volume of available data is growing rapidly. This growing data is getting too much and we need to dwindle it down to a meaningful subset. A new technology has appeared and has aroused great expectations and that is "Big Data".

Big Data is a term used to describe the collecting, processing and making available huge volume of streaming data in real-time. The three V's are Volume, Velocity and Variety with credit to Doug Laney [4]. Having a lot of data which are pouring into your organization is one side of the coin, being able to store, analyse and visualize the mentioned data in real-time is a whole different thing, the other and the most important side of the same coin.

In this project, we are trying to have a complete study on big data tools and tested techniques in various light sources around the world for data in beamlines, emphasizing on the storage and analytics aspects.

SYNCHROTRONS DATA ISSUES

In many scientific fields such as physics, statistical analysis of large data sets is common. The particle accelerator's data offers a good example of scientific data. Particle accelerators generate data at a rate of 1 MB per collision event, and such events happen at a rate of about 600 million per second. Handling this huge amount of data is a core problem and the solution is Big Data [5]. For instance, accelerators are able to generate 3 Petabyte data just in one experiment [6]. Synchrotrons industry's data is an example of the volume and velocity of data. Synchrotron's data is too big to be analyzed at once. Though some light sources can deal with 11 Petabyte, they confront with data problems [6]. The explosion of data becomes an important and serious issue in today's synchrotrons world.

Totally, these data problems pose in different fields like storage, analytics, visualisation, control and monitoring. To cope with these problems, they prefer HDF5, grid computing, cloud computing and Hadoop/Hbase and NoSQL [7]. Recently, Big Data has attracted lots of attention from academic and industrial organizations. We are basically looking for an appropriate and feasible solution for data issues at ILSF. Contemplating Hadoop and other up-to-date tools and components is not out of mind as a long term solution.

OUR APPROACHES

In this regard, an interview was designed and sent to the interviewees after validation procedures. This interview has 10 sections. Which is shown in the Figure 1. Each of these sections is for an interview. This interview is structurally a semi-structured interview.

Given that we did not have direct access to the interviewers and it was not possible to set a specific time for online interviews on Skype, so I came across interviews and online forms which I encountered with many forms. Examining the advantages and disadvantages, in fact, assessing which online forms would provide more opportunities for our interview and could meet our demands, was our next step in this study.

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HIGH LEVEL CONTROL SYSTEM CODE WITH AUTOMATIC PARAMETRIC CHARACTERIZATION CAPABILITIES

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Abstract

Several degree of freedom have been introduced in the design of the proton source (named PS-ESS) and in the Low Energy Beam Transport line (LEBT) developed at INFN-LNS for the European Spallation Source (ESS) project. The beam commissioning was focused on the most important working parameters in order to optimize the beam production performance taking into account the ESS accelerator requirements. The development of a MATLAB custom code able to interact with the EPICS control system framework was needed to optimize the short time available for the beam commissioning. The code was used as an additional high level control system layer able to change all source parameters and read all beam diagnostics output data. More than four hundred of thousand configurations have been explored in a wide range of working parameters. The capability to connect Matlab to EPICS enabled also the developing of a genetic algorithm optimization code able to automatic tune the source towards a precise current value and stability. A dedicated graphical tool was developed for the data analysis. Unexpected benefit come out from this approach that will be shown in this paper.

ION SOURCE PARAMETERS FLEXIBILITY

The proton source [1-2] developed at INFN-LNS for the European Spallation Source [3] is a Microwave Discharge Ion Source (MDIS) working at 2.45 GHz. The most important parameters having a direct effect in the plasma production are the magnetic field, the microwave power and the gas inlet pressure. The magnetic field is provided by a three coils magnetic system packaged with XC10 steel to increase the flexibility in the magnetic field production. Three are the parameters the user can select to change the produced magnetic field: the amount of current flowing in each coil (named Injection, Middle and Extraction). Starting from this set of current values the magnetic field profile inside the plasma chamber is evaluated with a magneto static simulation and the strength in three points close to the three coils is extracted. The amount of microwave power provided by the magnetron can be selected by the user and the adsorbed power can be monitored. The microwave injection line consists also of a four stubs (two couples) tuning unit that is used to match the impendence of the plasma chamber and increase the microwave to plasma coupling. This device show to the user two parameters that are the positions of the X stubs couple and the Y stubs couples. The pressure inside the plasma chamber is driven by the amount of gas (pure Hydrogen) that is injected in the plasma chamber.

The main parameter that change the beam transport in the LEBT [4-5] are the magnetic field of two focusing solenoids and four steerers. The beam transport is strongly affected by the space charge of the beam that is neutralized by a gas addition in the LEBT. Two type of gas can be selected in our installation, Hydrogen and Nitrogen. Both in the source and in the LEBT the gas adduction is regulated by a dedicated mass flow controller able to regulate and measure with high precision and repeatability the amount of gas injected. The used ranges for the parameters of the source and of the LEBT are shown in the tables 1 and 2. Others parameters that increase the source flexibility but that were not connected with the software layer described in this paper are present but not here reported.

Table 1: Main Source Parameters

Parameter	Minimum value	Maximum value
Microwave power	100 W	1200 W
X stubs	0	10000
Y stubs	0	10000
Coil Injection	0 A	400 A
Coil Middle	0 A	400 A
Coil Extraction	0 A	400 A
H_2 gas flow	0.2 SCCM	10 SCCM

Table 2: Main LEBT Parameters

Parameter	Minimum value	Maximum value
Solenoid 1	0 A	400 A
Steerer Vertical 1	0 A	50 A
Steerer Horizontal 1	0 A	50 A
Solenoid 2	0 A	400 A
Steerer Vertical 2	0 A	50 A
Steerer Horizontal 2	0 A	50 A
H_2 gas flow	0.2 SCCM	10 SCCM
N_2 gas flow	0.2 SCCM	10 SCCM

CONTROL SYSTEM

The control system developed by ESS and CEA is based on EPICS and the graphical interface was developed with Control System Studio. The graphical interface uses two screens one for the parameters setup and one for the beam diagnostics measurements. The most important parameters of the source and the LEBT are shown in two tabs shown in the Figure 1 and 2. A detailed view of all working parameters of each used device is shown in different tabs here

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MULTI-CRITERIA PARTITIONING ON DISTRIBUTED FILE SYSTEMS FOR EFFICIENT ACCELERATOR DATA ANALYSIS AND PERFORMANCE OPTIMIZATION

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M.Z. Rela CISUC, University of Coimbra, Portugal

Abstract

Since the introduction of the MapReduce paradigm, relational databases are being increasingly replaced by more efficient and scalable architectures, in particular in environments where a query will process Terabytes or even Petabytes of data in a single execution. The same tendency is observed at CERN, where data archiving systems for operational accelerator data are already working well beyond their initially provisioned capacity. Most of the modern data analysis frameworks are not optimized for heterogeneous workloads such as they arise in the dynamic environment of one of the world's largest accelerator complex. This contribution presents a Mixed Partitioning Scheme Replication (MPSR) as a solution that will outperform conventional distributed processing environment configurations for almost the entire phase-space of data analysis use cases and performance optimization challenges, as they arise during the commissioning and operational phases of an accelerator. We will present results of a statistical analysis as well as the benchmarking of the implemented prototype, which allow defining the characteristics of the proposed approach and to confirm the expected performance gains.

INTRODUCTION

The operation and maintenance of the Large Hadron Collider (LHC) are very complex and resource intensive processes, both relying on highly sophisticated hardware and software systems. Among others, the currently deployed accelerator transient data storage and processing solutions are a crucial tool for many of the activities conducted by the hardware experts and are an integral part of the operational accelerator cycle. Diagnostic data is primarily collected by two systems, the CERN Accelerator Logging Service (CALS) [1] and the Post Mortem system (PM) [2], which in parallel to acquiring the measurements from the same sources, serve different purposes. The CALS system continuously monitors the accelerator hardware and logs data at frequencies up to a few Hz, allowing for long-term trend and behaviour analysis. On the other hand, the PM system acquires higher frequency measurements (up to GHz) from internal device buffers, but only for a short time-window around the events of interest (like beam extraction from accelerator for example). This allows for the detailed reconstruction of the LHC state around the occurrence of relevant events.

Upgrades of the LHC hardware systems performed during the last long shutdown phase have pushed the originally provisioned data ingestion rates well beyond the initially defined boundaries, resulting in a considerable performance loss of the deployed solutions. Despite the fact that both systems are capable of ensuring high input throughputs, they are no longer capable of providing the same quality of service for the increasing user requests and new, large scale analytical use cases. Besides the scalability issues, both architectures provide a very limited support for data analysis operations, forcing users to perform calculations on their local environments rather than being integrated with each other.

The next generation data analysis system, based on modern distributed data analysis solutions is being developed as a response to the arising challenges. The Hadoop backend provides resilience to failures storage solutions as well as data locality-aware application execution scheduling. The flexibility of the Hadoop Distributed File System (HDFS) [3] allows the development teams to integrate tools, like Parquet [4], which improve the performance of the storage by enhancing the format of the persisted files. Data processing is performed using the Apache Spark [5], which according to multiple reports [6, 7] is more efficient than the traditional Hadoop [8] MapReduce [9] approach. The developed infrastructure is horizontally scalable and resilient to various sources of failures.

In contrast to the possible performance gains which can be achieved by integrating modern data analysis tools into the accelerator environment, none of the aforementioned systems address a very important issue - the workload heterogeneity. The inspection of today's workloads and a survey conducted with LHC hardware experts has suggested that the profile of the queries submitted to the system is very broad and prioritize different stored object predicates when operating on the data. The currently employed partitioning scheme does not make a distinction between the different query categories and provides a single time-based partitioning data organization strategy, which is sub-optimal for many of the submitted user requests. Providing a solution to this shortcoming becomes a primary goal of the multi-criteria partitioning scheme replication presented and studied in this work.

This paper is organized in five sections. This first section provides an introduction to the context and problem. The second section presents the core concepts of MPSR and describes its integration boundaries. The following sections describe the architecture of the developed prototype and summarizes the results of the executed benchmarks. The last section presents a summary of the main conclusions.

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FUTURE ARCHIVER FOR CERN SCADA SYSTEMS

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Abstract

The paper presents the concept of a modular and scalable archiver (historian) for SCADA systems at CERN. By separating concerns of archiving from specifics of data-storage systems at a high abstraction level, using a clean and open interface, it will be possible to integrate various data handling technologies without a big effort. The frontend part, responsible for business logic, will communicate with one or multiple backends, which in turn would implement data store and query functionality employing traditional relational databases, as well as modern NOSQL and big data solutions, opening doors to advanced data analytics and matching the growing performance requirements for data storage.

INTRODUCTION

Robust and scalable archiver (historian) for large control systems such as those of CERN's LHC accelerator and is associated experiments, has been a recurrent topic discussed over the past decade at the ICALEPCS conference. In particular, the evolution of the RDB Oracle Archiver component of the WinCC Open Architecture (OA) [1] commercial SCADA system has been presented in [2][3].

With the already planned ramp in luminosity of the CERN accelerator complex, one may expect the corresponding rise to be required in the throughput of control systems and in the amount of produced and processed data. Moreover, a more and more widespread adoption of data analytics is a notable trend for industrial control systems, empowering the operators with new tools such as predictive maintenance, event classification and plant optimization. In this context, the archiver becomes one of the key component of modern control systems bridging the gap between domains of classical control systems and data analytics. On the other end, the Internet-of-Things revolution yields appliances capable of embedding advanced control systems into small form factor devices with ultra-low power consumption, requiring scaled-down versions of archiver to be running locally, or in cloud/swarm deployments.

Based on the experience gathered over a decade of operation of the WinCC OA-based control systems at CERN, notably using the archiving systems based on large relational Oracle databases and anticipating future challenges, we propose an architecture for the new scalable and modular archiver for industrial-control systems. Even though primarily aimed to be used with WinCC OA (de-facto standard for CERN deployments), the open architecture allows its integration with "any" other control system that needs to store and query historical process data (such as C2MON [5]).

The NextGen Archiver project presented in this paper is developed in collaboration between CERN and Siemens/ETM (the vendor of WinCC OA), in the framework of the CERN openlab project [4].

RDB Archiver

The RDB archiver was originally developed for the LHC experiments and later on, extended to other CERN systems (accelerators and technical infrastructure). The main driving force for the new development were the requirements in terms of writing/reading performance as well as the long-term storage of the data. At the time of the development (mid 2000s) the ubiquitous technology for databases was based on the relational model. A first attempt was made to have a generic relational archiver; however, it didn't meet the requirements and a specialized version had to be developed for Oracle, the CERN IT chosen solution at the time [3]. The project was a very successful common effort between several CERN groups and ETM. The main outcome was a scalable archiver solution that could be tailored, with the appropriate hardware, to the different CERN installations.

The RDB archiver was put in production for the LHC start-up and used since, with systematic modifications and a major evolution during the first LHC Long Shutdown to meet the ever-growing performance requirements.

Since the initial development, a number of technologies have come up in the domain of data logging and analysis (e.g. Hadoop ecosystem, timeseries databases, etc). This made necessary to reconsider the initial choice of technologies for the major upcoming upgrades for the CERN control systems linked to the High Luminosity LHC.

MOTIVATION

Based on the fruitful experience of the collaboration on the RDB Archiver, CERN and ETM/Siemens decided to start a R&D project on the next generation archiver for WinCC OA systems, in the scope of the Openlab project.

Following the trends observed in the IT sector, the main motivations in this project for CERN were:

- Provide an archiving solution capable of scaling-up to data throughputs required for next upgrades of the LHC and its experiments beyond 2020.
- Enable effective use of data analytics tools.
- Enable the usage of NOSQL (Not Only SQL) data store and processing technologies.

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* supported by Siemens through CERN openlab collaboration

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UPGRADE OF THE CERN RADE FRAMEWORK ARCHITECTURE USING RabbitMQ AND MQTT

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Abstract

AMQP (Advanced Message Queuing Protocol) was originally developed for the finance community as an open way to communicate the vastly increasing over-the-counter trace, risk and clearing market data, without the need for a proprietary protocol and expensive license. In this paper, we explore the possibility to use AMQP with MQTT (Message Queue Telemetry Transport) extensions in a cross platform, cross language environment, where the communication bus becomes an extendible framework in which simple/thin software clients can leverage the many expert libraries at CERN.

INTRODUCTION

The Rapid Application Development Environment (RADE) was initially developed to make it possible to interface LabVIEW™ based equipment and software with the CERN technical infrastructure. As part of this implementation, a multi-tier communication layer was introduced called RADE Services [1].

The current implementation of the RADE Services are based on custom-coded Java application interfaces linking the RADE client interfaces with an Apache Tomcat Web Server [1]. Despite the stability and performance of this implementation, there are several issues that need to be addressed in order to improve the scalability, reusability and cluster performance of the service.

Custom code forces developers to rewrite and sometimes re-design whenever the dependent libraries change. Maintenance has proven to be time-consuming and with heavy traffic, the solution doesn't scale well.

To address this, we started looking at industrial solutions working in a more efficient and compartmentalized way, reducing code redundancy. Moreover, in search of better approach it was necessary to uphold two major requirements– platform independence and plugin support for JAVA – LabVIEW™ communication [1].

In this paper, we will show how we try to address this problem by linking most of the various services and interfaces via a commercially supported, well documented software layer called RabbitMQ, and leverage the interoperability by reducing the software complexity and maintenance efforts [2].

CERN Infrastructure

The technical infrastructure at CERN consists of several different front-end devices, databases, sensors and experimental equipment (See figure 1).

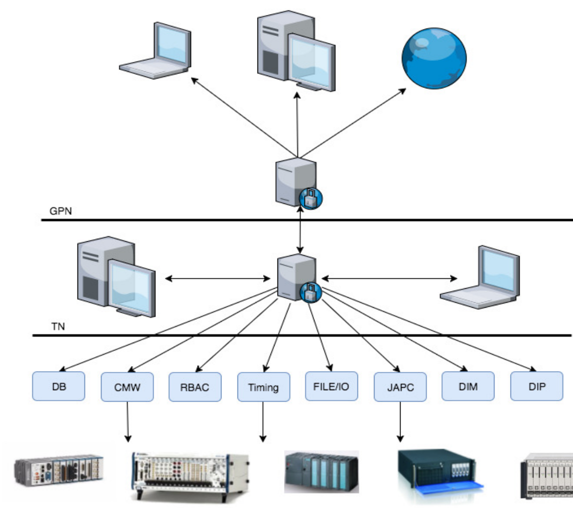

Figure 1 : Simplified view of the CERN Technical Infrastructure

To keep track of the equipment, the CERN Controls Configuration Database (CCDB) holds the information describing the different data interfaces and the relations between the hardware and software. You will also find information describing the network interfaces and every device connected to the CERN technical and general purpose network [2].

Access to the CCDB is provided by the middleware and communication layers.

The Controls Middleware (CMW) framework enables client applications to connect and retrieve data from CERN accelerator equipment [3] [4].

Apart from databases there are also several file systems designed for data storage [5]:

- DFS (Distributed File System)
- NFS (Network File System)
- AFS (Andrew File System)
- EOS

RADE Services

The RADE framework aims to give users a total package for development, maintenance and support through well-defined templates, guidelines and documentation. RADE libraries make use of a distributed architecture (See figure 2), with several application servers hosting dedicated communication and analysis libraries [1].

As an example, the Java API for Parameter Control (JAPC) is a communication layer to control accelerator devices from Java. In the RADE Services stack, JAPC is used as a unified software API where you can get access to most parameters of the CERN accelerators control parameters.

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INFORMATION SYSTEM FOR ALICE EXPERIMENT DATA ACCESS

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Abstract

The main goal of this paper is the presentation of Dcs ARchive MAnager for ALICE Experiment detector conditions data (DARMA), which is the updated version of the AMANDA 3 software currently used within ALICE experiment at CERN [1].

The typical user of this system is either a physicist who performs further analysis on data acquired during the operation of the ALICE detector or an engineer, who analyses the detector status between iterations of experiments. Based on the experience with the current system, the updated version aims to simplify the overall complexity of the previous version, which leads to simpler implementation, administration and portability of the system without sacrificing the functionality. DARMA is realized as an ASP.NET web page based on Model-View-Controller architecture and this paper provides a closer look at the design phase of the new backend structure in comparison to the previous solution as well as the description of individual modules of the system.

INTRODUCTION

The ALICE experiment studies the ultrarelativistic heavy ion collisions provided by the Large Hydron Collider (LHC). To cope with extreme track densities, many subdetectors based on different technologies have been deployed within ALICE [1]. That is why the ALICE Detector Control System (DCS) has to access many different components and various types of data. A closer look on ALICE DCS can be found in [2], details of the data flow in ALICE DCS are available in [3]. Most of the values monitored by the DCS are stored into the central database, where every detector uses its own schema to prevent possible conflicts.

Over the years, many different ways to access the data from this database were used – from the simple client server tool AMANDA to currently used AMANDA 3 package, which allows the concurrent access to DCS archive using multiple clients. Usage of AMANDA 3 brings to light the need of designing the simplified solution with easier implementation and administration and better portability. The acronym DARMA (Dcs ARchive MAnager) was chosen as the name of this information system. Both AMANDA 3 and DARMA were developed by members of CERN and Center of Modern Control Techniques and Industrial Informatics in the Department of the Cybernetics and Artificial Intelligence, Faculty of the Electrical Engineering and Informatics, Technical university of Košice, so in the design of DARMA, experiences from AMANDA 3 development and usage were used and transferred into the latest version. DARMA respects the main features of the AMANDA 3 solution and has been designed to deal with weak spots of its ancestor with focus on improvement of the functionality along with the reduction of its backend structure.

AMANDA 3 SOFTWARE OVERVIEW

AMANDA 3 is the software solution for the retrieval of the large amounts of DCS data with the main goal of enabling faster access to the multiple users of the system. When compared to previous solutions, AMANDA 3 was designed as a decentralized system, with services running on separate servers in order to deal with the requests traffic and to serve all the users as fast as possible. Windows Communication Foundation (WCF) services system was used to interconnect all decentralized parts of the system to ensure the fast and reliable communication between separate modules. Structure of the AMANDA 3 solution is shown in Figure 1.

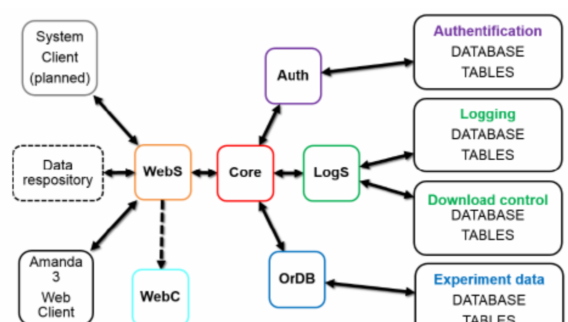

Figure 1: Structure of AMANDA 3.

AMANDA 3 is still used in CERN infrastructure, but with the fast technological changes in IT environment, the development of a new version of the AMANDA 3 was necessary. [4]

OVERVIEW OF DARMA

The new DARMA solution aims to be simpler and more user-friendly than AMANDA 3, but also retains all the benefits of AMANDA 3. In DARMA, separate services are not considered and the entire solution is implemented in the form of an ASP .NET Web site using the Model – View – Controller (MVC) architecture - Figure 2.

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ASCI: A COMPUTE PLATFORM FOR RESEARCHERS AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The volume and quality of scientific data produced at the Australian Synchrotron continues to grow rapidly due to advancements in detectors, motion control and automation. This means it is critical that researchers have access to computing infrastructure that enables them to efficiently process and extract insight from their data. To facilitate this, we have developed a compute platform to enable researchers to analyse their data in real time while at the beamline as well as post-experiment by logging in remotely. This system, named ASCI, provides a convenient web-based interface to launch Linux desktops running inside Docker containers on high-performance compute hardware. Each session has the user's data mounted and is preconfigured with the software required for their experiment.

INTRODUCTION

ASCI consists of a cluster of high performance compute nodes and a number supporting applications. These include an application for launching and managing instances (asci-api), a web interface (asci-webui) and a proxy server for relaying connections (asci-proxy).

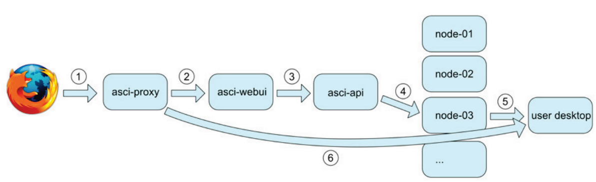

Figure 1: Overview of launching an ASCI session.

The sequence of events involved in creating and connecting to an ASCI desktop session is illustrated in Fig. 1. Users first log in to the web interface and select an environment appropriate for processing their data. The webui sends a request for a new instance of that environment type to the asci-api. The asci-api selects the best compute node to launch the instance on based upon the requirements of the environment and the load on the cluster. Once it has picked a node, the asci-api launches a Docker container based upon the requested environment. The user is then presented with an icon representing the running session and they can connect to this desktop from their web browser.

When the user initiates a connection, a VNC session is created inside the Docker instance with a one-time password. This password is used to launch a NoVNC connection in the user's browser and the user is presented with their desktop and can commence analysing their data.

DOCKER AND ASCI ENVIRONMENTS

Docker containers are a technology for creating isolated process environments on Linux [1]. We chose this technology for the ASCI user environments because they deliver almost identical performance compared with running applications on the bare-metal operating system, while enabling multiple users to simultaneously utilise the node. Docker also enables us to create predefined environments, tailored with the applications required for different types of experiments. Each environment is based on a Docker image which is defined by a text file outlining how to prepare the desktop. These image recipes support inheritance, enabling us to have a base image with installs the ASCI infrastructure applications and then child images with the specialised scientific software for the different experiments, as shown in Fig. 2.

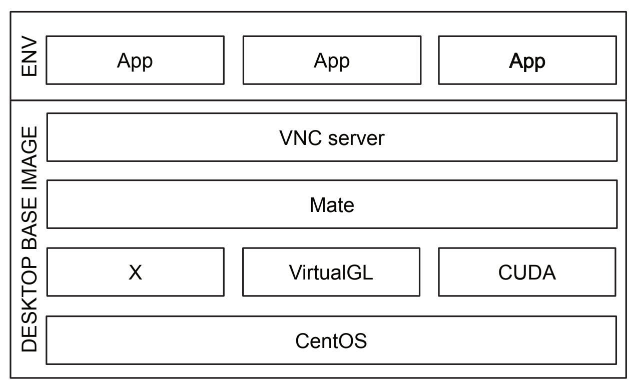

Figure 2: Components of an ASCI Environment.

WEB INTERFACE

A goal of the ASCI project was to allow users to connect to desktop sessions through their standard browser rather than requiring users run a specialised application such as a VNC client. This greatly lowers the barrier to entry to using the system and allows users to access it from any operating system.

We built the web interface using Flask for the server and React for generating the front-end. For rendering the desktops in the browser, we utilise NoVNC [2] which delivers a VNC connection over WebSockets. This results in a responsive interface that runs on all platforms, including mobile and tablet. The appearance of an ASCI Desktop connected over NoVNC is shown in Fig. 3.

VIRTUALGL

In order to provide GPU hardware acceleration to multiple ASCI instances on one node, we need to use a modification

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LIGHTFLOW - A LIGHTWEIGHT, DISTRIBUTED WORKFLOW SYSTEM

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Abstract

The Australian Synchrotron, located in Clayton, Melbourne, is one of Australia's most important pieces of research infrastructure. After more than 10 years of operation, the beamlines at the Australian Synchrotron are well established and the demand for automation of research tasks is growing. Such tasks routinely involve the reduction of TB-scale data, online (realtime) analysis of the recorded data to guide experiments, and fully automated data management workflows.

In order to meet these demands, a generic, distributed workflow system was developed. It is based on well-established Python libraries and tools. The individual tasks of a workflow are arranged in a directed acyclic graph and one or more directed acyclic graphs form a workflow. Workers consume the tasks, allowing the processing of a workflow to scale horizontally. Data can flow between tasks and a variety of specialised tasks is available.

Lightflow has been released as open source on the Australian Synchrotron GitHub page [1].

INTRODUCTION

With the advent of sample changing robots and automated analysis tools, the beamlines at the Australian Synchrotron require the automation of data processing and analysis tasks. Looking into the individual automated workflows for the beamlines it is found that the implementation of the workflows share a very similar set of requirements. This allows the deployment of a common workflow system across all beamlines. An example for an automated workflow is shown in Fig. 1. A detector captures the data produced in an experiment and writes the data to files on a high speed storage. Upon the arrival of new files a pipeline is started which reads, processes, and analyses the new files. Often the result of processing the new files has to be merged with previous runs of the pipeline, recorded in a central storage. At the end, the result of the pipeline is displayed to the user.

A system that supports such a workflow has to offer the capability to start one or more pipelines based on external events, such as the appearance of new files or the change of EPICS Process Variables; model complex pipelines and allow their execution on a distributed computing system; and offer a central storage for keeping intermediate results. Lightflow, the workflow system presented here, fulfills those requirements.

ARCHITECTURE

Lightflow models a workflow as a set of individual tasks arranged as a directed acyclic graph (DAG). This specification encodes the direction that data flows as well as dependencies between tasks. Each workflow consists of one or more

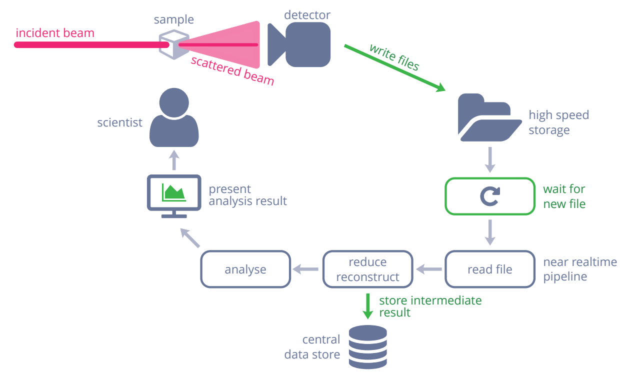

Figure 1: Near realtime pipeline at a beamline. Data captured by the detector is processed in near realtime in order to provide users with quick feedback.

DAGs. While the arrangement of tasks within a DAG cannot be changed at runtime, other DAGs can be triggered from within a task, therefore enabling a workflow to be adapted to varying inputs or changing conditions during runtime.

Lightflow employs a worker-based queuing system, in which workers consume individual tasks. This allows the processing of workflows to be distributed. Such a scheme has multiple benefits: It is easy to scale horizontally; tasks that can be executed in parallel are executed on available workers at the same time; tasks that require specialised hardware or software environments can be routed to dedicated workers; and it simplifies the integration into existing container based cloud environments.

In order to avoid single points of failure, such as a central daemon often found in other workflow tools, the queuing system is also used to manage and monitor workflows and DAGs. When a new workflow is started, it is placed in a special queue and is eventually consumed by a worker. A workflow is executed by sending its DAGs to their respective queues. Each DAG will then start and monitor the execution of its tasks. The diagram in Fig. 2 depicts the worker-based architecture of Lightflow.

IMPLEMENTATION

Lightflow is written in Python 3 and supports Python 3.5 and higher. It uses the Celery [2] library for queuing tasks and the NetworkX [3] module for managing the directed acyclic graphs. As redis [4] is a common database found at many beamlines at the Australian Synchrotron, it is the default backend for Celery in Lightflow. However, any other Celery backend can be used as well. In addition to redis, Lightflow uses MongoDB [5] in order to store data that is persistent during a workflow run. Examples include the

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REALTA AND pyDART: A SET OF PROGRAMS TO PERFORM REAL TIME ACQUISITION AND ON-LINE ANALYSIS AT THE FERMI FREE ELECTRON LASER

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Abstract

During the optimization phase of the FERMI Free Electron Laser (FEL) to deliver the best FEL pulses to users, many machine parameters have to be carefully tuned, like e.g. the seed laser intensity, the dispersion strength, etc. For that purpose, a new python-based acquisition tool, called REALTA (Real Time Acquisition program), has been developed to acquire various machine parameters, electron beam properties and FEL signals on a shot-by-shot basis thanks to the real time capabilities of the TANGO control system. The data are saved continuously during the acquisition in a HDF5 file. The pyDART (Python Data Analysis Real Time) program is the post-processing tool that enables a fast analysis of the data acquired with REALTA. It allows studying the correlations and dependences between the FEL and electron beam properties and the machine parameters. In this work, we present the REALTA and pyDART toolkit developed for the FERMI FEL.

INTRODUCTION

FERMI is the free electron laser facility in operation at Trieste in Italy. Based on a normal conducting linear accelerator, FERMI produces coherent pulses in the extreme ultraviolet (EUV) and soft - X-ray spectral range [1,2,3]. Stable operation of a FEL in the seeded mode as FERMI, requires a careful control of all the machine parameters. This requires a flexible control system that provides an effective integration of the machine devices. The Tango [4] toolkit is used at FERMI as a control system software allowing to easily include most machine hardware with dedicated device servers [5].

In high gain FELs such as FERMI, each electron bunch is an independent source of radiation whose properties critically depend on the electron beam properties. This leads to the need of a distributed real-time framework integrated into the control system that provides reliable information of electron and machine parameters on a pulse-to-pulse basis [5]. Within this framework, a unique "bunch number" time-stamp is distributed to all of the systems. Most of the measurement detectors (e.g., electron and photon diagnostics) and actuators (e.g., power supplies, RF systems) are synchronized with the bunch trigger and can have the "bunch number" associated to their measurements.

This capability is essential for the users operations of the FEL since it allows sorting and filtering the experimental data based on the required FEL properties. Moreover the real-time capability is very suited for machine studies since it allows to better identify the sensitivity to single parameters and recognize hidden correlation between FEL properties and jittering variables.

For most critical measurements both on the electron beam and on the FEL, it is important to allow operators and machine physicists to take advantage of the real-time capability of FERMI and use it for a post-processing on the data removing signal associate to non-desired shots. This capability was given at FERMI by a Matlab acquisition tool [6] interfaced to the control system via the available Tango bindings. For taking full advantage of the recent upgrade of FERMI to a 50 Hz operation it has been necessary to modify the available acquisition tool. While preserving a similar scheme, in order to increase the flexibility, the new acquisition tool has been programmed using the open source language Python [7] and takes advantage of the permanent development of open packages for data processing such as SciPy [8]. As for the old Matlab version, the new tool is divided in two main programs: one dedicated to the acquisition of real-time data (REALTA) and one to the quick analysis of the data (PyDART) that is necessary for a fast interpretation in control room. Datafiles are saved in the open HDF5 format [9]. HDF5 results in a versatile file format for storing and managing data and is compatible with many software platforms, such as Matlab, Mathematica, IGOR Pro, LabVIEW that can be used for a more deep offline analysis.

REALTA: THE ACQUISITION PROGRAM

REALTA is the new program developed in Python to perform flexible acquisitions of the numerous machine parameters. Using the Python bindings of Tango, it allows communicating with tango devices in a faster way than in Matlab. For the 50 Hz operation of FERMI, this is a critical point for reliable recording of 2D images from CCD cameras.

The acquisition program is controlled by a graphical user interface (GUI) that allows the operator to set various parameters for the acquisition. The GUI has two main panels, one dedicated to the setting of the list of devices to be acquired and one to the type of acquisition to be done.

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PACKAGING AND HIGH AVAILABILITY FOR DISTRIBUTED CONTROL SYSTEMS*

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Abstract

The ALMA Common Software (ACS) is a distributed framework used for control of astronomical observatories, which is built and deployed using roughly the same tools available at its design stage. Due to a shallow and rigid dependency management, the strong modularity principle of the framework cannot be exploited for packaging, installation and deployment. Moreover, life-cycle control of its components does not comply with standardized system-based mechanisms. These problems are shared by other instrument-based distributed systems. The new high-availability requirements of modern projects, such as the Cherenkov Telescope Array, tend to be implemented as new software features due to these problems, rather than using off-the-shelf and well-tested platform-based technologies. We present a general solution for high availability strongly-based on system services and proper packaging. We use RPM Packaging, oVirt and Docker as the infrastructure managers, Pacemaker as the software resource orchestrator and life-cycle process control through Systemd. A prototype for ACS was developed to handle its services and containers.

INTRODUCTION

The ALMA Common Software (ACS) was designed on the early 2000s, with the objective of providing a basic control and communication codebase for the ALMA observatory [1]. The technologies used for its construction were probably the best technical choices back then, but not all of them have aged well. For instance, ACS relies on the CORBA standard, which regulates almost every aspect of a distributed system using RPC. This was the main research topic in distributed systems at the time, but currently is in its way to obsolescence and is known to have a low performance among similar tools [2]. On the other hand, ACS is still a very powerful and tailored solution for complex array control, with a solid architecture and modular development that allows reusing the code for new projects like the Cherenkov Telescope Array [3]. This imposes new challenges for the framework not only at the software development level (e.g., gradually replacing CORBA interfaces), but also at the construction and deployment levels. In this paper we address this last problem to increase ACS robustness, flexibility and availability using generic solutions from modern, large and distributed software systems.

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ACS PACKAGING AND DEPLOYMENT

The ACS framework is currently built by using its own construction system based on `make` [4]. It consists in a master `Makefile`, which enters each software module and tool searching for a standard directory structure that have other `Makefiles`, which needs a common base file called `acsMakefile` to operate. This recursive `Makefile` paradigm is widely considered a bad practice, because dependencies are hard to maintain and the construction process is difficult to track and resume. Also, it requires to previously compile other tools known as External Products, with specific versions and patches different from the ones offered by the operating system distribution. Moreover, the construction paths and configurations are setup through environment variables handled by the `bash_profile.acs` file that must be sourced. All this software is finally packaged as a very large monolithic tarball meant to be uncompressed in a very specific OS version.

Besides the direct difficulties at the construction stage, the software distribution produce a steep learning curve for its installation and environment setup, a non-modular deployment of the software packages, a replace-all update method, and no separation between runtime, configuration, development, example and testing packages. A few attempts to update the ACS construction and deployment system have been tested in the past[5]. Among the tools used, two of them stand out: RPM [6] and Docker [7].

RPM Packaging of ACS

RPM is the package manager of multiple operative systems and handles the building, installing, updating and dependency restrictions of the software. It has existed since 1997, and it's core file contains the step-by-step instructions to build the software once, and deploy the binaries and other products ready to use, many times. It also allows to distribute updates with controlled dependencies and versions. One of the resulting products, the Source RPM, allows migration among different architectures almost transparently.

For ACS, we address the packaging problem in a pragmatic fashion, assuming a simple tree-like dependency model, where at the leafs were the components that were dependency-free but needed by the parent node. The ACS-base is divided in three groups: *External Tools*, *Tools* and *Kit*, with External Tools as the lowest group in the tree. With the off-the-shelf notion, each software was searched for in the repositories of Fedora (21 to 26), CentOS and the special repositories SCL, SIG and OpenSUSE, searching for the nearest match regarding the version shipped with ACS.

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NETWORK SYSTEM OPERATION FOR J-PARC ACCELERATORS

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Abstract

The network systems for J-PARC accelerators has been operated over ten years. This report gives: a) an overview of the control network system, b) discussion on relationships between control network and the office network, and c) recent security issues (policy for antivirus) for terminals and servers. Operation experiences, including troubles, are also presented.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator complex. It consists of three accelerators: a) 400-MeV Linac (LI), b) 3-GeV Rapid Cycling Synchrotron (RCS), c) 30-GeV Main Ring (MR), and three experimental facilities: d) Material and Life Science Facility (MLF), e) Hadron Facility (HD), f) Neutrino Facility (NU) [1-2]. Since the initial beam in 2006, J-PARC has been improving beam power. Recent studies demonstrated a 1-MW equivalent beam [3].

The control system for J-PARC accelerators was developed using the EPICS (Experimental Physics and Industrial Control System) toolkit [4-5]. In advance of the initial beam, the network system for the control system started operation for Linac around 2005 [6], followed by extensions to whole facilities. It has been operated over ten years since then.

CONTROL NETWORK FOR ACCELERATORS

Network Overview

The logical configuration of the control network is shown in Figure 1. The "core switches", main and sub, are located in CCB (Central Control Building), which are the center of the network system. The accelerator buildings (LI, RCS, MR-D3) and the MLF building are linked to the core at the 10Gbps rate. While other buildings (MR-D1, MR-D2, NU, HD) are linked to the MR-D3 building at the 1Gbps rate. Buildings layout with fibre-optic cable network is shown in Figure 2.

"Edge switches", which have physical network connections, are shown in the lower part of each building in Figure 1. Typical edge switch has 24 or 48 ports of the 1Gbps rate. Numbers of edge switches in buildings are given in Table 1. Total number is about 250 in 2017. The photo of the core switches and typical edge switches are shown in Figure 3.

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As shown in Figure 1, each edge switch has two routes to the core. In normal operation, the main route is used and the sub is stand-by. When the main route is stopped by a trouble, the sub takes over in a few seconds, and network operation continues. This redundancy guarantees non-stop operation against single fault in the system.

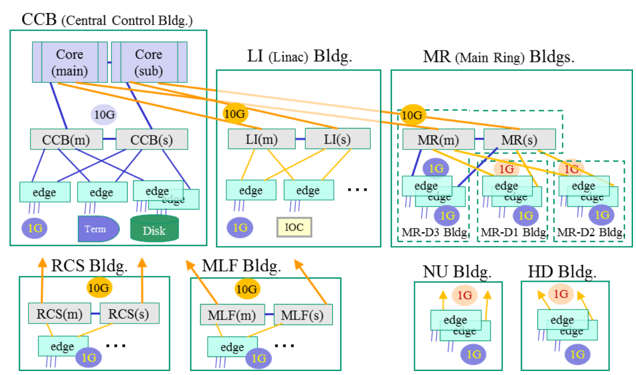

Figure 1: Logical configuration of the network system.

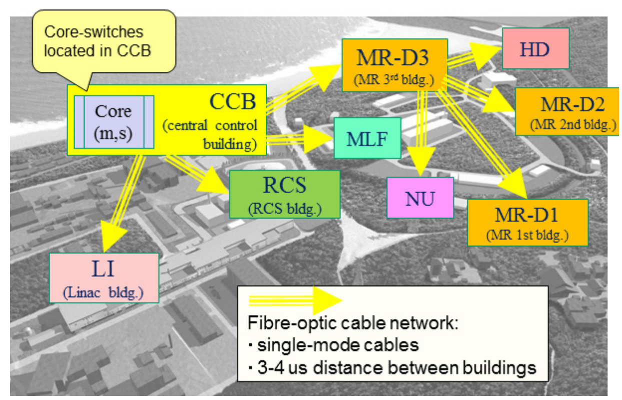

Figure 2: Buildings layout with fibre-optic network.

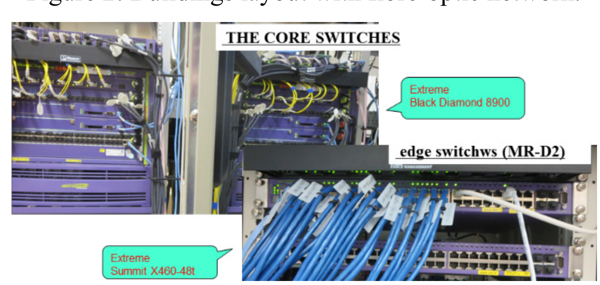

Figure 3: The core switches and typical edge switches.

VLAN Configuration

In order to avoid traffic concentration, we divided the control network into multiple VLANs. As shown in Table

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NEW IT-INFRASTRUCTURE OF ACCELERATORS AT BINP

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Abstract

In 2017 the Injection Complex at Budker Institute, Novosibirsk, Russia began to operate for its consumers - colliders VEPP-4 and VEPP-2000. For successful functioning of these installations is very important to ensure a stable operation of their control systems and IT-infrastructure. The given article is about new IT-infrastructures of three accelerators: Injection Complex, VEPP-2000 and VEPP-4. IT-infrastructure for accelerators consists of servers, network equipment and system software with 10-20 years life-cycle and timely support. The reasons to create IT-infrastructure with the same principles are costs minimization and simplification of support. The following points that underlie during designing are high availability, flexibility and low cost. First is achieved through redundancy of hardware - doubling of servers, disks and network interconnections. Flexibility is caused by extensive use of virtualization that allows easy migration from one hardware to another in case of fault and gives users an ability to use custom system environment. Low cost – from equipment unification and minimizing proprietary solutions.

INTRODUCTION

Two BINP colliders VEPP-4M and VEPP-2000 were commissioned with feeding from VEPP-5 injection complex in 2016 [1-4]. In order to ensure continuous operation it was proposed to create highly available IT-infrastructure for both colliders and injection complex. Injection complex and collider control systems should exchange online operation data and send queries over common network to request beam and obtain beam parameters. Since all facilities have similar requirements for IT-infrastructure we tried to reduce initial deployment efforts and costs by using the same hardware and software basis for all facilities.

High availability and simple maintenance of the IT-infrastructure are the main ideas that were laid down in the base of the system. When designing it, such important requirements also where considered:

- high fault tolerance;
- recovery after failure;
- administration ease (applying specialized high-level tools);
- flexibility according to custom needs;
- equipment unification with the purpose of reducing the nomenclature (backup equipment minimization);
- the possibility of the hardware upgrading.

DESIGN DECISIONS

Hardware

After a long period of using PCs as management servers at BINP, it became obvious that their relatively low cost cannot be a decisive argument in favour of choosing this equipment for the control systems of large experimental facilities.

Personal computers have a number of disadvantages, such as:

- relatively low quality of manufacturing;
- they are not designed for continuous operation (24x365);
- poor cooling;
- limited resources;
- complexity of operational maintenance and expansion;
- inconvenient form-factor (there is no possibility to install them in telecommunication and server cabinets and racks);
- lack of advanced hardware solutions (communication interfaces, reliability enhancement technologies, etc.).

Only relatively low cost and off-the-shelf availability can be considered as advantages.

Due to foresaid, it was decided to switch to specialized server hardware, designed for long-term operation and satisfying the technical requirements for productivity in order to improve the quality of work and accessibility of the management system. As a result, the common IT-infrastructure was developed.

In general it consists of few pairs of servers. Any server in each pair can fully (and automatically) perform all the functions assigned to their pair, in case the second machine fails. Also the structure includes workstations for interaction with operators and a set of thin clients located in the most needed places on facility for local operation. To increase maintainability and availability, some of servers have redundant power supply units. Two Uninterruptible Power Supplies (UPS) are used to provide guaranteed power for all infrastructure equipment located in the rack. Each of the servers in the pair is connected to different UPS. In case of redundant power supplies in server each power supply connects two different UPS. Finally, for better availability each power supply plugged in different power lines. The scheme of hardware and network interconnection is shown on the Fig. 1.

To increase *reliability* servers are equipped with ECC memory. That can correct small errors and detect bigger ones. For remote control all servers have Intelligent Platform Management Interface (IPMI) with dedicated Ethernet port. It allows to perform any operation with server beginning from remote graphical console (full replacement for local VGA output) and finishing with BIOS configuring and firmware upgrading.

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DEVELOPMENT, COMMISSIONING AND OPERATION OF THE LARGE SCALE CO_2 DETECTOR COOLING SYSTEMS FOR CMS PIXEL PHASE I UPGRADE

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Abstract

During the 2017 Year-end Technical Stop of the Large Hadron Collider at CERN, the CMS experiment has successfully installed a new pixel detector in the frame of Phase I upgrade. This new detector will operate using evaporative CO_2 technology as its cooling system. Carbon Dioxide, as state of the art technology for current and future tracking detectors, allows for significant material budget saving that is critical for the tracking performance.

The road towards operation of the final CO_2 cooling system in the experiment passed through intensive prototype phase at the CMS Tracker Integration Facility (TIF) for both cooling process hardware and its control system.

This paper briefly describes the general design of both the CMS and TIF CO_2 detector cooling systems, and focuses on control system architecture, operation and safety philosophy, commissioning results and operation experience. Additionally, experience in using the Ethernet IP industrial fieldbus as distributed IO is presented. Various pros and cons of using this technology are discussed, based on the solutions developed for Schneider Premium PLCs, WAGO and FESTO IOs using the UNICOS CPC 6 framework of CERN.

INTRODUCTION

CMS Pixel Phase I Upgrade

Compact Muon Solenoid (CMS) is one of the two large multi-purpose detectors installed on the Large Hadron Collider (LHC), operating at the European Organization for Nuclear Research (CERN). The Pixel detector is the innermost CMS sub-detector and it is used for precise tracking of the particles produced by the collisions. Due to the vicinity to the interaction point (i.e. the small region where the particle collide), the radiation harm have a major impact on the lifetime of the silicon sensor. To limit the radiation ageing effect, the temperature of the silicon sensors must be kept below -10°C. In order to cope with the increase in the collision rate provided by the LHC, the CMS experiment replaced all of its Pixel detector during an extended winter technical stop in 2016/2017 year. The new detector features several important improvements including: new front-end chips, a nearly twofold increase of the active surface, reduced amount of inactive material in the tracking volume. Following the upgrade, the Barrel Pixel (BPIX) grew from 48M to 80Mchannels and the Forward Pixel (FPIX) from 18M to 45M channels. The new design of the detector, despite the larger area and increase of channels, substantially reduced the amount of material. This was achieved mainly by the introduction of a new two phase CO_2 cooling system that replaced the C_6F_{14} liquid cooling [1].

The Cooling Requirements

The cooling system needs to cope with the heat load produced by the detector electronics but also with the heat leak from the ambient environment to the cold elements of the system. For the BPIX detector, the estimated power is around 6 kW, for the FPIX is around 3 kW, while an estimation around 2kWis made for the heat leak from the ambient. For redundancy reasons, it has been decided to install two cooling plants working in parallel. However, each of the cooling plants has been designed to handle a heat load of 15 kW, which provides sufficient safety margin to provide alone the required refrigeration power to the full detector for operation in the temperature range from 15°C up to −22°C.

Tracker Integration Facility (TIF)

In order to handle the requirements of the CMS Pixel upgrade [PP1], at first stage a full-scale prototype of a 15kW evaporative CO_2 cooling system has been designed, constructed and commissioned in 2013 [2] in a dedicated surface installation called Tracker Integration Facility (TIF). The TIF cooling system prototype consist of three main units: one cooling plant core, one manifold and one accumulator. The prototype represents one half of the final cooling system which was installed in the underground area of the CMS experiment.

CMS Final

The final CO_2 cooling system comprises two individual cooling units. In normal operation, one is dedicated to the BPIX detector and the other to the FPIX detector. Each unit consists of three main sections: the Accumulator, the Plant Core and the Manifold.

- The accumulator is a vessel always filled with a mixture of liquid and vapour CO_2. It is connected to the return line of the refrigeration loop, keeping the 2-phase CO_2 returning from the detector at the same pressure as in the vessel. The accumulator pressure is regulating by the heating and cooling action.
- In the plant core, the returning two-phase CO_2 is cooled down and liquefied in a heat exchanger by a standard primary chiller, based on R507a refrigerant. Afterwards, the liquid CO_2 is pumped by a membrane pump through vacuum insulated transfer lines to a distribution manifold. The plant core is also equipped

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PRESENT STATUS OF THE DAEJEON ION ACCELERATOR COMPLEX AT KAERI*

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Abstract

The Daejeon ion accelerator complex (DIAC) is being built at the Korea atomic energy research institute (KAERI) for various applications. Based on linear accelerators (linacs) of the Tokai Radioactive Ion Accelerator Complex (TRIAC) given from the high energy accelerator research organization (KEK) [1–4], Japan, the dedicated accelerators in the DIAC are designed to produce stable heavy ion beams. In this article, status, plans, and some test results for the DIAC construction are presented and discussed.

INTRODUCTION

The DIAC is being constructed at KAERI in order to fulfil an increasing demand for heavy ion beam facilities for structural material study, biological research and nanomaterial treatment. The dedicated accelerators in the DIAC are designed to produce stable heavy ion beams with energies up to 1 MeV/u and beam currents up to 300 μA [5, 6]. The construction has now reached the stage where the DIAC system is ready for beam tuning.

OVERVIEW OF DIAC CONSTRUCTION

The heavy ion beam line of the DIAC consists roughly of an electron cyclotron resonance (ECR) ion source, a radio-frequency quadrupole (RFQ) linac, a rebuncher (RB), and an interdigital H-type (IH) linac as shown in Figure 1.

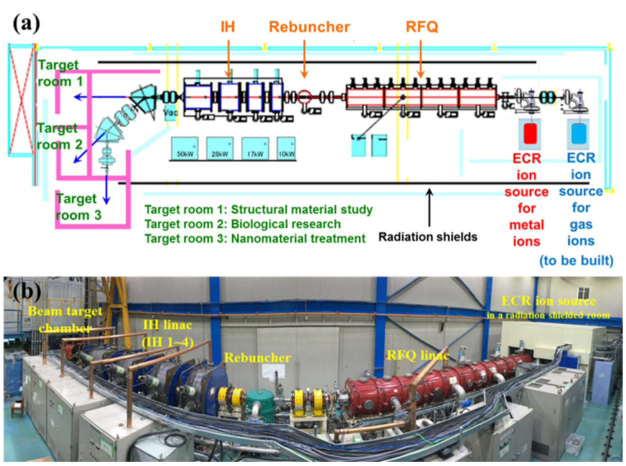

Figure 1: (a) Schematic layout of the DIAC, (b) Panoramic view of the DIAC beam line.

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The DIAC facilities are designed to handle stable non-radioactive beams. According to user demand, the separated two ECR sources (i.e., an 18 GHz KEK – the high energy accelerator research organization ECR ion source with a metal oven and a 14.5 GHz KAERI ECR ion source) together with low energy beam transport line (LEBT) can supply linacs with both metal and non-metal ions. The 25.96 MHz RFQ linac accelerates ions up to 178 keV/u. Then, the ions accelerated by the RFQ reach to the 51.92 MHz IH linac via a transport system composed of a RB and two sets of quadrupole doublet. Finally, the IH linac can re-accelerate the ions up to 1 MeV/u. The detailed specifications of the DIAC linacs can be found in Table 1 [1–4].

Table 1: Specifications of the DIAC Linacs

	RFQ	IH
Frequency	25.96 MHz	51.92 MHz
Synchronous phase	- 30 deg	- 25 deg.
Charge-to-mass ratio	≥1/28	≥1/9
Input energy	2.07 keV/u	178.4 keV/u
Output energy	178 keV/u	178–1090 keV/u
Normalized emittance	0.6πmm·mrad	
Energy spread	1.03%	≤2.8%
Duty factor	30–100%	100%
Repetition rate	20–1000 Hz	
Total length	8.6 m	5.6 m

To date, (1) assembly of the ECR ion source and linacs delivered in pieces from the KEK, (2) installation of the power supply, coolant circulation system, and vacuum pump system, (3) acquisition of the radiation safety license, (4) operation test of the ECR ion source, (5) full-power tests of IH and RFQ power amplifiers, (6) construction of radiation shielded walls for the DIAC, (7) tests on the RFQ, RB, and IH RF tuners, (8) reorganization of the integrated control system, and (9) development of a beam target chamber have been completed. Presently, beam tuning of the DIAC accelerators is in progress. The following section gives results on the full-power test of the RFQ/IH linacs, the reorganization of the DIAC integrated control system, and development of the beam target chamber.

FULL-POWER TEST OF THE LINACS

To check performance capacity of the reinstalled IH, RB, RFQ and their power amplifiers, measurement of Q factors of the cavities, stored electromagnetic energy of the IH cavities as a function of peak RF power, and full-power test of the RFQ linac were carried out.

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LIA-20 CONTROL SYSTEM PROJECT

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Abstract

The project of the control system of linear induction accelerator LIA-20 for radiography is presented in this paper. The accelerator is a complex pulsed machine designed to provide a series of three consecutive electron pulses with an energy up to 20 MeV, current 2 kA and lateral beam size less then 1 mm. To allow reliable operation of the whole complex, coordinated functioning of more then 700 devices must be guaranteed in time frames from milliseconds to several nanoseconds. Total number of control channels exceeds 6000. The control system is based on a variety of specially developed VME and CAN modules and crates. Tango program infrastructure is used. The first stage of commissioning will take place in the end of 2017 and will include launching 5 MeV version of the accelerator.

INTRODUCTION

Linear Induction Accelerator LIA-20 is designed in BINP to be used for the flash X-Ray radiography. It will provide three consecutive electron beams with an energy up to 20 MeV, current up to 2 kA and the beam lateral size after focusing on the target less than 1 mm. Successsfully commissioned LIA-2 accelerator (2 MeV, 2 kA) could be considered a prototype for the injector of the 20 MeV installation [1].

To facilitate the launching process and test all equipment first a 5 MeV version of the installation would be assembled at BINP. Then after necessary beam parameters would be obtained, 20 MeV single-pulsed installation would be built. After that, several-pulsed version is planned.

It is necessary to design an adequate control system for such an installation taking into account different requirements and a scope of the project. Such a project, however not final is presented in this paper.

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STRUCTURE OF THE ACCELERATOR

LIA-20 consists of the injector, a number of accelerating modules (AM) and transport channel. The injector has 92 inductors and generates an electon beam with the current up to 2 kA and the energy 2 MeV. 30 "short" accelerating modules (SAM) are placed after the injector. Each of them consists of 16 inductors and adds an energy of 0.33 MeV to the beam. Then 12 "long" accelerating modules (LAM) are placed each of them consists of 32 inductors. Each LAM adds an energy of 0.66 MeV to the beam.

The total length of the accelerator is about 75 meters without the transport channel and about 120 meters with it. Therefore controlling the positioning of optical system is critical. Two position control systems are provided to control the horisontal, vertical and angular offsets of the beam axis.

Focusing solenoidal lenses and correctors are placed between accelerating modules. The lenses are powered by pulsed power supply that provides 0.5 kA, 2.05 ms sinusoidal pulse. Beam position monitors (BPM's) are present between accelerating modules. Several other technological sub-systems including vacuum and insulating gas pressure require control.

Accelerating pulses on the inductors are formed by the modulators, each of them provides 40 kV 60-300 ns pulse with fronts better than 50 ns for two inductors. To provide several consecutive pulses, several modulators will be used. Each thyratron in modulator has it's own delay, therefore to attain required accelerating voltage pulse form, starting moments must be tuned with accuracy better than 4 ns.

The modulators are grouped in racks called pulsed power supply racks (PPSR). Eight modulators provide one pulse, 16 are used for two-pulsed regime and 24 are required for three consecutive pulses. The injector is supplied by 3 PPSR's,

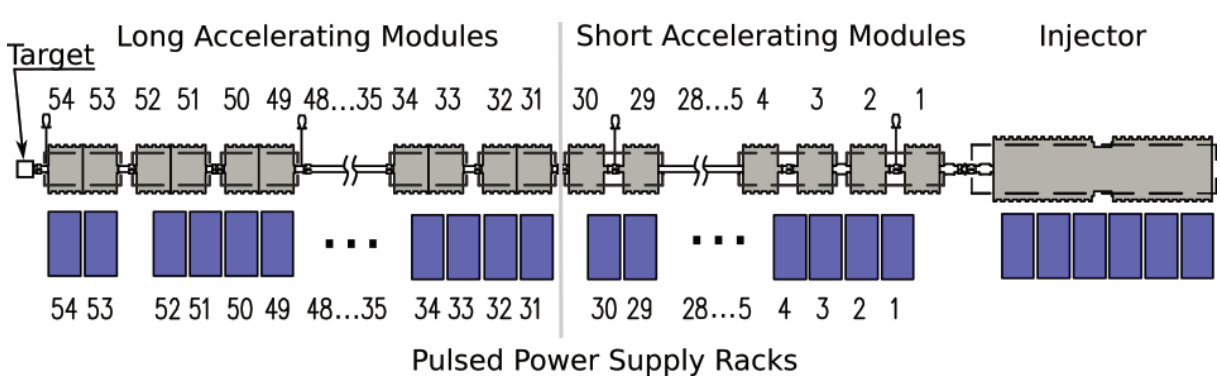

Figure 1: Scheme of LIA-20 Accelerator.

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STATUS OF THE LIPAC MEBT LOCAL CONTROL SYSTEM*

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Abstract

The Linear Ifmif Prototype Accelerator (LIPAc), a 125 mA 9 MeV deuteron accelerator, is being commissioned in Rokkasho, Japan. The Medium Energy Beam Transport (MEBT) line [1] has already been installed and connected to the ancillary systems and the adjacent systems, the Radio Frequency Quadrupole (RFQ) and the Diagnostics Plate (DP). The status of the MEBT Local Control System (LCS) was presented in the previous edition of ICALEPCS [2]. Since then, the functional specifications of the MEBT components controls have been completed, the control cabinets have been designed and are now being installed, and the software has been written. In this paper, the final architecture and functionality of the MEBT LCS will be described and the preliminary results of its commissioning will be presented.

INTRODUCTION

The MEBT line of LIPAc transports and matches the beam out of the Radio Frequency Quadrupole (RFQ) into the Superconducting RF linac. The devices have been described in [1]. The LCS is in charge of the supervision and actuation of the MEBT devices and auxiliary systems:

- the vacuum system components: pumps (primary, turbos and ionic) valves, heaters and gauges.
- the instrumentation of the water cooling system.
- the instrumentation of the buncher cavities[3].
- the beam scrapers.
- the instrumentation of the magnets.
- the magnets power supplies.

The control system of LIPAc is based on EPICS. As part of the IFMIF/EVEDA project, CEA-Irfu[1]has designed the Common Software Platform (CSP) [4] with two main goals: providing a common set of programs for the different subsystems and defining the templates for the EPICS top directories and the operator interfaces (OPI).

LCS DESCRIPTION

Physical Layout

The LCS is housed in two seismic EMC 47U cabinets (see Fig. 1), 800 mm(D) × 600 mm(W). The power supplies (PSU) for the quadrupole magnets and the steerer are mounted in an additional two cabinets of the same dimensions. The cabinets are housed in the RF area of the accelerator building. Power and signal cables run from the cabinets to the MEBT devices, with a length of about 50 m. Interlock cables connect the LCS to the Machine Protection System (MPS) and to the Low Level RF system of the buncher cavities. The power for the cabinets is supplied via the MEBT secondary board, which is part of the power distribution system of the accelerator building.

Hardware

The Input Output Controller (IOC) is a fanless computer running CentOS. The IOC is connected to the Control System Network. It is also connected to the MEBT PLC and the power supplies, via a dedicated 16-port switch. Communication between the IOC and the power supplies is performed via the Modbus driver, version 2.7. Communication with the PLC uses the S7plcDriver, version 1.17. A diagram of the LCS can be seen in Fig. 2. The main PLC consists of a Siemens CPU S7-319, digital and analog input/output modules and a CP340 module for serial communication (ASCII over RS-485). The PLC acts also as Profinet I/O controller and Profibus master. The instrumentation of the rebuncher cavities, the water cooling system and the magnets is directly connected to the input/output modules.

Figure 1: MEBT cabinet 2.

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STATUS OF THE NSRC SOLARIS CONTROL SYSTEM

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Abstract

A National Synchrotron Radiation Centre SOLARIS is a first synchrotron light source in Poland. SOLARIS consists of a linear accelerator, 1.5 GeV storage ring and 2 beamlines (PEEM and UARPES). The beamlines are in commissioning phase and should be ready for the first users in 2018. Additionally there are plans for a few next beamlines. The control system is based on Tango Controls. The system is fully operational. An archiving system uses HDB, TDB and HDB++ tools. PLC system consists of two parts: MPS (Machine Protection System) and PSS (Personal Safety System). The control system has been upgraded recently and it is constantly being improved to meet expectations of its users. The status of the SOLARIS Control System will be presented.

TANGO CONTROL SYSTEM

A software platform for the SOLARIS control system is Tango Controls [1,2]. The control system based on Tango Controls has a lot of elements: a Tango Host server with database, an archiving system, high level and low level software [3]. At Solaris, there are three instances of Tango: one for the linac and the storage ring (Tango 9) and one per each of two beamlines (Tango 8 at UARPES and Tango 9 at PEEM/XAS). The upgrade of the control system for the linac and the storage ring from Tango 8 to Tango 9 took place in December 2015, while for the beamline PEEM/XAS in December 2016. During these upgrades the operating system was also changed from CentOS 6.5 to CentOS 7. Control systems are responsible for acqui-sition of more than 5000 signals. The archiving system uses TDB and HDB tools from Soleil. At PEEM/XAS beamline, there are held tests of the HDB++ archiving system. At Solaris, low level applications are developed in the Python program-ming language using an API to the Tango core – the PyTango package. Device servers are used for connection of hardware to the control system. The facade device library from MAX IV (Lund, Sweden) is used for high-level Tango devices. The Taurus package from ALBA (Barcelona, Spain) is used for writing high level soft-ware, like GUIs. In addition, there is preparation work for introducing new synoptic panels of LINAC and water interlocks based on Max IV library svgsynoptic2. Water interlocks panel has been shown on the Fig. 1. For browsing Tango database and checking each device, operators use an open source application ControlProgram. The ControlProgram is also used for running Tango tools and another GUIs. The ControlProgram has been shown on the Fig. 2.

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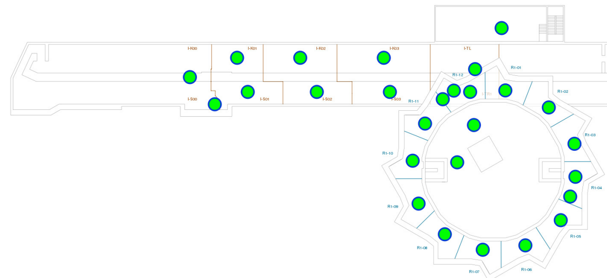

Figure 1: Water interlocks synoptic panel.

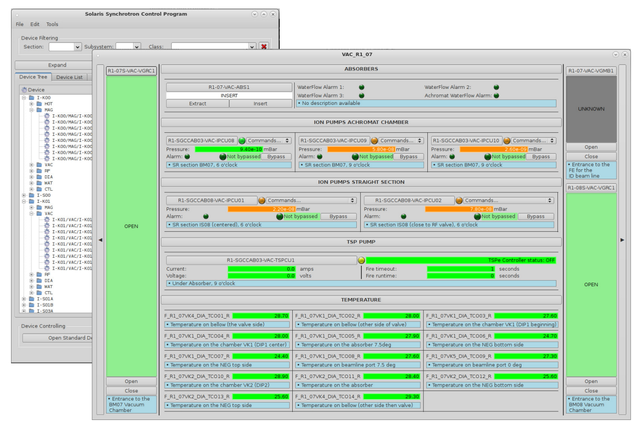

Figure 2: Control Program.

PLC SYSTEMS

There are two different PLC systems at Solaris. The first one is MPS (Machine Protection System). It is used to protect devices against working in unwanted conditions. It is based on Rockwell Automations solutions. The sec-ond one is PSS (Personal Safety System). It provides radiation safety. It is based on the Siemens S7-300 fail-safe controller. The Personal Safety System GUI has been shown on the Fig. 3.

TIMING

The SOLARIS timing system is based on Micro Re-search Finland (MRF) hardware. It consists of event generators (EVG) and event receivers (EVR). EVGs generate a stream of events and send them to EVRs. Upon receipt of the event EVR performs the action. Basic structure of SOLARIS timing system has been shown on the Fig. 4.

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THE LINAC4 VACUUM CONTROL SYSTEM

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Abstract

Linac4 is 160 MeV H- linear accelerator replacing Linac2 as the first injector to the CERN accelerator complex, which culminates with the Large Hadron Collider. This new Linac will increase the beam brightness by a factor of two.

The vacuum installation consists of 235 remotely controlled pumps, valves and gauges. These instruments are either controlled individually or driven by pumping stations and gas injection processes. Valves and pumps are interlocked according to gauge pressure levels and pump statuses. The vacuum control system communicates with the beam interlock system, the ion source electronics and the Radio Frequency control system, through cabled digital and analog signals.

The vacuum control system is based on commercial Programmable Logical Controllers (Siemens PLCs) and a Supervisory Control And Data Acquisition application (Siemens SCADA: WINCC OA). This paper describes the control architecture and process, and reports on the control requirements and the implemented solutions.

INTRODUCTION

CERN, the European Organization for Nuclear Research, has built a new linear accelerator called Linac4. Linear accelerators are the first stage of the Large Hadron Collider (LHC) injector complex. The Linac4 is intended to replace Linac2 that is in operation since 1978, and will accelerate H− ions up to 160 MeV.

Linac4 is 90 m long machine composed of 11 vacuum sectors. This sectorisation reduces the effort of the commissioning and limits the impact of leaks or mechanical interventions. More than 230 remotely controlled instruments are used to achieve a high vacuum level all along the Linac4 line. The vacuum level depends on the sector: at the source it is limited by gas injections and reaches 10^{-6} mbar; the sector of the radiofrequency quadrupole (RFQ) reaches 10^{-9} mbar; and the pressure of other sectors is between 10^{-7} and 10^{-8} mbar. The remotely controlled vacuum instruments include pumps, gauges, valves…

The vacuum control system is based on the LHC vacuum control architecture [1], but differs on some aspects: from circular to linear accelerator, specifications change; the hardware interlock system is slightly different; a new type of logic for fixed pumping groups and a specific control process for gas injection have been developed.

HARDWARE ARCHITECTURE

The hardware architecture is a three-layer control system: field vacuum instruments are driven by the controller layer composed of commercial and in-house designed electronic units; the automation layer is based on Siemens™ Programmable Logic Controller (PLC); the supervisory layer is a data server running WinCC-OA™ application. The hardware architecture is illustrated by the Figure 1.

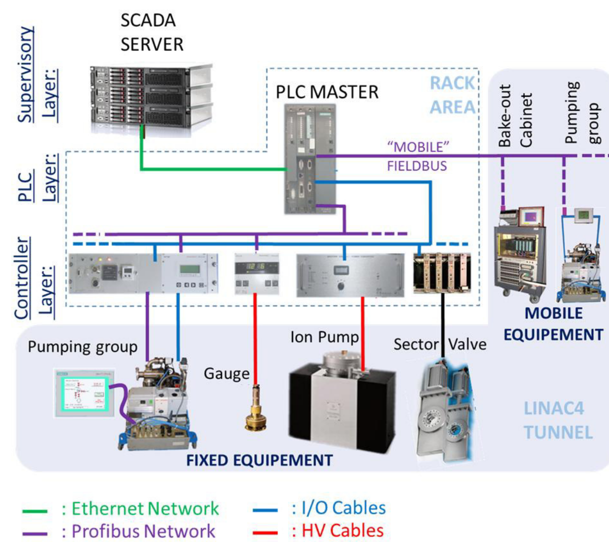

Figure 1: Vacuum Control Hardware Architecture.

Sector Valve Interlock System

The vacuum controls of Linac4 have a hardware interlock system to prevent the propagation of a pressure increase and to protect beam instruments. Sector valve control crates are connected to the Beam Interlock System, in the case of a sector valve closing, the beam is stopped.

The sector valves are interlocked by relays from gauge controllers or from ion pump controllers. The ion pumps are preferred because they are less sensitive to pressure spikes and so reduce the number of false interlocks and therefore of unnecessary beam stops.

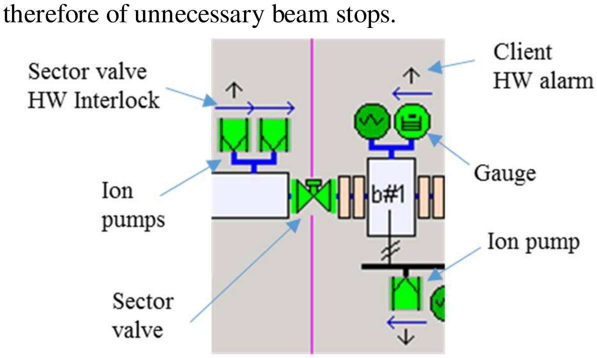

Figure 2: Supervisory panel with instrument widgets and illustration of hardware interlocks.

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DESIGN AND IMPLEMENTATION OF SESAME'S STORAGE RING CONTROL SYSTEM

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Abstract

SESAME is a synchrotron light source located in Allan, Jordan. It is expected to become operational in late 2017. Storage ring is currently under commissioning. SESAME's control systems are based on EPICS used for developing both soft and hard IOCs. Control System Studio (CSS) is used to build the graphical user interfaces. PLCs are used in machine protection and personal safety systems. VME crates are used in timing and power supplies control systems. This paper presents progress made in design and development of the Storage ring's control systems including: vacuum, power supplies, RF, diagnostics, cooling, MPS, PSS and timing systems.

INTRODUCTION

SESAME consists of a 22 MeV Microtron, an 800 MeV Booster Synchrotron and a 2.5 GeV Storage Ring. The storage ring is composed of 16 cells; each cell consists of a bending section and a straight section.

EPICS base version R3.14.12 is used in control system implementation. EPICS Input/ output Controllers (IOCs) are running as servers. A custom build of CSS based on V.3.16 is used to implement graphical user interfaces. Scientific Linux version 6.4 is used as a main operating system in development and administration platform. A Git version control is used to track development and documentation. Siemens S7 PLC controllers are used for the Machine Protection System (MPS). Allen Bradley PLC controller is used for the Personal Safety System (PSS). VME crates are used in the Timing and Power Supplies systems. All clients, servers, and controllers are connected to an isolated machine network. Twelve virtual servers are reserved to run the IOCs, archive system, alarm system and Git repositories.

The storage ring's control system is divided into several subsystems: vacuum, power supplies, RF, diagnostics, cooling, MPS, PSS and timing. Each control subsystem consists of one or more clients, servers, and controllers.

DESIGN AND IMPLEMENTATION

Vacuum

The vacuum subsystem for the Storage Ring consists of 106 ion pumps, 27 vacuum gauges, 16 gate valves, 32 ion pump controller, 8 vacuum gauge controllers, and one PLC. Ion pumps are connected to a quad ion pump controllers, where each controller is connected to the control network through Ethernet communication port. Gauge controllers have RS232 serial communication ports. Four serial terminal servers are used to connect the gauge controllers to the control network. Gate valves and gauge controllers' set points are connected to the PLC which is used for machine protection system.

Vacuum control system consists of CSS Operator Interfaces (OPIs), One EPICS IOC is running on a virtual server with Linux-x86 platform to control all vacuum subsystem devices. Stream device and S7PLC EPICS support modules are used in the IOC. Table 1 shows a summary of the devices used in the vacuum subsystem.

Table 1: Vacuum Subsystem Devices

Device	Qty.	Manufacturer
Ion pump Controller	32	Gamma Vacuum - QPC
Ion Pump	106	Gamma Vacuum
Gauge Controller	8	Agilent - XGS600
IMG Gauge	27	Agilent
Serial terminal server	4	3onedata
PLC	1	Siemens – S7 300

Power Supplies

The power supply subsystem for the Storage Ring consists of DC power supplies and pulsed power supplies. DC power supplies consist of 141 power supplies selected from EEI [1], TDK-lambda [2] and PSI [3]. For the quadrupoles and sextupoles, commercial off-the-shelf units from TDK-Lamda were selected. These power supplies are controlled by an analogue voltage. The dipole power supply was chosen from an existing design by EEI, Italy, in operation at Medaustron, Austria. The power supply is controlled digitally via an RS422 link. Finally, the corrector power supplies were supplied by PSI (Paul Scherrer Institute). Power supply controller (PSC) is used from PSI. The PSC reads the measurement from the current transducer and generates the voltage reference to be sent to the voltage source in order to produce an accurate current. The regulation loop is implemented in the digital domain but the voltage reference can be either analogue or digital. This requires a high precision current transducer and ADC for the reading of the current and a DAC to generate an analogue voltage reference.

Power supplies' control system consists of CSS OPIs (clients), EPICS IOCs, (gateways or servers), power supply controllers (PSCs), and a timing system. EPICS IOCs are running on Linux based PowerPC platforms hosted inside 1U VME crates. Gateways relay commands from the clients to the PSCs, and report back process variables. Each gateway controls up to 16 PSCs. There are a total of 6 gateways controlling a total of 93 PSCs. Gateways communicate with clients over a Gigabit Ethernet network, and communicate with PSCs over

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CONCEPTUAL DESIGN OF THE CRYOGENIC CONTROL SYSTEM OF CFETR COIL TEST FACILITY

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Abstract

China Fusion Engineering Test Reactor (CFETR) is superconducting Tokamak device which is next-generation engineering reactor between ITER and DEMO. It is now being designed by China national integration design group. In the present design, its magnet system consists of 16 Toroidal Field (TF) coils, 6 Center Solenoid (CS) coils and 8 Poloidal Field (PF) coils. A helium refrigerator with an equivalent cooling capacity of 5kW at 4.5K for CFETR TF coil test facility is proposed. It can provide 3.7K & 4.5K supercritical helium for TF coil, 50K cold helium with a 10g/s flow rate for High Temperature superconducting (HTS) current leads and 50K cold helium with a cooling capacity of 1.5kW for thermal shield. This paper presents the conceptual design of cryogenic control system for CFETR TF coil test including of architecture, hardware design and software development.

INTRODUCTION

China Fusion Engineering Test Reactor (CFETR) is superconducting Tokamak device which is next-generation engineering reactor between ITER and DEMO [1].It is now being designed by China national integration design group. CFETR is envisioned to provide 50~200M fusion power and a demonstration of long pulse or steady-state operation with duty cycle time not less than 0.3~0.5 and the full cycle of tritium self-sustained with TBR not less than 1.2 based on the existing EAST and ITER physical and technology. Magnet system of CFETR consists of 16 TF coils, 6 CS coils and 6 PF coils and another 2 PF coils (CC1 and CC2) at the bottom of the device to produce the snowflake and super-x equilibrium shape[2]. The Fig.1 shows the structure of the superconducting magnets system. The toroidal magnetic field of CFETR is generated by 16 D-shaped superconducting coils which is winded with 132Nb3Sn CICCCs with a height of about 14m and about 11m width[3].

CFETR TF test facility includes cryogenic system, cryostat, vacuum system, power supply system, magnet protection system, instrumentation and control system. Helium refrigerator is key component of the cryogenic system which provides adequate refrigeration power to cool down and maintain the testing coil in superconducting state under normal test phase. So the 5kW/4.5K helium refrigerator is designed at ASIPP. This paper presents the conceptual design of cryogenic control system for CFETR TF coil test including of architecture, hardware design and software development.

CRYOGENIC SYSTEM OF TF COIL TEST FACILITY

The CFETR TF coil will be installed in a large cryostat and mechanically fixed by low thermal conductivity material when in the process of cold test. In order to further reduce the heat load to 4.5K, a 60K thermal radiation shied between the magnet vessel and the cryostat shell is designed and cooled by 50K cold helium gas. All of cold components of the CFETR TF coil test facility will be refrigerated by a helium refrigerator. The heat loads of the whole system consist of heat radiation, residual gas heat conduction box, control Dewar, cryogenic transfer lines, HTS current lines and super critical helium(SHe) circulators, Joule heat from superconducting joints and eddy current loss of the testing coil[4]. According to the estimation of the heat loads, a certain refrigeration capacity margin and a reserved ability to supply 3.7 K sub-cooled helium to test CFETR cryopumps, the helium refrigerator is designed at a capacity of 1500W/3.7K +2500W/4.5K +10g/s/50K+ 1.5Kw/50K, which is approximately equivalent to a helium refrigerator with the capacity nearly 5kW at 4.5K.

The cryogenic system of CFETR coil test facility consists of compressors, oil removal system, cold box, pure gas helium(GHe) storage, helium external purifier, impure GHe storage, recovery compressor, LHe dewar, LN2 tanks gas bags and distribution system and so on, which is shown in Fig. 2. The refrigeration system is based on Modified Claude refrigeration cycle and possesses of one optional LN2 pre-cooling stage, several reverse Brayton refrigeration stages and J-T valve throttle cooling stage. The helium refrigerator system has three operating mode. (1) Standard refrigeration mode. (2) Peak refrigeration mode. (3) Liquefier mode. LN2 pre-cooling stage only runs in cool down phrase, peak refrigeration mode and liquefier mode. In standard refrigeration mode, the HP(high pressure) helium is cooled down by turbines T1&T2 while LN2 pre-cooling stage is cut off, which largely reduces the consumer of LN2. When the coil test facility is put into operation, the helium refrigerator should supply enough cold sources to cool down all cold components in coil cryostat, including superconducting coil, HTS current leads, thermal shield and so on. At this time, the helium refrigerator works at standard refrigeration mode. Without the supply of LN2, there is no heat exchange in HX3 &HX4. The HP helium is cooled down to 132.8K in counter-current heat exchanger HX1. At the outlet of HX1, the flow rate is divided into two flows: one to the turbines T1 & T2 and the other

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LHC TRAIN CONTROL SYSTEM FOR AUTONOMOUS INSPECTIONS AND MEASUREMENTS

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Abstract

Intelligent robotic systems are becoming essential for inspection and measurements in harsh environments, such as the European Organization for Nuclear Research (CERN) accelerators complex. Aiming at increasing safety and machine availability, robots can help to perform repetitive or dangerous tasks, reducing the risk for the personnel as the exposure to radiation. The Large Hadron Collider (LHC) tunnel at CERN has been equipped with fail-safe trains on monorail able to perform autonomously different missions as radiation survey, civil infrastructures monitoring through photogrammetry, fire detection as well as survey measurements of accelerator devices. In this paper, the entire control architecture and the design of the low-level control to fulfil the requirements and the challenges of the LHC tunnel are described. The train low-level control is based on a PLC controller that communicates with the surface via 4G through VPN, where a user-friendly graphical user interface allows the operation of the robot. The low-level controller includes a PLC fail-safe program to ensure the safety of the system. The results of the commissioning in the LHC are presented.

INTRODUCTION

Industrial as accelerators experimental areas have the needs of being remotely inspected by robots because of dangers for humans, time or space constraints.

Operating robots for maintenance in hazardous environments on often expensive machines requires skilled and well trained and dedicated shift operators. This is costly and highly time -consuming and is mainly caused by the not intuitive human robot interfaces present on industrial robots.

The European Organization for Nuclear Research (CERN) [1] is the world largest high-energy physics laboratory in the world. At CERN, there are more than 50 km of underground-unstructured accelerators areas with thousands of different items of equipment that need to be inspected and maintained. Due to the presence of human hazards, mainly produced by radiation and high magnetic fields, the accelerators equipment at CERN needs to be inspected and maintained remotely, possibly using robots.
CERN unstructured environments present also more constraints like accessibility, long distances, objects with various pose and occlusion in cluttered areas. These aspects require a safe robotic system that can travel long distances, possibly with a user-friendly human-robot interface (HRI) allowing its use by accelerators operators without a too specific training for use of robots.

Figure 1: TIM in the LHC.

The Large Hadron Collider (LHC) [2] at CERN, built in a 27 km long underground tunnel, is the most powerful machine in the world. It needs to be inspected during few days long technical stops, and machine shutdowns. There are several challenges in applying autonomous robotic systems in harsh and hazardous environment (Table 1), like the CERN accelerators complex. The control system of a robotic inspector must be designed to overcome these challenges in a safe way, as it is detailed in the following sections of this paper.

The LHC tunnel has been equipped with the fail-safe Train Inspection Monorail (TIM) (Figure 1) systems, able to perform autonomously different missions as visual inspections, radiation survey, civil infrastructures monitoring through photogrammetry, fire detection as well as survey measurements of accelerator devices as collimators [3] and superconducting magnets [4].

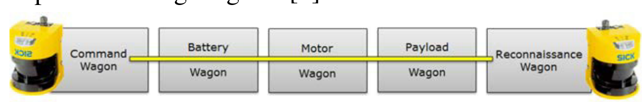

Figure 2: TIM train wagons composition.

TIM is a battery powered train composed by different wagons (Figure 2) and connected to a monorail linked to the ceiling all around the LHC tunnel structure. Thanks to its mechanical design, it can be adapted to different I-beam profiles used as monorail. Due to the dimensions of the LHC ventilation and sector doors, the cross section of TIM is limited to 30 x 30 cm (Figure 3). According to the mission' configuration different mechatronic systems (e.g. robotic arms) are deployed. Thanks to a precise on-board positioning system, when the train passes narrow areas, the autonomous fail-safe control automatically retracts all the deployed mechatronic systems into safe positions for avoiding collisions. Moreover, the train is equipped with

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FIRST PRODUCTION USE OF THE NEW SETTINGS MANAGEMENT SYSTEM FOR FAIR

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Abstract

With the successful commissioning of CRYRING, the first accelerator being operated using the new control system for FAIR (Facility for Antiproton and Ion Research), also the new settings management system is now used in a production environment for the first time.

Development efforts are ongoing to realize requirements necessary to support accelerator operations at FAIR. At CRYRING, new concepts for scheduling parallel beams are being evaluated. After these successful tests and the first production use, the focus now is to include major parts of the existing facility (synchrotron SIS18, storage ring ESR and transfer lines) into the system in the context of the Controls Retrofit project. First dry runs are planned for Q4 this year.

The settings management system is based on the LSA framework [1], that was introduced at CERN in 2001 and is being developed and enhanced together in a collaboration with GSI. Notwithstanding all successes of LSA at both institutes, a review study was set up with the goal to make the LSA framework fit for the future. Outcomes of this study and impacts on the settings management system for FAIR are being presented.

USING THE NEW SETTINGS MANAGEMENT SYSTEM

The CRYRING heavy-ion storage ring is a Swedish in-kind contribution to the FAIR project. The machine includes its own linac with a MINIS type ion source, an RFQ linear accelerator and an electron cooler. It was set up at GSI (see Fig. 1) and successfully commissioned in 2015 with several beamtimes until now, including an injection test from the existing ESR storage ring performed in 2016 and recent successes with longer beam storage times [2].

While the other GSI accelerators are in shut-down for the FAIR upgrade, CRYRING represents a unique opportunity, since it is the first machine fully operated with the new control system for FAIR. With the equipment controllers, device class implementations with FESA [3], new middleware and service layer, the settings management system based on the LSA framework and new Java-based applications, new developments on all layers of the control system [4] have been successfully brought into operation.

Making LSA Ready for Production Use

For the FAIR settings management system, this first use in a production environment posed several challenges. So far, the machine developments done with LSA have been performed using a test database where basically everyone was allowed to enter data manually at any time. Since LSA is strongly data-driven, the data integrity is very important.

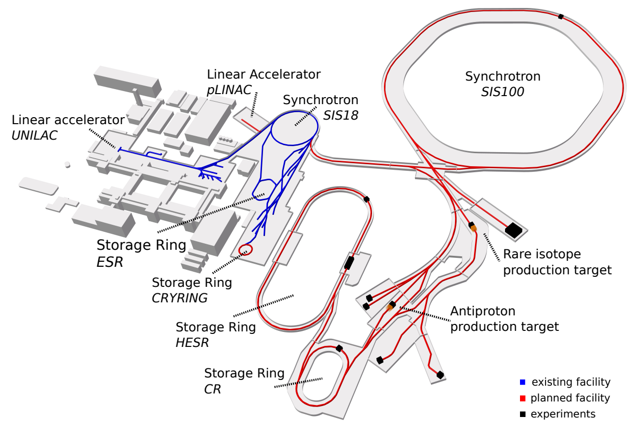

Figure 1: FAIR facility, FAIR.

Therefore, on the new production database, no manual user access to the data is allowed. Only scripts can do modifications, which either pull data from other databases (e.g. accelerator layout, devices, calibration curves, etc.) or from data files that are kept under version control together with their import scripts (e.g. optics, twiss information). Efforts are ongoing to provide a Java-based importer toolset for all necessary data. Also, the production database itself was not set up as a structural copy of the existing test database. Instead, an agreed-upon database state was taken from CERN and it was transformed into a set of defined scripts, making it possible to set up a new database at any time, using these structural scripts, together with the data content scripts mentioned above.

Besides these measures on the database, also the release process had to be formalized. So far, tests with LSA have been mostly performed from the developer's workspace. For production use, releases have to be performed inline with control system releases. The whole control system is developed with a major release every half year. In order to formalize the release of LSA at GSI and make it possible to introduce bugfixes on the last release state whenever needed, release branches were introduced on all levels, LSA as well as applications (roughly 50 artifacts). Now, developers are able to continue development for the next release, even introducing incompatible changes, without compromising the current production state.

Realization of New FAIR Concepts

The major development that is ongoing in the LSA framework is to realize the parallel beam scheduling concepts designed for operation of the FAIR facility. FAIR operation poses unique challenges with up to five parallel beams and pulse-to-pulse switching between particles. The idea is to move away from an accelerator-oriented to a more

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STATUS OF THE CLARA CONTROL SYSTEM

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Abstract

STFC Daresbury Laboratory has recently commissioned Phase 1 of CLARA (Compact Linear Accelerator for Research and Applications) [1], a novel FEL (Free Electron Laser) test facility focussed on the generation of ultra-short photon pulses of coherent light with high levels of stability and synchronisation.

The main motivation for CLARA is to test new FEL schemes that can later be implemented on existing and future short wavelength FELs. Particular focus will be on ultra-short pulse generation, pulse stability, and synchronisation with external sources. Knowledge gained from the development and operation of CLARA will inform the aims and design of a future UK-XFEL.

The control system for CLARA is a distributed control system based upon the EPICS software framework. The control system builds on experience gained from previous EPICS based facilities at Daresbury including ALICE (formerly ERLP) [2] and VELA [3].

This paper presents the current status of the CLARA control system and discusses the systems deployed for Phase 1 and future plans for later phases.

INTRODUCTION

CLARA will be primarily an FEL R&D facility [4] and will inform the aims and design of a future UK-XFEL. It is intended to be flexible such that different FEL schemes can be investigated, with the emphasis on the generation of short, temporally coherent pulses via HB-SASE, mode-locking and seeding [5, 6]. Figure 1 shows the facility layout.

CLARA is being constructed across three main phases. Phase 1 is the front-end of the facility which has recently been commissioned. It includes the photo-injector and first linac (up to 50 MeV). Phase 2 will begin installation early in 2019 and includes all of the accelerating sections (up to 250 MeV). Phase 3 is the FEL section and will be installed following commissioning and a short operational period of the accelerator section.

The front-end sits alongside the VELA photo-injector allowing beam from the front-end to be switched into the VELA beamline via a new dipole and dog-leg transfer line.

The control system for CLARA is an evolution of the control system developed for VELA. It retains the use of the EPICS [7] software toolkit and Input/Output Controllers (IOCs) running the Linux operating system on the PC/x64 platform but extends this architecture to support the additional requirements of CLARA. After their intentional absence on VELA, the implementation of the control system for CLARA sees a return to VME architecture for several systems due to the requirement for an integrated timing system and demanding data acquisition systems.

In this paper we give an overview of the current status of the major sub-systems of the control system.

MOTION CONTROL

In the past, solutions for motion control on our accelerator projects have used a variety of manufacturers' custom interfaces. This has led to a disparate range of systems which become difficult to maintain and support.

Since the facility will require several hundred axes of motion control it is desirable to have a consistent approach throughout. Similar technology will be used to serve a wide range of requirements including the positioning of diagnostic screens, electron beam conditioning equipment, laser transport mechanisms, and magnet array positioning in undulators. Beckhoff EtherCAT fieldbus motion control systems have been chosen to satisfy the requirements of CLARA.

In Phase 1 a system has been implemented using Beckhoff TwinCAT 3 and CX5020 embedded PCs with EtherCAT modular I/O terminals. A virtual PLC running in this environment handles feedback from sensors and controls motors and servos in a closed loop. A network service running on the embedded PC provides access to, and control of, TwinCAT virtual PLC parameters via the Modbus TCP protocol. Integration into the EPICS control system is implemented via this interface.

For Phase 1, several one and two-axis systems controlling motion for diagnostic screens and devices, laser transport and beam conditioning devices have been implemented and are currently operational. For Phases 2 & 3, a similar approach utilising Beckhoff EtherCAT will be used for multiple axis systems including a Variable Bunch Compressor and 2 modulator undulators along with an array of 17 radiator undulators as part of the FEL section.

STATUS & INTERLOCKING

The status & interlocking system is responsible for on/off control and interlocking of hardware on the facility. It provides slow (>10ms) machine protection for technical sub-systems by only allowing operation of devices when predetermined conditions are met. The system being implemented was originally designed for the VELA facility [3]. It comprises of Omron CJ2M PLCs with digital input and output modules to marshal signals to and from hardware. ADC modules are also used to allow analog levels to produce interlocks directly within the PLC. The status system operates in a stand-alone nature with supervisory control provided by the EPICS control system. Requests are received by the status system from

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CONTROL SYSTEM STATUS OF SuperKEKB INJECTOR LINAC

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Abstract

The SuperKEKB injector linac provides the electron and positron beams of different properties for the four independent storage rings. The required beam energy is from 2.5 GeV to 7 GeV, and the amount of bunch charge is from 0.3 nC to 10 nC. Especially, the injection beam to SuperKEKB electron and positron storage rings require the low emittance and high intensity beams for the nano beam scheme operation for aiming at the luminosity of $8x10^{35}$ cm^{-2} s^{-1}, 40 times higher than the luminosity record of previous KEKB project. The Phase I beam commissioning of SuperKEKB has been already conducted from February to June in 2016. The injector linac has successfully delivered the electron and positron beams to the SuperKEKB main rings. The linac beam studies and subsystem developments have also been intensively going on together with the daily normal beam injection to both rings of the SuperKEKB and two light sources.

Towards Phase II and III beam commissioning of SuperKEKB, the key issues are the fine beam control for the low emittance beam transport, the high intensity positron generation with the flux concentrator, the pulsed quadrupole and steering magnets for the four ring simultaneous top up injection, and the low emittance photo cathode rf gun. For the stable beam operation with the newly developed accelerator subsystems, the robust control system is strongly required. In this paper, we report the control system status of SuperKEKB injector linac.

INTRODUCTION

The SuperKEKB injector linac is a linear electron positron accelerator with the total length of about 600 m [1]. Figure 1 shows the schematic layout of injector linac. Two straight sections of 120 m long and 500 m long are connected with the 180 degree bending section. The both electron sources of thermionic and photo cathode rf gun are situated at the most upstream end. The thermionic electron gun is utilized for the light source injection with bunch charge of about 0.3 nC and the primary electron of positron generation with bunch charge of 10 nC. The photo cathode rf gun is required for the low emittance electron beam injection to the SuperKEKB electron high energy ring (HER). Eventually, the electron beam with the vertical normalized emittance of less than 20 mm·mrad is required for getting the high peak luminosity in Belle II physics experiment. The low emittance electron beam transport without damping ring is one of key issues of injector linac operation. Both of the fine component alignment and the beam orbit manipulation are crucial issues for the success of SuperKEKB project. The beam studies related to these issues are now on going. The main parameters required for SuperKEKB operation are summarized in Table 1 together with ones for the former KEKB project [2, 3, 4, 5].

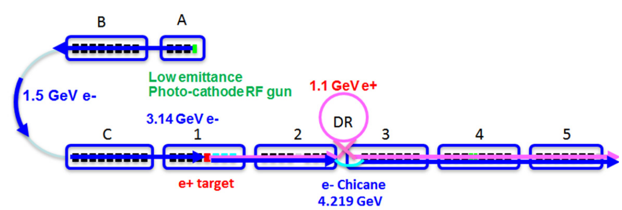

Figure 1: Schematic layout of the SuperKEKB injector linac. It comprises two strait sections of 120 m and 500 m long. They are connected 180 degree bending section. The both electron sources of thermionic and photo cathode rf gun are situated at the most upstream end of the injector linac.

PREVIOUS CONTROL SYSTEM

At the beginning of KEKB project, the injector linac control system was based on the library software developed in house. They have been implemented by C language and conducted on the Tru64 UNIX server computers. As the data storage system, the RAID system has been used, and it was connected to the server computer of HP DS20 alpha server via SCSI interface. The operator interfaces (OPIs) were designed by the Tcl/Tk scripting language and displayed on the X terminals, Macintosh, and Windows PC via X server software. For the local controllers of magnet, vacuum, and safety systems, the programmable logic controller (PLC) were utilized since its robustness are suitable for the stable accelerator control. For the beam monitor of beam position monitor and profile monitor, the VME bus based system were in operation. The timing delay modules have been also developed as the VME bus module board.

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OPERATION EXPERIENCES OF THE TPS CONTROL SYSTEM

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Abstract

TPS Control system was operated near three years from summer of 2014 to support commissioning and operation of the TPS. TPS control system adopts EPICS toolkits as its framework. The subsystems control interfaces Include event based timing system, Ethernet based power supply control, corrector power supply control, PLC based pulse magnet power supply control and machine protection system, insertion devices motion control system, various diagnostics related control environment, and etc. Experiences accumulated in last three years in hardware, software have been confirmed it can fulfil its mission. Functionality and reliability were improved during last three years. Long term strategic for performance improvement and maintenance are revised. Efforts will be summarized in this reports.

INTRODUCTION

The TPS is a low emittance 3 GeV synchrotron light source which is constructed at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan. The control system environment was ready at the summer of 2014 to support subsystem integration test and commissioning. The TPS has delivered its first synchrotron light [1, 2] on the last day of 2014. Since then the control system support follow-up machine commissioning and user service of the TPS.

Adequate and reliable functionality of control system play a key role to the success of TPS commissioning and operation. Control system for the TPS is based on the EPICS framework [3]. The EPICS toolkits provide standard tools for display creation, archiving data, alarm handling and etc. The EPICS is based on the definition of a standard IOC structure with an extensive library of driver and support a wide variety of I/O cards. The EPICS toolkits have various functionalities which are employed to monitor and to control accelerator system.

The TPS control system [4, 5] consists of more than two hundreds of EPICS IOCs. The CompactPCI (cPCI) is equipped with input/output modules to control subsystems as standard IOC due to its maturity and low cost. The other kinds of IOCs are also supported by the TPS control system, such as BPM IOC, PLC IOC, various soft-IOC and etc.

To achieve high availability of the control system, hardware and software configuration are very careful considered. Software engineering techniques and relational database for system configurations. Data channels in the order of 10^5 will be serviced by the control system. Accessibility of all machine parameters through control system in a consistent and easy manner will achieved. High reliability and availability of TPS control system with reasonable cost and performance are confirmed during last three years operation.

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SYSTEM CONFIGURATION

The system installation and integration with subsystems for the control system was done. Details of the control system are summarized in the following paragraph.

Networking

Mixed of 1/10 Gbps switched Ethernet are deployed for the TPS control system [6]. The Gigabit Ethernet connection was delivered at edge switches installed at control and instruments area (CIA). The control network backbone is a 10 Gigabit link to the control system computer room. 1G/10 G service are available at beamline also. Private Ethernet is used for Ethernet based devices access which support fast Ethernet and GbE. Adequate isolation and routing topology will balance between network security and needed flexibility. Availability, reliability, cyber security, and network management are strengthened continually.

General EIPCS IOC Interface

There are many different kinds of IOCs at equipment layer to satisfy various functionality requirements, convenience and cost consideration, shown in Table 1. Most of the devices and equipment are directly connected to cPCI IOCs with EPICS. The cPCI EPICS IOC is equipped with the ADLINK cPCI-6510 CPU board. The ADLINK cPCI-7452 128 bits DI/DO module is used for BI, BO solution. ADC and DAC modules in IP (Industry pack) module form-factor are used for smaller channel count application, such as insertion devices control. Event system modules are in 6U cPCI form-factor. Private Ethernet will be heavily used as field-bus to connect many devices. Power supplies of all magnets except for correctors are equipped with Ethernet to the EPICS IOC. Multi-axis motion controller with Ethernet interface is the standard for the control system.

Ethernet attached devices are connected to the EPICS IOC via private Ethernet. Devices support VXI-11, LXI, Raw ASCII and Modbus/TCP protocol are connected to EPICS IOC directly by TCP/IP interface. Devices of this category include power supply, temperature acquisition, digital multi-meters, oscilloscopes, signal generator, and other instruments.

All corrector power supplies are driven by the corrector

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MeerKAT: PROJECT STATUS REPORT*

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Abstract

The MeerKAT radio telescope is currently in full production in South Africa's Karoo region and will be the largest and most sensitive radio telescope array in the centimetre wavelength range in the southern skies until the SKA1 MID telescope is operational. This paper identifies the key telescope specifications, discusses the high-level architecture and current progress to meet the specifications. The MeerKAT Control and Monitoring subsystem is an integral component of the MeerKAT telescope that orchestrates all other subsystems and facilitates telescope level integration and verification. This paper elaborates on the development plan, processes and roll-out status of this vital component.

MEERKAT TELESCOPE

MeerKAT is being constructed 90km from the nearest town of Carnarvon in the sparsely populated Karoo region of South Africa. The area is regulated by the Astronomy Geographic Advantage Act and is uniquely suited to radio astronomy given the low levels of radio frequency interference. Backend systems are housed in a specially designed Karoo Array Processor Building located a short distance from the core, whilst a support base has been established about an hour's drive away in Klerefontein.

Key Specifications

The key technical specifications [Table 1] have been driven by science cases, where some of the top ranked science projects now include:

- MeerTime, focusing on pulsar timing, particularly millisecond pulsars;
- MHONGOOSE, studying the flow of gas into galaxies and feedback effects using deep HI in ~30 nearby galaxies;
- LADUMA, an ultra-deep survey of HI gas in the early universe up to z≈1.4 to constrain the role of HI in star formation;
- Fornax, improving our understanding of cluster formation and evolution using HI in the Fornax Cluster;
- TRAPUM, studying transients and pulsars, particularly targeting Fermi-LAT sources.

Given the science targets, sensitivity was identified as a key requirement [1], demanding a large collecting area (A_e) and a low system temperature (T_{sys}) [2]. The collecting area will be provided by 64 offset Gregorian dishes each of 13.5m diameter [3]. High sensitivity furthermore implies that there be a matching imaging dynamic range with signal stability over the imaging period [4]. The offset Gregorian dish configuration provides an unblocked optical path for a clean beam pattern and polarisation purity [3]. Initial results indicate that a sensitivity of 300-400 m^2/K is achievable [5], *significantly* exceeding the specification.

Table 1: Key Specifications [3]

Specification	Value
Dishes	64 Offset Gregorian
Reflector Diameter	13.5m
Sub reflector Diameter	3.8m
Minimum Baseline	29m
Maximum Baseline	8km
Frequency Bands	0.9-1.67 GHz (L-band) 0.58-1.015 GHz (UHF) 1.75-3.5 GHz (S-band)
Sensitivity	220m^2/K
Aperture Phase Eff.	0.67 (at 14.5 GHz)
Surface Accuracy	1.0mm (RMS)
Pointing Accuracy	5"/20min (optimal conditions) 25"/20min (normal conditions)
Pointing Jitter	<15" RMS

Architecture

Figure 1 depicts the major subsystems comprising the MeerKAT telescope system, their primary functions, signal and control flows.

Receptor Each receptor is comprised of three main components, namely a steerable dish referred to as the antenna positioner, a receiver system and an associated set of digitisers [3]. The main reflector is made of 40 aluminium panels, whilst the sub-reflector is a single composite structure. The aluminium panels are mounted on a steel backup structure, that in turn is mounted on a pedestal assembly. The pedestal assembly incorporates a yoke to provide an elevation over azimuth positioning system. The receiver system consists of a receiver indexer, a receiver system controller and the supporting vacuum and helium services. The receiver indexer is capable of supporting four receivers and is mounted in the "feed low" position. Three receivers will occupy the receiver indexer, namely L-band, UHF and S-band. The digitisers are located on the receiver indexer to eliminate the need for an intermediate frequency stage by digitising the entire Radio Frequency (RF) bandwidth after amplification [2]. Strict Radio Frequency Interference (RFI) controls are exercised given the proximity of the digitiser to the receivers. Digitised data is down-converted to baseband

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EtherCAT BASED DAQ SYSTEM AT ESS

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Abstract

The European Spallation Source (ESS) [1] is a research facility being built in Lund, Sweden. The Integrated Control System (ICS) division at ESS is responsible for the whole ESS machine and facility control, i.e., accelerator, target, neutron scattering instruments and conventional facilities. Therefore, ICS has to be able to handle a wide variety of input and output signals with different user requirements. Moreover, EPICS is selected as the generic control system framework at ICS and the aiming goal is to achive high performance, cost-effective, safe, reliable and easily maintainable systems. In order to meet these goals, ICS needs hardware standardisation. Therefore, to fulfil these requirements different hardware platforms were selected, such as MicroTCA for Fast real-time Input Output, PLC for Industrial Input Output without real-time response requirements, and EtherCAT [2] for real-time requirements and cost-effective applications.

INTRODUCTION

ICS has selected EtherCAT, in order to cover the medium range data rate, e.g., several kHz. The reason is, because, EtherCAT provides many features of Industrial Ethernet at a lower price than a classic fieldbus system, and there is an available open-source EtherCAT master [2]. In addition, it meets real-time requirements with the signal data rate, because EtherCAT is a real-time Ethernet-based fieldbus that relies on conventional Ethernet frames but employs a conceptually different mechanism to communicate with multiple devices. Therefore, EtherCAT standard uses Ethernet wiring but has a specialised protocol that enables tight time synchronisation. Moreover it allows a flexible topology, and a high synchronisation between nodes.

At ESS, for instance, EtherCAT will be used when the Input Output (I/O) system needs to be beam-synchronous; needs to acquire signals in the kHz range; or needs to be spread across locations that are far from each other and would need cumbersome cabling, but still belong to one system.

EtherCAT SYSTEM ARCHITECTURE

As many other fieldbus network systems, EtherCAT is based on Master and Slave configuration. EtherCAT Master relies on standard Ethernet hardware communication with the bus, so any generic network interface card (NIC, 100 MB/s Full duplex) is sufficient. Using the open source IgH EtherCAT Master [3] makes cost-effective and flexible configuration of the EtherCAT system architecture at ESS, meaning that a typical EPICS input-output controller (IOC) can be executed within an industrial PC as an EtherCAT master. However, it needs dedicated and separated Ethernet hardware ports only for the EtherCAT communication.

Contrary to the operation of standard Ethernet, the slaves process the EtherCAT frames on the fly. This requires the use of specific hardware-integrated in the slaves; EtherCAT Slave Controllers (ESC). ESC are available from multiple manufacturers. In ESS, Beckhoff automation technology [4] will be used.

OPEN-SOURCE IgH EtherCAT MASTER

An open-source EtherCAT master [3], IgH EtherCAT Master, works as a Real Time kernel module loaded within the open source operating system Linux to communicate with peripherals devices as EtherCAT slaves through dedicated Ethernet ports. Since it is integrated in the Linux kernel, it has got better realtime characteristic and the master code can directly communicate with any Ethernet hardware. At ESS, to meet real time performance, the PREEMPT Real Time kernel patch should be used with EtherCAT. If there is no need for the real time performance, the typical Linux kernel should be used as well. The IgH EtherCAT Master can contain more than one master running at the same time. Each master is linked with one Ethernet device identified by its MAC address.

Each EtherCAT master can be matched with a character device as an userspace interface

$$\texttt{/dev/EtherCATx}, \tag{1}$$

where `x` is the unit number of the EtherCAT master. This device node is created automatically with `udev` while the master kernel module is loading.

The information transferred from slaves to masters is called Process Data Objects (PDOs), which is in different frequencies and is limited by the size of an Ethernet frame. Master is responsible for the configuration of the Fieldbus Memory Management Unit (FMMU). The IgH EtherCAT Master also provides command-line tools, which allow users to get information about the master, slaves, PDOs and Service Data Objects (SDO) of all the slaves connected to the EtherCAT chain. One example of command line tools is to read PDO information of the Beckhoff terminal `EL3202-0010`, located in the position 10 of the EtherCAT test chain as follows:

```
$ ethercat pdo -p 10 -v
  SM3: PhysAddr 0x1180, DefaultSize 8,
  ControlRegister 0x20, Enable 1
  TxPDO 0x1a00 "RTD TxPDO-Map Ch.1"
  PDO entry 0x6000:01, 1 bit, "Underrange"
  PDO entry 0x6000:02, 1 bit, "Overrange"
  PDO entry 0x6000:03, 2 bit, "Limit 1"
  PDO entry 0x6000:05, 2 bit, "Limit 2"
  PDO entry 0x6000:07, 1 bit, "Error"
  PDO entry 0x0000:00, 7 bit, "Gap"
```

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PandABlocks OPEN FPGA FRAMEWORK AND WEB STACK

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Abstract

PandABlocks is the open source firmware and software stack that powers PandABox, a Zynq SoC based "Position and Acquisition" platform for delivering triggers during multi-technique scanning. PandABlocks consists of a number of FPGA functional blocks that can be wired together at run-time according to application specific requirements. Status reporting and high speed data acquisition is handled by the onboard ARM processor and exposed via a TCP server with a protocol suitable for integration into control systems like "EPICS" or "TANGO". Also included in the framework is a webserver and web GUI to visualize and change the wiring of the blocks. The whole system adapts to the functional blocks present in the current FPGA build, allowing different FPGA firmware be created to support new FMC cards without rebuilding the TCP server and webserver. This paper details how the different layers of PandABlocks work together and how the system can be used to implement novel triggering applications.

INTRODUCTION

This paper describes the firmware and software stack powering PandABox [1]; a development project, which is the result of a collaboration between Diamond Light Source [2] and Synchrotron SOLEIL [3] that was started in 2015. PandABox is a multipurpose platform for multi-technique scanning and feedback applications. It has a flexible and modular framework allowing it to be configured for numerous custom applications. The components of the PandABlocks project, described in this paper, are open source and hosted on GitHub [4].

FPGA ARCHITECTURE

A customised Linux XiLinx [5] kernel with busy-box [6] is deployed on the ARM dual Cortex-A9 [7] as shown in Fig. 1. Specific types and quantities of different IP blocks, both standard and customised, can be loaded on the FPGA to individually be activated or instantiated by a user. Instantiated blocks representing different components can then be wired together by the user to achieve overall functionality for specific applications. These connections are shown as white lines in Fig. 1. The Processing system communicates with these IP blocks via the AXI Interconnect register interface for the ARM processor.

Individual IP blocks for use on PandABox are defined in a configuration file and are instantiated when building the system. Once built and installed, the number and type of blocks are fixed on the system with the routing/ signal flow fully configurable between them at run time. The flexibility of the IP blocks configuration at build time is to facilitate the modularity of the PandABox device itself. It is possible to install different types of FMC cards on the board and thus a method of accommodating these different configurations is necessary. This also gives the added benefit that the general configuration of the whole system is flexible. Custom blocks can be written and instantiated along with combinations of the standard supplied blocks.

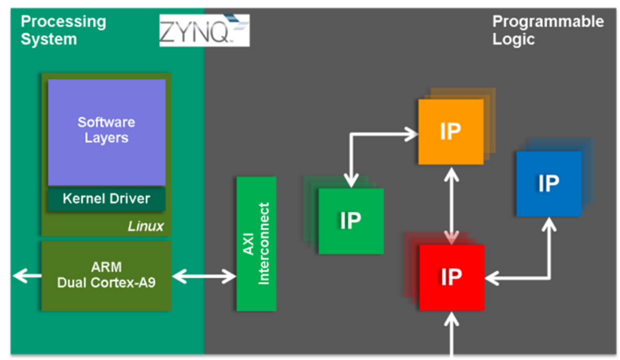

Figure 1: FPGA architecture.

SIMULATION FRAMEWORK

Once an IP block is written, its functionality can be tested with the PandABlocks simulation framework. The simulation framework is made up of a number of different components; the input sequence file, python block simulation, output vector file, and documentation. The sequence file is a list of inputs, commands and expected outputs to be executed sequentially at given time intervals. The python code emulates the behaviour of the blocks and tests the expected behaviour as defined in the sequence file. This is useful for testing edge cases without using the actual hardware. From the simulation, an output vector file is generated which is used as input for the FPGA simulator, running the VHDL/ Verilog code. The simulation environment also provides the possibility of generating signal diagrams for each test sequence described by the sequence file; an example of one of these graphs as generated for a pulse block is shown in Fig. 2.

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CONTROL SYSTEM FOR ATLAS TileCal HVRemote BOARDS

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Abstract

For the high luminosity LHC one of the proposed solutions for upgrading the high voltage (HV) system of the ATLAS central hadron calorimeter (*TileCal*), consists in removing the HV regulation boards from the detector and deploying them in a low-radiation room where there is permanent access for maintenance. This option requires many ~100 m long HV cables but removes the requirement of radiation hard boards.

This solution simplifies the control system of the HV regulation cards (called *HVRemote*). It consists of a Detector Control System (DCS) node linked to 256 *HVRemote* boards through a tree of Ethernet connections. Each *HVRemote* includes a smart Ethernet transceiver for converting data and commands from the DCS into serial peripheral interface (SPI) signals routed to SPI-capable devices in the *HVRemote*. The DCS connection to the transceiver and the control of some SPI-capable devices via Ethernet has been tested successfully.

A test board (*HVRemote-Ctrl*) with the interfacing subsystem of the *HVRemote* was fabricated. It is being tested through SPI-interfaces and several devices were already validated. A next version adds a few more ADC/DAC devices for checking their suitability for the final design.

INTRODUCTION

The Tile Calorimeter (*TileCal*) [1] is the central hadronic calorimeter of ATLAS [2], one of the two multi-purpose experiments at the Large Hadron Collider (LHC) at CERN. The high luminosity LHC (HL-LHC) aims to deliver a luminosity increased by a factor of 5 to 10 compared to the LHC design value [3]. The HL-LHC environment presents several challenges for *TileCal* and an upgrade program is being prepared for the detector. *TileCal* uses iron plates as absorber and plastic scintillating tiles as the active material. Light produced in the scintillators is transmitted by wavelength shifting fibres to photomultiplier tubes (PMTs). An electronic system currently being upgraded is that in charge of the control and distribution of high-voltage (HV) to the approximately 10^4 PMTs of the *TileCal* detector. In the current operational version, its core comprises two cards [4]: the *HVOpto* and the *HVMicro*. In the current ATLAS setup, this system is located inside the detector, so it operates under high doses of radiation. Current *TileCal* HV electronics is in operation for more than 10 years and, as a result, is ageing despite its design accounted for radiation hardness. Another severe constraint is the difficulty in maintaining and replacing faulty *HVOpto* or *HVMicro* cards: it is never possible to replace them when the LHC is running, and the maintenance is possible only during the yearly winter shutdowns.

To alleviate these constraints, the solution proposed for the upgrade [5, 6] moves the *TileCal*'s *HVOpto* electronic control system from the detector innards, to a location in the USA15 room which is a low radiation environment far away (100 m) from the detector. This will improve the lifetime of the system and provides for immediate maintenance and replacement. On the other hand, the *HVRemote*[1] board will now be connected to the PMTs through several 100 m long cables, which may worsen slightly their stability and noise levels. Since the current electronic design is about 20 years old, some components in the *HVOpto*, such as the ADCs and DACs[2], are obsolete and have to be replaced by modern alternatives.

In addition, an HV system was developed by Argonne National Laboratory team, which keeps the HV regulation and distribution electronics in the detector [7], and is a possible alternative solution for the upgrade.

In this note we describe the ongoing work regarding the upgrade of the control system of the HV cards for the *HVRemote* version. Most of the tests presented here, which aim at evaluating and validating several design options, were based in prototype boards, called *HVRemote-Ctrl* cards, which contain downsized replicas of the hardware of the communications interface of the full *HVRemote* board. One of the *HVRemote-Ctrl* cards is described below.

THE HVRemote CONTROL SYSTEM

The HVRemote Control Path and Hardware

The architecture of the upgraded electronics system of the *TileCal* is shown in Fig. 1. The control master is a PC/workstation configured as a node of the DCS of ATLAS. The DCS commands sent to, and the data read from the *HVRemote* boards, flow through a tree of Ethernet links, connecting the PC and 256 boards, each of these managing 48 PMT channels.

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[1] The "old" HV system, now in operation is referred to as *HVOpto* and the upgraded system is referred to as *HVRemote*.

[2] DAC refers to a generic Digital-Analogue Converter; ADC refers to a generic Analogue-Digital Converter.

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MULTIPLEXER FOR THE Em# ELECTROMETER

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Abstract

Small currents need to be measured from a number of devices at a synchrotron and its beamlines. To meet this demand, MAX IV have joined a collaboration with ALBA to develop the Em# electrometer that will ensure low current measurement capabilities and seamless integration into our Tango control system. To further enhance the electrometer flexibility, a multiplexer has been designed with 8 individual inputs controlled by the electrometer and one output that is preferably connected to the Em# input. The multiplexer is suited for stronger currents than 10 pA and currents that needs to be monitored only at a low frequency.

ALBA Em# ELECTROMETER

The Em# electrometers has 4 independent channels that measure in the 1 mA to 100 pA in 8 ranges. Using the 1 nA range, 25 fA resolution has been demonstrated [1]. Each input has 5 2nd order analog filters from 0.1 Hz to full bandwidth. The 18 bit SAR ADC is operating at 400 kS/s and each channel has its own ADC.

The front panel of the electrometer, Fig. 1, presents a touch panel where currents can be read and filters and ranges can be changed together with other parameters.

The back panel of the electrometer, Fig. 2, contains the interconnections such as input current, output voltages, trigger signals, I/O signals, together with the internal NUC computer ports. In case of the low voltage version, current input connectors and proportional analog voltage output connectors are BNC while for the high voltage model, a connector for bias voltage up to 1 kV is present, the current input is triaxial and the analog proportional voltage connectors are omitted for safety reasons.

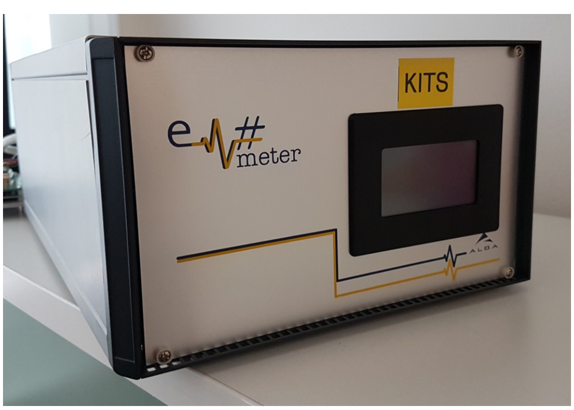

Figure 1: A touch panel is located at the electrometer front panel.

Figure 2: The back panel of the electrometer contains the interconnections such as input current, output voltages, trigger signals, I/O signals, together with the internal NUC computer ports.

MULTIPLEXER

Many devices produce large currents and only need low sample rate, which the performance of the electrometer exceeds by far. Other channels only need to be measured with long time periods in between. To make the electrometer more flexible and also meet those situations, KITS at MAX IV have developed a multiplexer, Fig. 3, with 8 independent input channels and one output channel after suggestions from the Veritas beamline.

The multiplexer is both powered by 5 V and controlled by the electrometer through its multipurpose HD26 SUBD IO interface. At most, an electrometer can control 4 multiplexers simultaneously and read its signals giving a system with 32 channels, but the number of multiplexers can be chosen freely. In case of a beam positioning device, where four currents are to be read simultaneously to calculate location, the four currents can be placed on the same channel number at different multiplexers, which means the electrometer does not need to change multiplexer channel to get a reading. The position can be calculated by the internal Em# FPGA and presented as a position variable and also fed to the analog voltage output with a PID loop also running in the Em# FPGA (under implementation).

The multiplexers are mounted in 19" frames and can easily be collocated with other patch panels from MAX IV [2]. The bias and address is chained to other cards by IDC10 flat cable, Fig. 4. A second grounded PCB is added on top of the main PCB to reduce EM interference with the surroundings.

CONTROL SYSTEM INTEGRATION

The Em# electrometer has been integrated into the control system in different layers, Fig. 5. As a first layer, we have the Tango CS [3] integration, for that purpose we are using

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PLANS AT CERN FOR ELECTRONICS AND COMMUNICATION IN THE DISTRIBUTED I/O TIER

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Abstract

Controls and data acquisition in accelerators often involve some kind of computing platform (VME, PICMG 1.3, MTCA.4...) connected to Distributed I/O Tier electronics using a fieldbus or another kind of serial link. At CERN, we have started a project to rationalize this tier, providing a modular centrally-supported platform which allows equipment groups to focus on solving their particular problems while benefiting from a set of well-debugged building blocks. The paper describes the strategy, based on 3U Euro crates with a generic FPGA-based board featuring space for FMC mezzanines. Different mezzanines allow communication using different protocols. There are two variants of the electronics, to deploy in environments with and without radiation tolerance requirements. The plans we present are the result of extensive discussion at CERN among all stakeholders. We present them here with the aim of gathering further feedback and potential interest for inter-lab collaborations.

INTRODUCTION

The control system for CERN's accelerator facility is built of multiple layers of hardware and software. These tiers are spanning from the hardware deployed close to the machine, up to the software running on computers that operators use for control and monitoring. As Figure 1 shows, one can distinguish the following three hardware layers:

- Front-end Tier - PLC or a powerful computer in various form factors (VME, PICMG 1.3, MTCA.4, etc.) running an operating system and a set of user applications controlling Distributed I/O Tier electronics over a fieldbus.
- Fieldbus Tier - a networking solution that ensures communication between the master in the Front-end tier and a set of slaves in the Distributed I/O Tier
- Distributed I/O Tier - electronics modules installed close to the machine in radiation-exposed or radiation-free areas controlled by the master in the Front-end tier over the fieldbus. These are usually FPGA-based boards sampling digital and analog inputs, driving outputs and performing various safety critical operations.

Depending on the needs of a given application, one can use either off the shelf equipment (like PLCs with remote I/O modules), design completely custom electronics or have a mix of the two. The very particular needs of the CERN accelerators often demand the development of custom electronics. For these, our group already provides a centralized

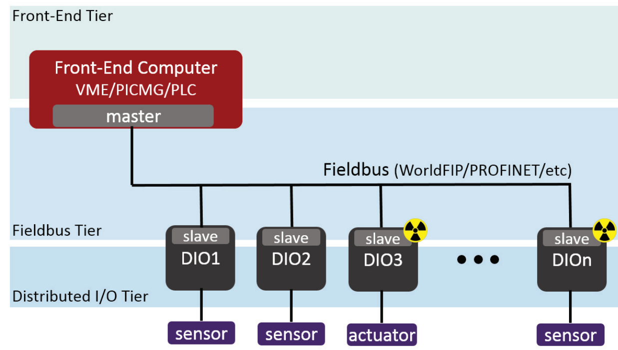

Figure 1: Three hardware tiers of the CERN's control system.

service in the Front-end Tier. It comes in the form of VME crates and PICMG1.3 computers that can host our modular FMC (FPGA Mezzanine Card) kit [1]. However, we currently miss a centrally supported service for modular and reusable electronics in the Distributed I/O Tier. Each equipment group so far (Power Converters, Cryogenics, Machine Protection, Beam Instrumentation, and others) has independently developed custom solutions for their needs. While those devices are different for each application, many of the needs are the same and we have identified that they could also be dealt with centrally.

In the Fieldbus Tier our current services for custom electronics are mainly built around the radiation-tolerant WorldFIP bus. With this project we also want to enhance our offering, to include the Ethernet-based fieldbuses widely used in industrial applications.

Our project does not aim at replacing all the already installed equipment, but rather targets new developments and foreseen upgrades.

INDUSTRIAL FIELDBUSES FOR ACCELERATOR CONTROL SYSTEMS

Ethernet's steady march over the decades has also found its way into the industrial environment as a means to interconnect field devices to the first level of automation. Protocols such as PROFINET, EtherNet/IP, POWERLINK, EtherCAT usually build on top of standard Ethernet so as to ensure deterministic data exchange and synchronization over the network.

Industrial Ethernet accounts for 46% of the market share of fieldbuses, according to 2017 research from HMS Industrial Networks [2]. The classic non-Ethernet fieldbus position remains strong at 48% of the market with

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A POSITION ENCODER PROCESSING UNIT

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Abstract
Typical motion controllers rely on a feedback position encoder to detect the actuator output and correct for external factors. Recent advancements in positioning systems increased the demand for the ability to process a variety of sensors and use the result to feedback the motion controller. In addition, data acquisition tools are becoming essential for metrology purposes to diagnose and analyse the behaviour of the system. A multi-sensor, multi-protocol unit with processing and data acquisition capabilities has been developed to address these requirements. Here we describe the main features of this unit, its internal architecture, and few examples of application.

INTRODUCTION

Modern high-accuracy positioning systems require a complex set of feedback information to correct the actuator position for external factors. The feedback information is obtained from several sensors that measure the position of the actuator, as well as any other relevant environmental physical quantities such as the temperature of the room.

The first difficulty with this approach is that typical motion controllers handle no more than one or two feedback sensors, usually a position encoder. That means that in multi-sensors cases, their information must be first processed and then synthesized as a single encoder for the motion controller. In other words, a mathematical function should be applied to the incoming data and the result be sent to the controller using an appropriated encoder protocol. This function will depend on the specificities of the system and therefore should be derived for each application.

Secondly, the encoders may use different protocols to transmit the measurement information. This requires appropriated readout devices to deal with each one of them. Popular encoders use quadrature signalling or SSI, BiSS-C, EnDat, and HSSL protocols. Moreover, not only can a system use encoders with different protocols but also similar encoders with distinct characteristics, for instance, two BiSS-C encoders with different data lengths.

The third and last aspect is the need of data acquisition capabilities for diagnostics and metrology purposes. The increasing complexity of high-accuracy systems demand sophisticated metrological tools to analyse their behaviour and performance. These tools should be able to retrieve the information from the relevant sensors, store it in a fast access buffer, and transfer it to the host computer for subsequent analysis.

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Pre-engineered [1] and turnkey [2] solutions exist to deal with multi-protocol encoders processing. However, their specific architecture and considerable cost constitute an obstacle for generic applications at the ESRF. Thus, to address the features described above, a new electronic unit, PEPU, has been designed to handle up to six encoders with different protocols, process the received data according to a user-defined function, and emulate feedback information to the motion controller. In addition, PEPU has the necessary data acquisition capabilities for the needs of metrology of complex systems. The design has been carried out having in mind the specificities of the ESRF applications and the integration of the unit in the existing control environment.

The next section describes the functional aspects of PEPU and gives details about its internal architecture. Then, a section discusses the implementation aspects of the unit. The following section presents some examples of applications and, finally, the last section presents the conclusions and the future improvements.

FUNCTIONAL DESCRIPTION

The Fig. 1 depicts the PEPU functional block diagram.

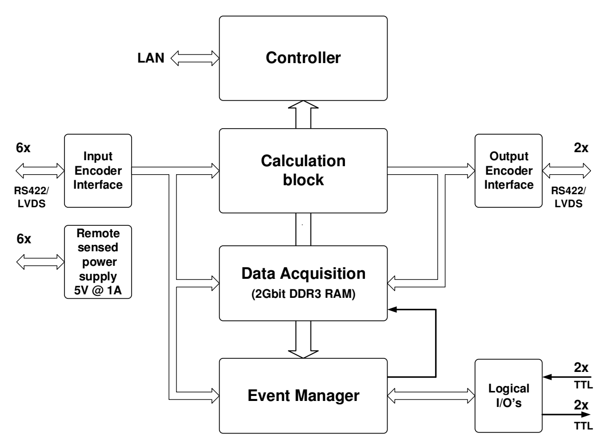

Figure 1: PEPU functional block diagram.

The controller allows the connection of PEPU to a host computer through the network (Ethernet) for remote control and data retrieval purposes. The controller treats, for instance, the configuration aspects by executing the commands received from the host.

On its side, the calculation block is in charge of performing operations on the incoming data according to a user-defined mathematical function. The outcome result can be transmitted through an output channel or pushed into the data acquisition buffer.

PEPU has six input channels that can handle both RS422 and LVDS signalling encoders. In addition, these

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FPGA-BASED BPM DATA ACQUISITION FOR LCLS-II

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Abstract

The LCLS-II facility currently under construction at SLAC will be capable of delivering an electron beam at a rate of up to almost 1MHz. The BPM system (and other diagnostics) are required to acquire time-stamped readings for each individual bunch. The high rate mandates that the processing algorithms as well as data exchange with other high-performance systems such as MPS (machine-protection system) or bunch-length monitors are implemented with FPGA technology. Our BPM-processing firmware builds on top of the SLAC "common-platform" [1–3] and integrates tightly with core services provided by the platform such as timing, data-buffering and communication channels.

INTRODUCTION

A new BPM data acquisition system has been built for the LCLS-II XFEL which is capable of acquiring beam-position readings at a sustained bunch rate of up to 1MHz while resolving individual bunches. It can be configured for different types of BPM pickups (striplines, cavities) which require different processing algorithms. Due to the high beam rate these algorithms must be implemented in FPGA logic.

Some systems (e.g., machine-protection, MPS) intrinsically operate at the full beam rate whereas most diagnostics (BPMs among them) capture time-stamped readings into deep on-board buffers. Capturing can be triggered and configured in a globally synchronized way in co-operation with the timing system. The buffers are then read-out by software and can be correlated with other diagnostics by aligning time-stamps off-line. This facility is called *beam-synchronous acquisition* or BSA.

The system builds on top of the *SLAC Common Platform Architecture* [1–3] which is an ATCA carrier hosting a FPGA with a framework of core firmware blocks (communication protocol stack, JESD204, timing, machine-protection, deep BSA data buffers etc) which are common to several high-performance systems (BPMs, bunch-length monitors, machine-protection etc.).

BPM is considered a specific *application* on top of the common-platform. Application-specific AMCs (e.g., high-speed digitizers) can be mounted on the carrier and application-specific FPGA logic is integrated with the common-platform firmware.

In the following we shall describe the BPM-specific aspects of this system.

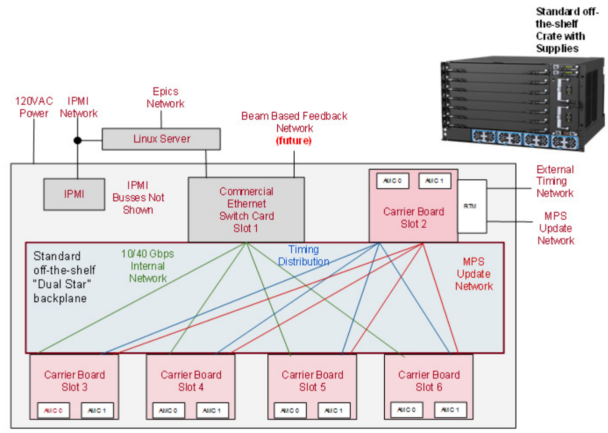

Figure 1: Block diagram of an entire ATCA shelf/crate which can host multiple AMC carriers each supporting different applications.

HARDWARE

Most of the BPM data acquisition hardware consists of common-platform components which can be shared with other subsystems (see also [1–3])

- COTS ATCA shelf with cooling, power-supplies, shelf-manager.
- COTS 10GigE switch blade (in slot 1).
- Timing distribution and MPS concentrator blade with RTM (rear transition module).
- Embedded linux server PC with connectivity to the 10GigE switch as well as the control-system LAN.

or are at least standardized

- Common platform carrier board.
- RTM with diagnostic connections.
- AMC modules (where applicable).

Figure 1 shows the topology of a complete ATCA shelf hosting multiple carriers and shared resources. The BPM subsystem we describe here can support up to two BPMs on a single carrier (i.e., more BPM carriers could be added to a single shelf).

Stripline BPM

Stripline BPMs measure position by detecting the amplitudes of the signals induced at two stripline pickups located at opposite walls of the beam pipe and computing the difference of these amplitudes (normalized to the sum of the amplitudes) [6]. Differential drift of gains in the two signal paths affect this “small difference of big numbers” type of measurement.

In order to overcome this problem a special AMC with the traditional SLAC on-line calibration circuit [4, 5], gain stages, filtering and high-speed ADCs was developed for

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A NOVEL GENERAL PURPOSE DATA ACQUISITION BOARD WITH A DIM INTERFACE

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Abstract

A new general purpose data acquisition and control board (Board51) is presented in this paper. Board51 has primarily been developed for use in the ALICE experiment at CERN, but its open design allows for a wide use in any application requiring flexible and affordable data acquisition system. It provides analog I/O functionalities and is equipped with software bundle, allowing for easy integration into the SCADA. Based on the Silicon Labs C8051F350 MCU, the board features a fully-differential 24-bit ADC that provides an ability to perform very precise DAQ at sampling rate up to 1kHz. For analog outputs two 8-bit current-mode DACs can be used. Board51 is equipped with UART to USB interface that allows communication with any computer platform. As a result the board can be controlled through the DIM system. This is provided by a program running on a computer publishing services that include measured analog values of each ADC channel and accepts commands for setting ADC readout rate and DACs voltage. Digital inputs/outputs are also accessible using the DIM communication system. These services enable any computer on a common network to read measured values and control the board.

INTRODUCTION

The main motivation for the development of the Board51 is to provide a general purpose low-cost device suitable for data acquisition of analog sensor values. The digital and analog outputs extend its application in various cyber-physical applications. The device has been developed mainly for educational purposes and will be used in several applications at the Center of Modern Control Techniques and Industrial Informatics at the Department of Cybernetics and Artificial Intelligence, FEEI, TUKE or at CERN. Two main mechanisms have been developed to monitor and control the board. The first option is the use of the MATLAB programming library, which allows for collection and processing of measured data, as well as the control of the board directly through the MATLAB functions. The second approach is based on a server application that mediates measured data and control the board using the DIM system [1]. This approach ensures compatibility with the communication architecture used in CERN experiments.

HARDWARE DESIGN OF BOARD51

The Board51 measuring board, shown in Fig. 1 is based on the C8051F350 micro-controller from Silicon Labs. Schematic design of the C8051F350 can be seen in Fig. 2. This chip has been selected for this application because its manufacturers focused on analog interfaces. It is equipped with a 24-bit 8-channel fully differential ADC with a sampling frequency of up to 1 kHz. This allows you to perform fast and very precise analog measurements, while the built-in multiplexer allows you to perform measurements between any channels or between the selected channel and the analogue ground. Since it has a large resolution, it must be provided with an accurate and constant reference voltage. This is ensured by the LM4121, which is calibrated to a 3V voltage and can be fine-tuned with a precision potentiometer mounted on the board.

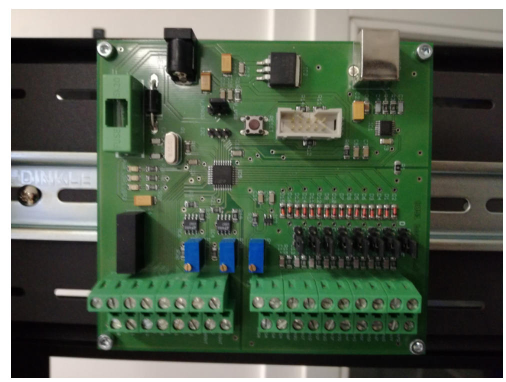

Figure 1: General purpose measuring board Board51.

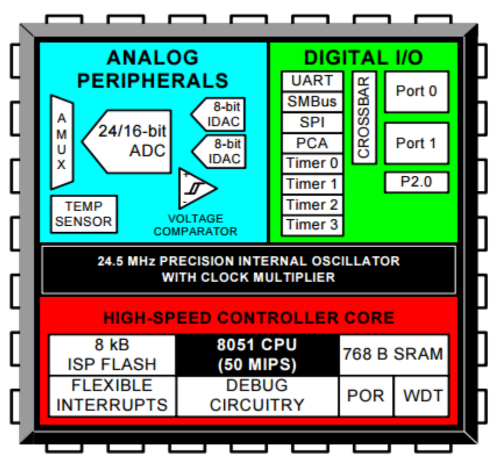

Figure 2: Schematic design of C8051F350 MCU.

Other important peripheral devices on this board are the two 8-bit current DACs that are connected via the resistors to an analogue ground, providing a voltage output instead of a current. Operational amplifiers are connected to the outputs with an adjustable amplification ratio so that the connected

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APPLICATION OF SOC BASED APPLICATIONS IN THE TPS CONTROL SYSTEM

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Abstract

System on a chip (SoC) based system widely apply for accelerator control recently. These system with small footprint, low-cost with powerful CPU and rich interface solution to support many control applications. SoC based system running Linux operation system and EPICS IOC embedded to implement several applications. TPS (Taiwan Photon Source) adopts some SoC solutions in control system, includes alarm announcer, RadFET reader, frequency and divider control, power supply control, etc. The efforts for implementing are summarized in this paper.

INTRODUCTION

Using a circuit board to implement functions as a computer is called SBC (single-board computer) [1]. Its applications cover in telecommunications, industrial control, blade and high density servers, and lately laptops and mini-PCs, etc. Duo to the latest generation SoC technology, putting all major functionality into an integrated chip, educational used credit-card size SBC [2] likes the Raspberry Pi (RPi) and Banana Pi (BPi) are highly successful products. The BPi is the latest product of such category with powerful CPU, low power consumption SBC indeed, and the area of circuit board is only as credit card size.

The BPi which design idea is similar to the RPi-style SBC, and it is a fork of the RPi project using different components while maintain compatibility as much as possible. Moreover the BPi is added the functions of SATA interface, infrared transmission, microphone, USB-OTG ports, power button, reset button, etc. Then the BPi has 40-pin GPIO which is compatible with the RPi. The Cortex-A7 SoC as CPU/GPU, DDR3 memory and Gigabit Ethernet connection are applied on the BPi. The hardware specification of BPi is shown as Table 1 [3]. Linux-based operation system can be worked well on the BPi.

Table 1: Hardware Specification of the Banana Pi

	Banana Pi M2+/M2U/M3
CPU	Coretx-A7 H3 Quad-core 1.2GHz Coretx-A7 R40 Quad-core 1.5GHz Cortex-A7 A83T Octa-core 1.8GHz
Memory	1GB DDR3 RAM / 2GB DDR3 RAM
Network	1Gbps Ethernet RJ45, Wi-Fi
Storage	MicroSD card slot (up to 64GB), eMMC (8GB onboard) Extensible with SATA interface
I/O	GPIO, UART, I^2C bus, SPI bus, PWM, +3.3V, +5V, GND
OS	Debian, Ubuntu, Android ...

The TPS control system of 3 GeV synchrotron light source is also based on the EPICS framework [4]. The EPICS toolkit provides standard tools for display interfaces creation, archiving, alarm handling, etc. Big success of EPICS is based on the definition of a standard IOC (Input Output Controller) structure together with an extensive library of driver software for a wide range of I/O cards. The EPICS framework which has various functionalities is employed to monitor and to control on embedded applications of accelerator system.

BANANA PI AS EPICS IOC

Stability and performance of Banana Pi (BPi) are enough as the EPICS IOCs for specific control applications. The EPICS framework can be built on the Linux-based BPi successfully [5]. Some control functions are implemented by use of the BPi platforms with EPICS support. The efforts of implementation are summarized as followings.

Software Architecture

To implement the BPi as the EPICS IOC for specific control applications, the EPICS base and modules are necessary to be set up on the BPi platform which operation system is the Debian or Ubuntu Linux. The device driver of SPI (Serial Peripheral Interface) bus is built for communicating with DAC/ADC modules, and the device support interface is also developed as the glue between the EPICS records and device drivers. The EPICS records support are created according to the specific functions. The EPICS archive server is set up to record various parameters variations for long time observation. The operation interfaces are created by used of the EDM, CS-Studio, etc. to control and monitor via PV (Process Variable) channel access, and the archived data can be retrieved with using a form of graphical representation of the CS-Studio based data browser. The schematic is shown as Fig. 1.

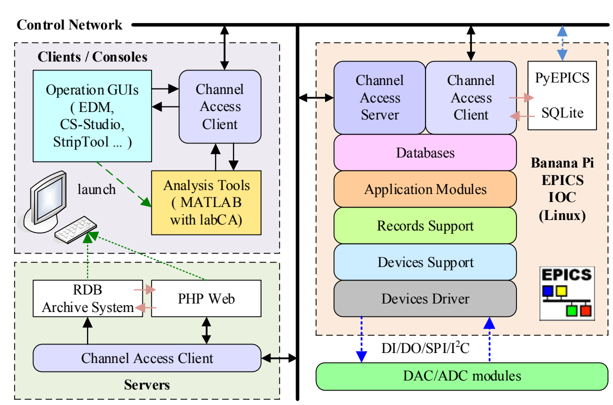

Figure 1: Software architecture of the BPi within EPICS support.

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LO BOARD FOR 704.42 MHz CAVITY SIMULATOR FOR ESS*

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Abstract

This paper describes the requirements, architecture, and measurements results of the Local Oscillator (LO) generation board prototype. The design will provide low phase noise clock and heterodyne signals for the 704.42 MHz Cavity Simulator for the European Spallation Source. RF signal detection has critical influence on the simulation's performance and its quality depends on the quality of the two aforementioned signals. The clock frequency is a subharmonic of the reference frequency and choice of the frequency divider generating the clock signals is discussed. The performance of selected dividers was compared. The LO frequency must be synthesized and frequency synthesis schemes are investigated. Critical components used in the direct analog scheme are identified and their selection criteria were given.

INTRODUCTION

This paper describes the requirements, architecture, and measurements results of the Local Oscillator Generation board prototype. It is a standalone module designed for the Cavity Simulator project [1] and is refered to as CS-LOG.

The Cavity Simulator will detect the amplitudes and phases of the input RF signals by downconverting them to an intermediate frequency (IF). Those signals will be sampled and digitized by high-speed precise analog-to-digital converters. The architecture necessitates synthesis of a low phase noise clock and heterodyne/LO signals. The CS-LOG module will be responsible for generation of those signals based on an externally fed reference signal. The prototype is also used to verify performance of the design intended for the low level radio frequency (LLRF) control system.

A LLRF system stabilizes the electromagnetic field inside accelerating modules. As with Cavity Simulator' signal detection, the field detection has critical influence on the regulation's quality.

The European Spallation Source(ESS) LLRF control system will be based on the Micro-Telecommunications Computing Architecture (MTCA) [2]. The remote diagnostic functionality is considered one of the main benefits of the platform. The LO board will have a rear transition module form factor and it will supply 4 neighboring LLRF systems [3].

REQUIREMENTS

The functional requirements put on the CS-LOG and the LO RTM slightly differ.The common requirements are presented below and the ones specific to CS-LOG follow.

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Common Requirements

The input reference frequency is 704.42 MHz. The clock to reference frequency ratio is 1/6 and the IF to reference frequency ratio is 1/28 or 1/22, corresponing to 117.40 MHz and 25.16 / 32.02 MHz, respectively. LO and clock signals' phase noise requirements are presented in Table 1 and they are dependent on the sufficient quality of the reference signal. Both clock and LO signals shall be sine waves with maximum harmonic spurious level of -60 dBc. The non-harmonic spurious shall be not greater than -60 dBc for clock and not greater than -50 dB for LO.

The VSWR on each port (Reference Input, LO Outputs, CLK Outputs) shall be not greater than 1.5, corresponding to return loss of -13.979 dB.

CS-LOG Requirements

The module shall additionally fulfill the following requirements:

- the module shall provide 2 LO outputs (power level range: +10 to +15 dBm),
- the module shall provide 4 clock outputs (power level range: +5 to +10 dBm),
- the module shall be controlled through an isolated I2C bus.

DESIGN

This section describes frequency synthesis and signal conditioning aspects of the design. The measurments presented were obtained using evaluation boards.

LO Frequency Synthesis Considerations

The LO frequency ($f_{LO} = f_{reference} \pm f_{intermediate}$) is not a harmonic or a subharmonic of the reference signal and must be synthesized. Synthesizers may be classified into three types:

- Direct Analog,
- Direct Digital,
- Indirect Digital.

The first approach uses frequency dividers, mixers, and filters. It closely follows the phase noise of the reference signal, with additional noise induced by the frequency divider and the mixer. Far from carrier the noise can be improved by using a narrow band-pass filter. Such filters increase the cost of the device and are sensitive to mechanical vibrations.

A Direct Digital Synthesizer (DDS) uses a numerically controlled oscillator feeding a digital-to-analog converter, both being synchronized by the reference clock. The intermediate to reference frequency ratio is 1/22 or 1/28 which results in systemic frequency error by using a binary frequency tuning word.

An Indirect Digital Synthesizer utilizes a PLL with an integer or fractional frequency divider. For offset frequencies

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SYNCHROTRON MASTER FREQUENCY RECONSTRUCTION FOR SUB-NANOSECOND TIME-RESOLVED XMCD-PEEM EXPERIMENTS

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Abstract

The timing and synchronization system at the ALBA synchrotron facility is based on the well-established event-based model broadly used in the particle accelerator facilities built in the last decade. In previous systems, based on signal model architecture, the master frequency was distributed using a direct analog signal and delayed at each target where the triggers were required. However, such strategy has proven to be extremely expensive and non-scalable. In the event-based model, the data stream is generated at a continuous rate, synchronously with the master clock oscillator of the accelerator. This strategy improves the flexibility for tuning the trigger parameters remotely and reduces the costs related to maintenance tasks. On the other hand, the absence of the pure RF signal distributed in the experimental stations implies much more complexity in the performance of time-resolved experiments. Abstract here explain how these difficulties have been overcome in the ALBA timing system in order to allow the signal reconstruction of the RF master frequency at the CIRCE beamline.

INTRODUCTION

The pulsed nature of synchrotron light can be potentially used for time-resolved experiments in highly dynamic systems. An excitation of the sample which is synchronous with the beam pulses allows acquiring static images using detectors that usually need a relatively long time for integration. The entire dynamic response of the system is then obtained by the subsequent analysis of measurements with different phase settings for the excitation (i.e., different delays between excitation and detection).

This methodology is used in ALBA CIRCE beamline in the research of the magneto-elastic dynamics by photoemission electron microscopy with x-ray magnetic circular dichroism (XMCD-PEEM). The magneto-elastic effect has been measured for Nickel microstructures under time-dependent elastic deformation at the sub-nanosecond timescale produced by a surface acoustic wave (SAW) in a piezoelectric substrate [1,2]. The responses of the magnetic microstructures at specific phases with respect to the sinusoidal excitation are acquired by synchronizing the SAW with the RF master frequency (499.654 MHz) of the accelerator.

Apart from the synchronization of the SAW excitation with the beam pulses, further requirements to obtain measurable deformations with reasonable accuracy are: first, a signal power reaching the sample of at least 100 mW (20 dBm) and, second, a signal jitter defined between the master oscillator and the SAW filter excitation smaller than 100 ps.

Moreover, a technical issue is the need to transfer the synchronism signal to the PEEM sample environment, in Ultra High Vacuum (UHV) and at High Voltage (HV), typically -20 kV. A fibre optic analog link available in the RF range provides complete galvanic isolation, preventing damage of expensive parts of the setup by propagation of arcs generated between the sample and the first microscope lens.

SYNCHRONISM STRATEGY

At ALBA, where an event-based timing system is used, the RF signal of the master oscillator is not pre-distributed around the synchrotron facility. Thus there is no straightforward implementation like in signal-based timing systems which however imply large costs in the installation, signal conditioning and maintenance. Alternatively the reconstruction of the master frequency from the present event-based timing system results in a smart solution. This option is more flexible, scalable, and easier to maintain.

Event-Based Timing System

In the ALBA event-based timing system [3,4,5], an event generator (EVG) produces a continuous data stream, synchronous to an external clock of 125 MHz that is one fourth of the accelerator RF. The sequence, composed by event frames (words), is transmitted by a tree structured fibre-optics network towards all the points where timing is required (see Figure 1). Fan Out units are responsible of distributing the event code by producing multiple identical data stream outputs from one event stream input. In the destination points, Event Receivers (EVR) decode the event frames and generates output pulses with configurable characteristics, such as delay and pulse width. This procedure provides full flexibility to change trigger parameters and a much easier maintenance. The output triggers are phase-locked with the clock reference with only a few picoseconds jitter, and are therefore synchronized to the master oscillator.

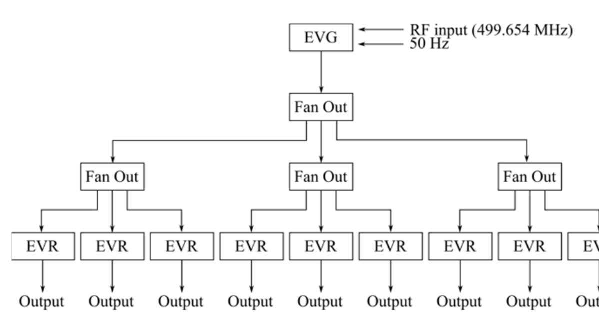

Figure 1: Event-based timing system topology.

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SKA SYNCHRONIZATION AND TIMING LOCAL MONITOR CONTROL - PROJECT STATUS

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Abstract

The Square Kilometre Array (SKA) project aims to build a large radio telescope consisting of multiple dishes and dipoles, in South Africa (SKA1-Mid) and Australia (SKA1-Low) respectively. The Synchronization and Timing (SAT) system of SKA provides frequency and clock signals from a central clock ensemble to all elements of the radio telescope, critical to the functionality of SKA acting as a unified large telescope using interferometry. The local monitor and control system for SAT (SAT.LMC) will monitor and control the working of the SAT system consisting of the timescale generation system, the frequency distribution system and the timing distribution system. SAT.LMC will also enable Telescope Manager (TM) to perform any SAT maintenance and operations. As part of Critical Design Review, SAT.LMC is getting close to submitting its final architecture and design. This paper discusses the architecture, technology, and the outcomes of prototyping activities.

SAT SYSTEM OVERVIEW

The SAT system of SKA Telescope project [1], designed by the Signal and Data Transport (SaDT) [2] Consortium of the SKA, provides frequency and clock reference signals from a central clock ensemble that are distributed in a phase-coherent manner to each antenna across the telescope's fibre network. The SAT system is divided into 4 modules – SAT.CLOCKS (CLK), SAT.STFR.FRQ (FRQ), SAT.STFR.UTC (UTC) and SAT.LMC.

The CLK module provides the timescales for the SKA Telescope and uses an ensemble of three hydrogen masers as the reference clocks, providing a 10 MHz reference and PPS signal. The timescales will be tied to coordinated Universal Time (UTC) as their time and frequency reference. Global Navigation Satellite System (GNSS) time transfer will be used as the primary time transfer method and the time transfers will be computed by the Bureau International des Poids et Mesures (BIPM). A steering mechanism has been designed to keep the time and frequency of the SKA Timescale within 5 ns of UTC.

The FRQ module distributes phase coherent frequency signals, using a custom design consisting of the Transmitter Module (Tx), Receiver Module (Rx) and a Communication Control Module, to all the receptors of the SKA1-Mid and SKA1-Low telescopes. The excess phase noise, induced by the various noise sources in the fibre-optic cables that degrade the quality (the coherence) of the transmitted signals by perturbing the phase, is detected and compensated in order to transfer reference signals with sufficient coherence over the longer link lengths.

The UTC module, uses the White Rabbit (WR) system to distribute the absolute time (from the timescale designed by CLK) to the receptors in SKA1-Mid and SKA1-Low. The WR signal is generated and distributed by WR switches that are synchronized to the SAT Clock ensemble. They each receive a 10 MHz reference and PPS signal, and use the Network Time Protocol (NTP) to determine the UTC time of a PPS edge. Their output is transmitted via a single fibre to a WR end point. The end point measures and compensates for the optical and system delays, and outputs a replica of the PPS pulse, which is delivered to the receptor equipment.

The SAT.LMC module monitors the health and controls the various pieces of equipment of the SAT system. It presents a rolled-up view of the health of the SAT system to TM.

SKA MONITOR AND CONTROL

The Monitor and Control system of SKA adopts a hierarchical approach. The SKA Telescope consists of a number of elements based on the functions that the telescope will perform. The TM element orchestrates, monitors and controls all the other elements of the telescope via Local Monitor and Control (LMC) systems, local to each element. These Element LMCs in-turn orchestrate, monitor and control the respective elements. The LMCs receive control commands from TM, which are translated into low-level commands by respective LMCs and sent to the element equipment(s). The Element LMCs gather monitoring data from each of the element equipment and send it up to TM. Figure 1 below shows the SKA Monitor and Control structure.

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A TIME STAMPING TDC FOR SPEC AND ZEN PLATFORMS BASED ON WHITE RABBIT

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Abstract

Sub-nsec precision time synchronization is requested for data-acquisition components distributed over up to tens of km^2 in modern astroparticle experiments, like upcoming Gamma-Ray and Cosmic-Ray detector arrays, to ensure optimal triggering, pattern recognition and background rejection. The White-Rabbit (WR) standard for precision time and frequency transfer is well suited for this purpose.

We present two multi-channel general-purpose TDC units, which are firmware-implemented on two widely used WR-nodes: the SPEC (Spartan 6) and ZEN (Zynq) boards. Their main features: TDCs with 1 nsec resolution (default), running deadtime-free and capable of local buffering and centralized level-2 trigger architectures. The TDC stamps pulses are in absolute TAI. With off-the-shelve mezzanine boards (5ChDIO-FMC-boards), up to 5 TDC channels are available per WR-node. A SPEC-TDC design with 0.25 nsec resolution is currently in exploration. The TDC units are under test for long-term performance in a harsh environment application at TAIGA-HiSCORE/Siberia, for the Front-End DAQ and the central GPSDO clock facility.

INTRODUCTION

Time measurement of sub-nsec precision is required in modern astroparticle experiments like Cosmic Ray, Gamma-Ray and High Energy Neutrino Telescopes, with sensor units distributed over large area and operating under harsh conditions. The White Rabbit (WR) technology for precision time and frequency transfer [1] offers technical performance parameters, adequat for this task.

White Rabbit is in use in an astroparticle experiment since 2012 [2, 3]. This WR-installation in the TAIGA Gamma-astronomy project [4, 5] aimed to supply precision timing to the distributed Air-Cherenkov detectors, and also served as a WR test-bed. In-situ nsec-performance-verification was an essential part of the system design.

After very positive experience [6] we proposed White Rabbit as the time-distribution system for the next generation Gamma-Ray Observatory, CTA [7, 8]. WR has numerous advantages compared to custom-made solutions, most noticably avoiding the substantial design, verification and maintenance effort for custom-made solutions.

Conceptually, WR offers a standard way to transport a precision clock over a network of WR-devices, via WR-switches from a central time-master to distributed WR-nodes (the 'WR endpoints'), see e.g. [1, 3]. These WR-nodes can either be (1) standalone WR-devices, or (2) have the WR-functionality integrated directly into the user-hardware.

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In this paper we follow option (1), which implies an exchange of signals between the WR-node and the user hardware (e.g. DAQ-components of a Telescope, or a detector station in a multi-component setup). It is convenient to rely on standard off-the-shelf WR-devices, which only need to be firmware-adapted for the specific functionalities (and eventually, equipped for with trivial signal-level adapters); since this minimizes development of new hardware.

In this paper, we present the design of a new universal multi-channel TDC for two types of popular commercial WR-nodes - the SPEC [9, 10] and the ZEN card [9]. We developed

- a deadtime-free 4-channel TDC with 1 nsec resolution on the SPEC and ZEN, and
- a TDC designed for improved time resolution up to 0.25 nsec.

These TDCs are also useful for efficient and flexible monitoring of the timing system functionality, as will be discussed.

EXTENSION OF THE 1 NSEC TDC

In [2] we presented a TDC based on the open source WR design for the SPEC in combination with the highly flexible DIO card. In this setup, shown in Fig.1, one signal of the DIO card is sampled with the in FPGA SERDES blocks and timestamped if above a certain adjustable threshold (a feature of the DIO card). We created for various applications firmware to run a time-precision DAQ, including dedicated IO-control [3]. A similar design has been implemented on the ZEN, see Fig.2).

4-Channel TDC

Due to the high flexibility of the DIO card all ports can be used as inputs. In our design we instantiated four TDC cores, each connected to one of the DIO input signals Each of the four TDCs is connected to a FIFO which keeps the timestamps until the CPU reads it and builds UDP packets. This implementation is realized in the SPEC and the ZEN node, (see e.g. Fig.3). While on the SPEC WR node the lm32 cpu is used to assemble the network packets the ZEN WR node the embedded ARM core is doing this job. The ARM core is connected to the WR core via an AXI-to-Wishbone Bridge. Due to the more powerful ARM core the trigger rate is by far higher than on the SPEC card. It is planned to use the Fabric Interface of the White Rabbit core to generate the packets without a CPU.

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CHANNEL SELECTION SWITCH FOR THE REDUNDANT 1.3 GHz MASTER OSCILLATOR OF THE EUROPEAN XFEL

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Abstract

The phase reference signal reliability is of utmost importance for continuous operation of the European XFEL machine. Since even very short interruption or glitch in the reference signal might break the precise synchronisation between subsystems, it is desirable to minimize probability of such events. While master oscillators often have a hot-spare to speed-up recovery after a failure, whether switched manually or electronically, it does not save from time-consuming resynchronisation.

Our experience from testing and commissioning E-XFEL 1.3 GHz Master Oscillator (MO) shows that a struggle to achieve demanding phase-noise requirements might negatively impact reliability of the system. In this paper we present an approach which allows for quick switching between independent reference generation channels while maintaining continuity of the output signal. This is a first step towards autonomous redundancy solution for the E-XFEL MO which will maintain continuous reference signal even in case of a failure of one of the generation channels.

INTRODUCTION

In modern accelerators, very precise synchronisation is required, especially in Free-Electron Laser (FEL) applications, often down to femtosecond levels. One of such facilities was recently put into operation: European X-ray FEL (E-XFEL) [1], located at Deutches Elektronen-Synchrotron (DESY) site in Hamburg, Germany. Whole facility spans over 3.4 km, which makes achieving such precision especially challenging. General issue of correct synchronisation can be split into two:

- short-term phase stability of reference signal (jitter or phase noise)
- long-term drifts of electrical (or optical) lengths in the distribution network

Such approach is of course a simplifiaction of many interconnected sub-issues, but allows for easier overview of system structure.

E-XFEL's Master Oscillator (MO) [2], a relatively complex system in itself, delivers 1.3 GHz signal with rms jitter below 20 fs[1] [3]. This signal is then distributed as a phase reference signal by the distribution system whose task is management and compensation of drifts. E-XFEL utilises a hybrid RF-optical distribution scheme: reference signal is delivered to all users by low-drift and relatively low-cost RF interferometric links and then further corrected at several points using laser-based links for improved precision [4] [5].

It is also important to note that using provided reference signal, with help of various frequency conversion techniques, users derive other signals of different frequencies, such as local-oscillator (LO) and clock signals. These derived signals are in a very specific time relation to the reference signal. If the reference signal disappears, even for a brief moment, all these precise relations between nodes and signals are disrupted or even lost completely. Similar result may come from other significant disturbances in the reference signal.

The following resynchronisation of whole facility will usually take at least several hours, which means that it is unavailable for the users for a significant period of time. It is then obvious that reliability of the synchronisation system is very important and largely depends on continuity the reference signal delivery.

While failures in the distribution network will also result in, at least partial, loss of synchronism, this work focuses on dealing with failures in the source of the reference signal—Master Oscillator itself. Our experience from development, tests, commissioning and operation of the part of E-XFEL's MO which is responsible for reference signal generation, shows that reliability vs performance trade-off can be an issue. Demanding requirements, especially for phase noise, often call for novel solutions and constrain component selection. This can leave little space for reliability considerations.

CONCEPT OVERVIEW

It is customary to have a hot spare of the MO, which in case of failure in the main MO allows for quick recovery of the reference signal, without need for immediate repair of the failed components. However, whether the switchover is done manually or electronically, loss of signal has already propagated downstream and, possibly, resulted in loss of synchronism.

We found that in order to solve issue of inferior reliability there is a need for a true redundancy solution which could react automatically to a failure and avoid any interruptions in the reference signal. In that case, there are two main issues to be solved:

- How to switch between sources without propagating loss of signal (or other large disturbances) downstream?
- How to detect a failure, quickly and reliably?

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[1] integration bandwidth: 10 Hz–1 MHz

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OPTIMISATION OF A LOW-NOISE 1.3 GHz PLL FREQUENCY SYNTHESISER FOR THE EUROPEAN XFEL

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Abstract

The Master Oscillator system of the European XFEL was built using frequency synthesis techniques that were found to have the best phase noise performance. This includes low noise frequency multipliers and non-multiplying phase lock loops, incorporated in the system to shape its output phase noise spectrum. Jitter of the output signal strongly depends on phase noise transmittance of the PLL and suboptimal design can worsen it by orders of magnitude. Taking into consideration that the PLL open loop transmittance usually can be shaped in multiple ways, and that the accurate phase noise measurements can easily take more than 30 minutes, designing an automated tool becomes a necessity. For this purpose an approach to the tuning system construction was chosen in order to make the phase noise optimisation process simpler. This paper describes the optimisation of PLL synthesizer phase noise, done to improve the performance of the European XFEL MO. We present the phase noise optimisation process and achieved results.

INTRODUCTION

Master Oscillator [1] is a low noise and high power reference signal generator for the European XFEL [2] (X-Ray Free Electron Laser) which was built in the DESY Institute in Hamburg [3]. System consists of three structurally identical generation channels, and a redundancy module designed to detect the failure of a generation channel and optionally change the output signal source. In this application, a very low phase noise of the 1.3 GHz reference signal is required to assure high precision of the accelerating field control. Therefore single MO channel incorporates a frequency synthesizers chain, starting with a GPS Disciplined Rubidium Oscillator (10 MHz), followed by a phase locked oscillators: 100 MHz OCXO (Oven Controlled XTAL Oscillator) and a 1.3 GHz DRO (Dielectric Resonator Oscillator). Apart from using high performance VCOs (Voltage Controlled Oscillator), big effort was also put on choosing the frequency conversion methods and a PLL (Phase Lock Loop) synthesisers parameters.

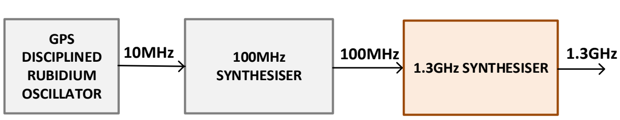

Figure 1: XFEL Master Oscillator block diagram. The optimised synthesiser is highlighted.

The following article describes the process of 1.3GHz PLL synthesiser tuning performed to improve the Master Oscillator output signal phase noise performance.

PHASE NOISE AND A PHASE LOCK LOOP

Phase noise is often one of the most important parameters of a frequency generator [4]. Output signal of an RF signal generator may be described as a pure sine wave modulated by both amplitude and phase noise. In case of RF oscillators, the phase noise usually dominates over the amplitude noise, so all of the further presented considerations will concern only the phase noise, which actually represents the signal short-term phase/frequency stability. The most common way of presenting the oscillator's phase noise is a ratio of the spectral power density measured in 1 Hz band at a specified offset frequency from the carrier to the total power of the carrier signal [5]. An example of a real oscillator phase noise characteristic is presented on Fig. 6 (yellow plot, "free-running VCO"). Stability of the generated signal may be also described using a jitter parameter – phase noise integrated in specific bandwidth.

Phase Lock Loops [6] (Fig. 2) are used to synchronize the VCO frequency and phase to the reference signal. PLL consists of three main functional blocks: phase detector, loop filter and the VCO. Phase detector output voltage is proportional to the phase difference between reference and VCO signal. In perfect case (without the noise) the signals are synchronized and the filtered phase detector output signal (VCO control signal, U_{VCO}) is a DC voltage. In real system, where both signals are modulated by the phase noise and each loop component adds its own residual noise, it contains also an AC component – an incidental, noise-caused phase difference between both signal phases, multiplied by the phase detector sensitivity and the loop filter transmittance. VCO control signal is tuning the oscillator in order to minimise the phase difference detected by the phase detector, closing the negative feedback loop.

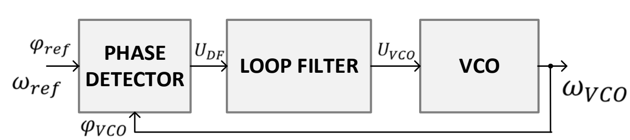

Figure 2: PLL block diagram.

The phase noise characteristic of the PLL output signal can be shaped by adjusting the loop filter (low-pass filter) transmittance. For low offset from carrier frequencies, where the phase detector signal is not attenuated by the PLL transfer function, the VCO phase is tracking the reference signal phase – which means, that even if the free-running oscillator output phase noise is high, inside the

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ALBA EQUIPMENT PROTECTION SYSTEM, CURRENT STATUS

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Abstract

ALBA [1] is the name of Barcelona's 3 GeV Synchrotron Light source. In operation since 2012, it currently hosts experiments 24/7 in its 8 beamlines with 3 more in development. The aim of ALBA Equipment Protection System is to avoid damage of hardware by managing sets of permits and interlock signals. The EPS scope covers not only ALBA accelerators and its beamlines but also the other existing laboratories like Radiofrequency, Optics, Vacuum, etc. It is built on B&R PLCs with CPUs installed in cabinets in ALBA service and experimental areas and a network of remote I/O modules installed in shielded boxes inside the tunnel and other irradiated zones. CPU's and Remote models are interconnected by the X2X field-bus. Signals managed by PLC's include interlocks, temperature readouts, flow-meters, flow-switches, thermal switches, shutters, pneumatic actuators, fluorescence screens, etc. This paper describes the design and the architecture of the Equipment Protection System, the current status, the tools used by the EPS team and the recent improvements in terms of reaction time and interaction with other systems via Powerlink and fast interlock system.

INTRODUCTION

The ALBA Equipment Protection Systems (EPS) [2] is a distributed PLC-based system autonomous from the TANGO Control System [3]. EPS is a homogeneous system based on B&R PLCs distributed along the facility. It became a versatile system that has been adapted for interlock, diagnostic acquisition and motion control in both, accelerators and beamlines.

EPS is being continuously improved and some changes has been made in the last times, among others: differential temperature Interlocks added, EPS Vacuum linked to the fast Machine Protection System (MPS) [4], Powerlink V2 [5] upgrade and adding all storage ring temperatures as interlocks. This last upgrade implied that no temperature diagnostics is available in the storage ring. To cover this need it's been created a wireless diagnostics system [6].

Although other PLC based systems are used in ALBA to control the Radio Frequency circulators, Linac control, bake out controllers and water or air cooling systems; the EPS is the most complex system managed by PLC's, using 59 B&R CPUs and 128 periphery cabinets to collect more than 7300 signals. In addition to the main purpose of protection, several hundreds of signals distributed across the whole system are acquired for diagnostics and control of pressures, temperatures and movable elements.

EPS installation in numbers:

- 35% cables installed
- Powerlink installation (only Service area)
    - 1 CPU B&R master Powerlink
    - 15 Network switches
    - 43 CPUs connected
- Vacuum
    - 512 thermocouples from storage ring
    - 172 Vacuum pneumatic valves (VAT)
    - 166 Ion Pump Controller (DUAL)
    - 112 Vacuum gauge controller (MKS)
- Magnets:
    - 698 Thermal Switches
    - 376 Flow Switches
- 8 Radiofrequency plants preconditions and interlock management
- 11 Front End
- 8 Insertion Devices
- Building facilities, Cooling Diagnostics:
    - 14 flow reading
    - 81 pressure transmitter
- Diagnostics:
    - 26 Fluorescence Screen (2 position)
    - 11 Fluorescence Screen with OTR (3 position)

SOFTWARE TOOLS FOR EPS

The integration of the management of an independent system like EPS in the TANGO Control System required several phases, starting from the collection of cables from the Cabling Database to the final Auto-generation of UI's for both EPS Expert GUI and operator users (Taurus).

ALBA Cabling and Controls Database

The CCDB python API [7] provides full access to the Cabling Database from our control system tools. The API methods allow searching for equipment and getting lists of cables connections details.

Every cable and equipment installed in the ALBA Synchrotron is registered in our Cabling and Controls Database (CCDB). It was developed in 2007 by our Management and Information Software section (MIS) using MySQL and web technologies. It was the main support tool for the design and construction phase and now it is still kept updated as the main repository of equipment and configurations in our Accelerators and Beamlines (Fig. 1).

As of 2017 it lists 397 racks with 7594 equipment of different 1057 equipment types. These equipments are connected using 21010 cables of 638 different cable types with a total length of 215.8 Km.

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DEVELOPMENT OF A PXI BASED TEST STAND FOR AUTOMATIZATION OF THE QUALITY ASSURANCE OF THE PATIENT SAFETY SYSTEM IN A PROTON THERAPY CENTRE

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Abstract

At the Centre for Proton Therapy at the Paul Scherrer Institute, a cyclotron, two gantries and a fixed beamline are being used to treat tumours. In order to prevent non-optimal beam delivery, an interlock patient safety system (PaSS) was implemented that interrupts the treatment if any sub-system reports an error. To ensure correct treatment, the PaSS needs to be thoroughly tested as part of the regular quality assurance as well as after each change. This typically required weeks of work, extensive beam usage and could not always cover all possible failure modes. With the opportunity of the installation of a new gantry, an automated PaSS test stand was developed that can emulate the rest of the facility. It consists of a NI PXI chassis with virtually unlimited IOs that are synchronously stimulated or sampled at 1MHz, a set of adapters to connect each type of interfaced signal and a runtime environment. We have also developed a VHDL based formal language to describe stimuli, assertions and specific measurements. We present the use of our test stand in the verification and validation of the PaSS, showing how its full quality assurance, including report generation was reduced to minutes.

INTRODUCTION

At the Paul Scherrer Institut (PSI) cancer patients are being treated using proton therapy for a number of indications. The facility currently includes a fixed beam line for eye cancer treatment, operating clinically since 2010, and Gantries 1 and 2 operating since 1996 and 2013 respectively [1, 2]. A dedicated 250 MeV cyclotron is used to provide beam for all the treatment areas. Recently a new Gantry 3 has been installed and is being commissioned. Both the latter Gantry and the accelerator are commercial products from the company Varian Medical Systems [3]. The rest of the treatment areas were designed in house.

Each for the treatment areas designed at PSI, as well as the adapter used for the integration of Gantry 3 include a Patient Safety System. PaSS is the system responsible to monitor the status of the different elements involved in the treatment and to stop the beam to avoid personal harm whenever any potentially unsafe condition is detected.

The Patient Safety System needs to be thoroughly tested in order to ensure correct treatment. The quality assurance first includes testing the monitors and final elements connected to it. This is typically part of the commissioning process and regularly scheduled QA tests [4]. Secondly the hardware undergoes unit testing. This involves a preparation phase, when a risk analysis is performed and a test specification based on the design specifications are written, and an execution phase. The execution is both performed as a simulation, and later physically tested in the lab with a test stand that stimulates all inputs and monitors all outputs and checks that the response is as expected. Thirdly an integration test in the facility is performed, when all supervision functions and all final elements are checked for correctness, and errors are injected to monitor the PaSS response. It is important to note that being executed in a clinical facility, not all cases can be covered in this last step.

UNIT TESTING CONCEPT

The unit testing consists of a series of test steps applied to the PaSS system to emulate real life conditions at the interface level. Each of the unit tests are derived from different aspects of the design specifications and specify both a stimulus to be applied to the input signals and an expected behaviour of the output signals. They are described in a document that describes the test using and timed signal diagrams.

With the introduction of Gantry 3, a new unit testing methodology was introduced and it is now also being gradually applied to the other treatment areas. The unit tests are specified in a formal language that was developed for this task and which will be detailed in the following section. This reduces the amount of manual work, removes the ambiguities of natural language and therefore minimizes the possibility of errors. Also, thanks to the technical progress of instrumentation hardware with a high count of fast digital IOs, such as National Instruments´ PXI crates, it is now possible to synchronously all input signals and sample all output signals instead of sequentially testing small subsets of signals, as was the case in our former unit testing setup.

The three main aspects described in the unit tests are the stimuli, expected reaction and time measurements. Stimuli can be both realistic as well as physically impossible in the real facility. The expected and forbidden reactions are described as logic assertions. A number of time measurements can be programmed to evaluate the performance of the hardware and its logic.

UNIT TEST FORMAL DESCRIPTION

After an investigation of different existing languages to describe tests and assertions, nothing was found that was both compact and close enough to natural language as to be able to replace the textual description in the unit test

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NEW CONCEPTS FOR ACCESS DEVICES IN THE SPS PERSONNEL PROTECTION SYSTEM

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Abstract

The accelerator facilities at CERN span large areas and the personnel protection systems consist of hundreds of interlocked doors delimiting the accelerator zones. Entrance into the interlocked zones from the outside is allowed only via a small number of access points. These are no longer made of doors, which have left their place to turnstiles and then to mantraps or Personnel Access Devices (PAD). Originally meant for high security zones, the commercially available PADs have a number of CERN specific additions. This paper presents in detail the purpose and characteristics of each piece of equipment constituting the access devices and its integration within the personnel protection system. Key concepts related to personnel safety (e.g. interlocked safety tokens, patrols) and to access control (e.g. access authorisation, biometric identity verification, equipment checks) are introduced and solutions discussed. Three generations of access devices are presented, starting from the LHC model put in service in 2008, continuing with the PS devices operational since 2014 and finally introducing the latest model under development for the refurbishment of the SPS Personnel Protection System.

INTRODUCTION

In 2008, a modern LHC Access System [1] was put in operation; this was followed by a complete refurbishment of the PS Personnel Protection System [2]. Today, preparations are under way for the renovation of the SPS Personnel Protection System and a 3rd generation Personnel Access Device (PAD) has just been ordered. A new design was done, providing ease of installation, use and maintenance. At the same time, new functionalities were added to the already long list of access control and safety requirements that the access devices at CERN have to meet.

ACCESS CONTROL KEY CONCEPTS AND EQUIPMENT

Access control to the installations at CERN is based on a principle of layers of protection, each one allowing only a more restricted number of people to enter. On-site access is permitted to identified affiliated personnel, entering a surface building housing an accelerator or an experimental hall requires special authorisations, and finally entering a beam facility is subject to the strictest control.

Identification

Entry into or exit from a beam facility is subject to prior identification of the person requesting access or egress. A user-ID number is obtained from a special RFID chip added to the personal dosimeter and not from the standard badge read at the site entrance. Thus, anyone accessing a beam facility is sure to be in possession of a valid personal dosimeter. The badge reader itself is a commercial-off-the-shelf device complying with the international standard for contactless Smart Cards ISO 14443.

Access Control

Once a user's identifier is read, it is checked against a database table for a given access point. This is a simple verification, but there is a lot going on behind the scenes. In a big organisation, a number of services are involved in validating a user's access permit to a given location. At CERN, these involve:

- Authorisation granted by the facility responsible to people recognized by the Organization and with a professional need to access the facility;
- Valid Safety Training - only people having successfully completed appropriate safety courses are allowed to enter the beam facilities;
- Activity Approval - the activities requiring access to the facilities are either planned or based on imminent maintenance needs. The organisational unit in charge of works coordination keeps a detailed list of planned and approved activities together with the assigned personnel as well as a nominative list of on-call personnel prone to intervene at short notice. Entry into an interlocked area is subject to a prior authorization by the works coordination unit.

Identity Confirmation

Entry into a beam facility is subject to positive identity confirmation by means of biometrics verification. The biometrics data of the user, acquired by the access control system at the access point, is compared to the data kept in an encoded format in a database. At CERN, iris recognition has been the biometric technology in use for the last 10 years, with very good user feedback.

Equipment Checks

Personal Protective Equipment is to be worn by users at all times and in every facility, hence it is a well-developed habit. However, some facilities may require additional equipment, e.g. an operational dosimeter. This is enforced by procedures, but an automatic check that the user requesting access is in possession of an operational dosimeter and that it is correctly set, is a new stage in access control [3]. It will be added in the SPS access devices and, at a later stage, in the rest of CERN's accelerator complex.

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INTEGRATION OF PERSONAL PROTECTIVE EQUIPMENT CHECKS IN ACCESS CONTROL

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Abstract

Access to the interlocked zones of the CERN accelerator complex is allowed only for personnel wearing standard personal protective equipment. This equipment is complemented by specialised personal protective devices in case of specific hazards related to the remnant radiation or the presence of cryogenic fluids. These complex devices monitor the environment in the vicinity of the user and warn the user of the presence of hazards such as radiation or oxygen deficiency. The use of the devices is mandatory, but currently only enforced by procedures. In order to improve the safety of the personnel it has been proposed to verify that users are carrying their devices switched on when entering. This paper describes the development of a specialised multi-protocol terminal, based on Texas Instruments digital signal processor and integrated in the personnel protection system. The device performs local checks of the presence and status of operational dosimeter prior to allowing access to the interlocked zones. The results of the first tests in the Proton Synchrotron accelerator complex are presented.

INTRODUCTION

Several layers of protection help ensure the safety of personnel working in beam facilities at CERN. A number of systems are deployed offering facility wide protection: the access control and safety system, the fire detection and extinguishing systems, the gas detection and evacuation systems. In case of localised hazards, this systematic approach is complemented with active personal protective equipment. It includes operational dosimeters and personal gas level detectors. Conventional protective equipment like self-rescue masks or safety helmets constitutes the last protection layer.

The devices providing active personal protection are very specialised and their use is not common outside CERN. Hands-on training is provided to the users and reminders posted on the obligation of wearing the equipment at the access points and in the elevators. However, a systematic check to ensure in an automatic way that everyone is in possession of the necessary active protective equipment when entering a beam facility has not been provided so far.

The proposed solution is a terminal unit capable of tracking the protective equipment and communicating with the access system. The terminal unit can be triggered by the programmable logic controller (PLC) of the access booth, once a person steps in. During the access control verification process, the terminal unit is commanded to execute reading cycles to check the presence and the status of the personal protective devices. If the equipment is not present or not correctly set, the access system notifies the person to wear it properly and refuses access into the given interlocked zone. In particular, the objective for the terminal unit is to the check for the presence of operational dosimeters and oxygen detectors.

Operational dosimeters are provided by the Dosimetry Service at CERN. They are mandatory for everyone working in Limited Stay, High Radiation and Controlled Radiation areas [1]. The dosimeter displays the amount of dose and it has alarm functions when thresholds for dose or dose rates are exceeded. Before entering a hazardous area, the person has to read out and reset the dosimeter via a contactless reader terminal.

Oxygen level detectors are used in cryogenic facilities to cover the risk of oxygen deficiency hazard (ODH). Their use is mandatory in the Large Hadron Collider (LHC) tunnel areas. The device displays oxygen levels and sounds an alarm when a threshold value is reached. There are no terminal readers provided and the device does not offer native contactless communication mechanism.

After initial research, our team decided to design a multi-protocol terminal capable of communicating with a large set of devices in a contactless manner. Two cases were taken into consideration: the devices that natively communicate with their terminal units wirelessly, and the devices that do not provide any wireless interface. In the first case, the objective was to use the existing communication mechanism and in the second case to add an RFID tag to the equipment. Furthermore, the multiprotocol terminal had to meet every criterion of the access system both mechanically and electronically, and not hinder the access process itself.

TRACKING EQUIPMENT WITH RFID

Low frequency (LF) systems are widely used in access control, logistics or in implants for animal tracking. In low frequency Radio Frequency IDentification (RFID) systems the physical layer of the communication is realised through magnetic coupling. It is more resistant to detuning in the presence of metal objects than higher frequency solutions. The antenna coils of the reader and the transponder act like the coils of an air core transformer. The typical low frequency RFID transponders are passive devices, meaning that the transponder is energised by the alternating magnetic field that the reader emits and communicates by modulating the magnetic field by changing the load on its antenna coil.

There are several public accessible communication protocols like the ISO11784/5, ISO14223 and ISO18000-2 standards [2-4]. Transponder chips in this RFID frequency range include EM41000/2 or HITAG with publicly accessible protocol [5-6]. RFID labels with these chips can be attached to the oxygen detectors in order to track their presence with the terminal unit.

Other devices like the Mirion Technologies DMC type operational dosimeters [7-8] use active communication,

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REVIEW OF PERSONNEL SAFETY SYSTEMS AT DLS

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Abstract

Diamond Light Source is celebrating 10 years of "users" at its facility in Oxfordshire, England. Its safety systems have been designed to the standard EN61508 [1], with the facility constructed in 3 phases, which are just concluding. The final "phase 3" beamline Personnel Safety System (PSS) has been signed-off; hence it is timely to review our experience of the journey with these systems.

INTRODUCTION

The Diamond Light Source Ltd (DLS) is a scientific research facility providing intense beams of light to expose samples in order to discover detail of structure or surface. The "light" is a broad spectrum of electromagnetic radiation from visible through to X-ray but predominantly used in the X-ray band. The light is generated by bending a beam of 3GeV electrons in a synchrotron. There are significant hazards to personnel from the light itself and from the consequences of accelerating electrons to high energy. It is necessary to provide a robust protection system to ensure that the hazards are managed effectively.

HISTORY

The Diamond accelerator was conceived by a team of engineers and scientists at Daresbury Laboratory. Many of the initial concepts were already established when DLS was set up in 2002, to build and operate the research facility in Oxfordshire, England.

As the accelerator is capable of generating ionising radiation, DLS must comply with IRR99 [2], the statutory instrument concerning the production of ionising radiation in the UK. Provision is made in the regulations for facilities to operate accelerators under the "Prior Authorisation for the use of Accelerators" providing that the facility follows the "The Approved Code of Practice" [3] (ACOP).

The original concepts for the PSS were that it should be designed to EN61508 and use the Daresbury logic solver.

Hence Diamond Personnel Safety System has been built with the following constraints:

- It conforms to IRR99.
- It conforms to the ACOP.
- It complies with EN61508.
- It uses the Daresbury Logic solver.

The Daresbury logic solver [4] is a dual guardline relay system that is configured using "wire-wrap" to produce AND and OR logic functions. The operation of the logic solver can be monitored on the control system via a VME interface and Ethernet connection.

The project was split into 3 phases:

1. 3 accelerators (14 zones) and 7 beamlines.
2. 14 beamlines.
3. 10 beamlines.

Each system has been designed, built, tested and become operational in turn, with the first beamlines now celebrating 10 years of users in 2017.

LESSONS LEARNED

The DLS PSS [5] has benefitted from the experience and support of staff at Daresbury Laboratory and other accelerators. Visiting other facilities enabled us to develop an understanding of "best practice" and establish policies of our own. This has enabled DLS to develop with confidence and without major incident.

In retrospect, there are always choices made and things done that we may have done differently with the benefit of hindsight. There have also been ideas that work better than anticipated or had unexpected benefits.

The following sections contain some of our "lessons learned"

Proof Testing and Diagnostic Coverage

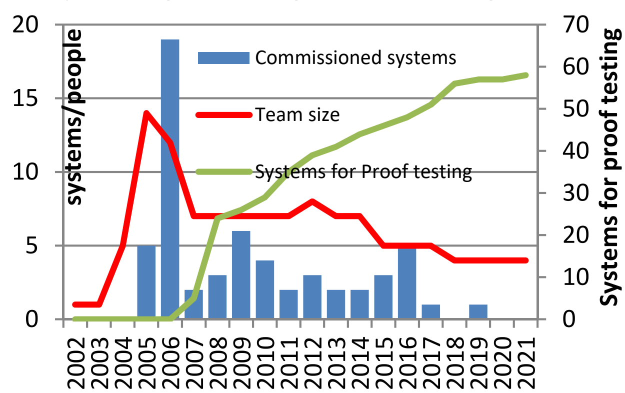

Figure 1: Development of DLS PSS.

Figure 1 above shows the development of DLS PSS over time. As new systems are built there follows a cumulative growth in proof testing requirements. We undertake proof tests on a 2 yearly programme which requires an average of 5 or 6 systems per shutdown. Even at this interval, this is a heavy burden and would require a larger team if the proof test period was any less. Consideration should be given to the level of diagnostic coverage in new systems to keep proof testing at a manageable level for a given team size and access periods for testing.

Architecture

DLS PSS functions with a "2 out of 2" (2oo2) architecture, or dual guardline system. This offers complete redundancy from a safety point of view but a single failure may force the facility "off" until it can be resolved. This

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ESS TARGET SAFETY SYSTEM DESIGN

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Abstract

The purpose of the Target Safety System (TSS) is to protect the public from exposure to unsafe levels of radiation, prevent the release of radioactive material beyond permissible limits, and bring the neutron spallation function into a safe state. In order to fulfill the necessary safety functions, the TSS continually monitors critical parameters within target station systems. If any parameter exceeds an acceptable level, the TSS actuates contactors to cut power to components at the front end of the accelerator and prevent the beam from reaching the target. The TSS is classified as a safety structure, system and component, relevant for the safety of the public and the environment. As such, it requires the highest level of rigor in design and quality for interlock systems at the ESS. Standards are applied to provide a guideline for building the TSS architecture and designing in resistance to single failures and common cause failures. This paper describes the system architecture and design of the TSS, including interfaces with target station and accelerator systems, and explains how the design complies with authority conditions and requirements imposed by development standards.

TSS SAFETY FUNCTIONS

The ESS target radiation safety functions were derived from the hazard and accidents analyses of target station systems and areas. A qualitative hazard analysis was performed to identify and evaluate potential radiological accidents, from which a collection of bounding events was selected for further analysis. The accident analysis detailed the identified accidents to determine the related level of risk. This involves quantification of severity, as measured by the dose consequences to both workers and the public, and definition of appropriate control actions to enable an acceptable level of risk.

To mitigate consequences of the accidents, different functions were identified in different levels of defence in depth (DiD) for systems in the target station. Functions to be fulfilled by the TSS were identified in DiD level three. Depending on the level, different constraints shall be applied on the design in terms of conditions from SSM (Swedish Nuclear Safety Authority) and design guidance from applicable standards.

Since the target contains a high inventory, many of the accident analyses address scenarios that could affect the target material or the helium cooling system. The most critical hazards tend to be related to increased temperature of the target wheel tungsten, which, if accompanied by oxidation of the tungsten and a loss of confinement, might have consequences of radiological releases. The following accident scenarios require TSS functions in order to prevent or mitigate the unacceptable consequences:

AA1: Target wheel rotation stop during beam on target

AA2: Proton beam events on target and proton beam window (non-rastered & focused beam)

AA3: Loss of target wheel cooling during beam on target wheel

In these accident scenarios, the increase of temperature in the target material leads to unacceptable radioactive material releases. Since the target is designed so that the decay heat can be dissipated by passive means, removing the beam removes the source of heat and puts the spallation process into the safe-state.

The following safety functions are dedicated to the TSS. The TSS shall monitor process variables in the wheel, helium cooling, and monolith systems to identify if the:

- Target helium cooling outlet velocity is below a certain limit
- Target helium cooling outlet pressure is below a certain limit
- Target helium cooling inlet temperature is above a certain limit
- Target wheel rotational speed is below a certain limit
- Monolith atmosphere pressure is above a certain limit

If any of the above conditions occur, the TSS shall bring the ESS spallation process to a safe-state (in terms of radioactive releases) by turning off the proton beam to prevent escalation of the situation. Figure 1 illustrates the location of the process variable monitored for radiation safety function.

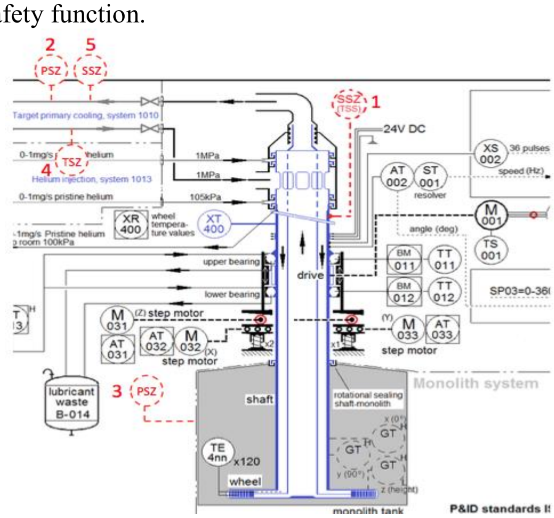

Figure 1: TSS process variables for safety functions.

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COMMISSIONING OF A NEW DOSE RATE MONITORING SYSTEM AT THE S-DALINAC*

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Abstract

Recently a new radiation protection interlock system has been established at the Darmstadt superconducting linear electron accelerator S-DALINAC. It prevents the staff from entering radiation protection areas during operation and allows a systematic scanning of these areas for workers before running the accelerator. As an extension of the new interlock, a new dose rate monitoring system has been developed using PIN-diode arrays and self-made ion chambers. These detectors will be used to perfom online dose rate measurements in order to switch automtically the status of illuminated radiation protection panels, which show the current level of protection area.

INTRODUCTION

Operating a charged-particle accelerator results in the production of ionizing radiation and the irradiation of its environment. The S-DALINAC is a superconducting recirculating electron accelerator that is operated in an energy range of 10 MeV (@ 60 μA) to 130 MeV (@ 20 μA). When the beam transport has been optimized the primary ionizing radiation is dominated by synchrotron radiation and, for example in the case of nuclear resonance fluorescence experiments, by bremsstrahlung. At beam energies larger than the neutron separation threshold one has to expect neutron fluxes as well. These neutron fluxes, but also the bremstrahlung, produce radioactive isotopes in the environment of the accelerator, for example Co-60 in steel or Na-22 in aluminum [1, 2]. The dose rates during operation and afterwards due to activation products can reach levels that the national radiation protection regulation has to be applied [3, 4]. Therefore, the accelerator and experimental hall as well as closely related technical rooms are declared as radiation areas to protect the workers against unreasonable exposure situations. While nuclear structure experiments are performed at the S-DALINAC the accelerator and experimental halls are restricted areas (potential local dose rate: $\dot{H} > 3$ mSv/h). Then, the closely related technical rooms are controlled areas (potential effective dose per 2000 h/a: $E > 6$ mSv). When no beam is prepared and no high frequency signal is fed to the cavities these halls and technical rooms are supervised areas (potential effective dose per 2000 h/a: $E > 1$ mSv). The current status of a radiation area is shown by an illuminated three-level panel in front of the doorways of that area, see Fig. 1. When beam and high frequency signals have been switched off the licensee has to validate that the dose rates do not exceed the regulatory limit of a supervised area. At the S-DALINAC, this has been done so far by manual measurements only. To prevent the radiation protection officer from potential exposure situation and to save time an online measurement system has been designed which will be permanantly installed inside the radiation areas. It will also allow to perform long term monitoring while operating the S-DALINAC. Furthermore, such a detector setup can be used to improve the beam diagnostics as well.

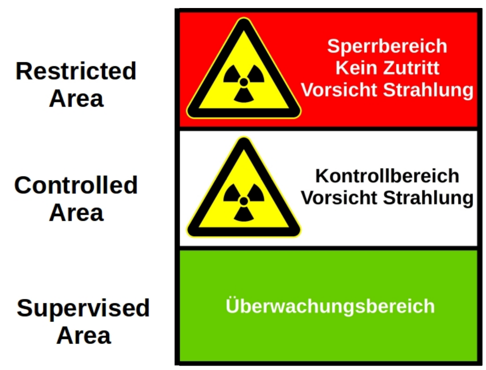

Figure 1: Radiation protection panel distinguishing the different radiation protection levels.

ARCHITECTURE

The new dose rate monitoring system consists of radiation detectors which are read out by micro controller boards (μC). Two boards have been used: the Nucleo-F767ZI [5] and the Arduino-UNO with ethernet shield [6]. If the measured signal exceeds a certain threshold the μC switches a relay which is connected to the personal interlock system (PIS) [7], see Fig. 2. The PIS is also responsible for controlling the illuminated radiation panels and to switch between the three levels. The new detector systems allow to measure the local dose rates before the level of radiation area is set from restricted or controlled to supervised. Furtherore, the online measured data can be accessed via the μC ethernet interface. The μC are device servers wich can easily be integrated into the EPICS-based control system using the EPICS stream device support [8, 9].

TESTED DETECTOR TYPES AND ELECTRONICS

Dosimetry has a long standing history of using geiger-tube counters and ion chambers [10–12], especially for examining environmental radiation-exposure situations [13]. Today, small semiconductor detectors are also capable of measuring

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SAFETY CONTROL OF THE SPIRAL2 RADIOACTIVE GAS STORAGE SYSTEM

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Abstract

The phase 1 of the SPIRAL2 facility, extension project of the GANIL laboratory, is under construction and the commissioning has started. During the run phases, radioactive gas, mainly composed of hydrogen, will be extracted from the vacuum chambers. The radioactive gas storage system function is to prevent any uncontrolled release of activated gas by storing it in gas tank during the radioactive decay, while monitoring the hydrogen rate in the tank under a threshold. The confinement of radioactive materials is a safety function. The filling and the discharge of the tanks are processed with monostable valves, making the storage a passive safety system. Two separate redundant control subsystems, based on electrical hardware technologies, allow the opening of the redundant safety valves, according to redundant pressure captors, redundant di-hydrogen rate analyzers and limit switches of the valves. The redundancy of the design of the control system meets the single failure criterion. The monitoring of the consistency of the two redundant safety subsystem, and the non-safety control functions of the storage process, are then managed by a Programmable Logic Controller.

INTRODUCTION

The SPIRAL2 facility, in the GANIL laboratory, will produce high-intensity ion beams for experimental nuclear physics. The accelerated ions will go from hydrogen to heavier ions such as carbon, argon or nickel. During the Phase 1, the ion beams are accelerated in the LINAC and sent to experiment rooms, S^3 (Super Separator Spectrometer) and NFS (Neutrons For Science), through the high-energy lines vacuum chambers. The extracted gas, coming from the impact of the beam on the beam stop, or from the degassing of the vacuum chambers, are radioactivated and have to be stored and monitored. This extracted gas is expected to be mainly composed of dihydrogen, as shown in Table 1.

Table 1: Extracted Gas Composition

Component	Rate at the start of the irradiation	Rate at the end of the irradiation
Dihydrogen	17 %	52 %
Water	69 %	43 %
Nitrogen	4 %	4 %
Carbon dioxyde	10 %	1 %

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Table 2: Expected Gas Volumes

Origin	Volume (litre/5 days)	H_2 volume (litre/5 days)
LINAC	9.6	7.8
NFS	1.4	1.2
S^3	7.2	5.8

After a predefined length of time, estimated at two to five days, the radioactive decay is checked and the gas is released into the environment.

MAIN FUNCTIONS OF THE STORAGE CONTROL SYSTEM

Protection Functions

The tanks of the radioactive gas storage system are the first containment barrier. To prevent any risk of dissemination, the system fulfills two protection functions, regarding two accidental events [2]:

- The uncontrolled release of activated gas towards the chimney of the nuclear ventilation system.
- The leak of a tank or a pipe, or the burst of a tank because of an excess of hydrogen rate in the tank.

The storage system is made of two tanks which will be filled one at a time, while the other one is isolated for its radioactive decay. The system is designed to add a third tank if needed. The dimension of their volume, 1.6 m^3, was calculated to allow an uninterrupted filling of one tank during the decay of the other one, while diluting the gas being stored to prevent any risk of burst caused by the hydrogen.

To prevent risks of leaks, the whole storage system, tanks and pipes, is working under low pressure. The tanks are jacketed, and the space between the two layers is maintained under slightly high pressure to prevent gas leaks towards the outside of the tanks. In the same way, the hydrogen rate analyzer systems are set up in low pressure ventilated boxes. A pump and a flow controller maintain an adequate flow into the hydrogen analyzers.

The Storage Control Phases

The process cycle of each tank is composed of several phases, illustrated in Figs. 1, 2 and 3. Only one phase is running at a time on each tank.

- The filling stage: The tanks are empty at first, at a pressure of 1mbar. The input valves of the tanks are opened to allow the gas in, until a maximal pressure of 0.95 bars. The tank is then considered full. During the filling phase, a hydrogen rate ana-

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VERSATILE SERVICE FOR THE PROTECTION OF EXPERIMENTAL AREAS AT CERN

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Abstract

CERN hosts a number of other experimental areas with a rich research program ranging from fundamental physics to medical applications. The risk assessments have shown a large palette of potential hazards (radiological, electrical, chemical, laser, etc.) that need to be properly mitigated in order to ensure the safety of personnel working inside these areas. A Personnel Protection System, typically, accomplishes this goal by implementing a certain number of heterogeneous functionalities as interlocks of critical elements, management of a local HMI, data monitoring and interfacing with RFID badge readers. Given those requirements, reducing system complexity and costs are key parameters to be optimized in the solution. This paper is aimed at summarizing the findings, in terms of costs, complexity and maintenance reduction, offered by a technology from National Instruments® based on cRIO controllers and a new series of SIL-3 certified safety I/O modules. A use case based on a service for the protection of Class 4 laser laboratories will be described in detail.

INTRODUCTION

The safety management of CERN has brought to light the need to mitigate the risks in a large number of different experimental areas of different configurations ranging from large caverns to small bunkers of a few square meters. These experiments are often the outcome of collaborations between CERN and worldwide research institutes and, therefore, access to these areas is granted to a potentially large and heterogeneous population of users.

Considering the large number of facilities we are requested to secure and the fact that the budget for safety is, in most of the cases, funded by the different home institutes, there is a strong need to look for solutions being: *simple*, in terms of architecture and number of devices to be installed; *compact,* in terms of space occupied inside the facility (a huge rack 2m high cannot fit in most of the cases); *easy to operate and maintain* and *cost effective*, especially considering that they might be used only during the short lifetime of the research activity.

Another key aspect to take into account is that, behind the purely safety interlock, a wide range of access control functionalities [1] are necessary in order to operate these facilities, such as: RFID identification of users, verification of required access rights, count of users in a zone, implementation of dedicated graphical display of relevant information for local users, and remote control/monitoring capabilities for control room operators.

In this paper we investigate the possibility to employ the NI cRIO 9030 controller [2] in conjunction with the new Functional Safety modules from National Instruments® in order to increase the global reliability and to make it suitable for safety related applications. The 903X generation of cRIO controllers are particularly interesting due to the fact that NI replaced their proprietary OS with a new version based on Real-Time Linux. This adds much more flexibility to the controller, on one hand offering the possibility to interface the cRIO with a wide palette of devices such as: USB key-board, USB mouse, video monitors, smart cameras, etc. In addition, thanks to the LabVIEW programming environment, it offers the possibility to <u>easily</u> implement IT tasks, such as big file management, database connections, OPC communications, image processing, complex vector/matrix manipulation, mathematical analysis, etc.

Another interesting aspect of the LabVIEW environment is the possibility to fully validate the entire user software even if the real hardware is not connected thanks to the emulation capabilities and testing tools of the programming environment. This allows to spot all logical bugs before the site commissioning tests.

CASE STUDY

The specific case study considered to demonstrate our technical proposal is the ATRAP[1] experiment [3] is has been used to apply our technical solution. ATRAP is a collaboration between CERN and Harvard University, with the intent to produce anti-hydrogen atoms and investigate their properties against their matter equivalents. To perform these measurements, a wide set of powerful class 4 lasers are employed for spectrography and for cooling the anti-electron particles down to an energy compatible with the formation of anti-hydrogen.

The ATRAP operational modes foresee to run these laser beams inside specific interlocked containment boxes that can be either closed or open. In the latter case no-one can access to the room with the exception of a restricted number of experts, who can only gain access by entering a personal pin code into a keypad.

The securing strategy for ATRAP experiment consist of a combination of two types of functionalities: access control and safety interlocks. The access control functionalities being the following:

- RFID CERN badge identification in addition to the keypad code in order to log and track all entries in the room. For this, an RFID reader has to be controlled and the access card data has to be checked against a central database storing all authorization models.

1 Anti-Hydrogen Trap

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IMPROVING THE SAFETY AND PROTECTIVE AUTOMATIC ACTIONS OF THE CMS ELECTROMAGNETIC CALORIMETER DETECTOR CONTROL SYSTEM

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Abstract

The CMS ECAL Detector Control System (DCS) features several monitoring mechanisms able to react and perform automatic actions based on pre-defined action matrices. The DCS is capable of early detection of anomalies inside the ECAL and on its off-detector support systems, triggering automatic actions to mitigate the impact of these events and preventing them from escalating to the safety system. The treatment of such events by the DCS allows for a faster recovery process, better understanding of the development of issues, and in most cases, actions with higher granularity than the safety system. This paper presents the details of the DCS automatic action mechanisms, as well as their evolution based on several years of CMS ECAL operations.

INTRODUCTION

During the first LHC long shutdown, the CMS ECAL DCS experienced a major upgrade [1, 2] to improve the control system. After this upgrade, the computing hardware was optimized from fifteen standalone to only three more powerful redundant servers. The software was adapted accordingly, to monitor and control the ECAL Barrel (EB), ECAL Endcaps (EE) and Preshower (ES) partitions in a redundant and distributed environment.

The CMS ECAL DCS software was originally written by developers with distinct programming styles, not following a common strategy for several mechanisms, including the automatic protective actions. When an automatic action is executed, experts are requested to investigate the cause and, once the problem is solved, to certify the detector readiness for data taking. The traceability of the automatic actions depends on the implementation of each mechanism, requiring sometimes considerable efforts to reach a complete understanding of its cause.

Different methods to perform DCS automatic actions are compared in the following paragraphs, highlighting the strengths and weakness of each model.

What is a DCS Automatic Action?

A DCS automatic action is a software mechanism to judge events in the DCS context and eventually to perform control operations in an automated way. These automatic actions consist of the following stages:

- Evaluation of conditions.
- Execution of actions.
- Notification.

CMS ECAL DCS Automatic actions are safety preventive actions for switching off detector subsystems with fine granularity at the partitions level. The report of these actions also help operators and experts to analyse large amounts of data in a short time. In this aspect, the DCS automatic actions can be compared to an expert system. The successful execution of the automatic actions depends on the availability of the underlying technology and cannot be always guaranteed due to the complex technology stack. For this reason, they should not be considered as a substitute for the CMS ECAL Detector Safety System (DSS).

Evaluation of Conditions

The CMS ECAL DCS monitors thousands of input parameters (process variables) from different hardware devices. Multiple signals are sampled at a certain rate and stored in the control system as discrete-time parameters. The signals registered by the control system are subject to a certain information loss due to the discretization and manipulation by different processes. Once the signals are stored in the control system as process variables, they can be analysed, combined and shaped into Boolean expressions. Boolean expressions can be combined to build triggering conditions, resulting in a true or false statement to execute the automatic actions.

Execution of Automatic Actions

The DCS automatic actions are software operations that aim to mitigate problems in a controlled way. These actions are translated into control commands to switch off one or more hardware devices, helping to guarantee the detector and related off-detector hardware integrity.

Notifications

The notification of automatic actions makes the experts aware of a problematic situation in real time. Summary messages are sent via e-mail and SMS to provide a starting point for the failure assessment.

CURRENT IMPLEMENTATIONS

Two different models of automatic actions can be found in the current implementation: the Barrel and Endcaps use Finite State Machines (FSM) while the Preshower uses control scripts.

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MACHINE PROTECTION SYSTEM RESEARCH AND DEVELOPMENT FOR THE FERMILAB PIP-II PROTON LINAC*

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Abstract

The Fermilab Proton Improvement Plan (PIP-II) includes a high intensity proton linac being designed to support a world-leading physics program at Fermilab [1]. Initially it will provide high intensity beams for Fermilab's neutrino program with a future extension to other applications requiring an upgrade to CW linac operation (e.g. muon experiments). The machine is conceived to be 2 mA CW, 800 MeV H- linac capable of working initially in a pulse (0.54 ms, 20 Hz) mode for injection into the existing Booster. The planned upgrade to CW operation implies that the total beam current and damage potential will be greater than in any present HEP hadron linac. To mitigate the primary technical risk and challenges associated with PIP-II, an integrated system test for the PIP-II front-end technology is being developed. As part of the R&D a robust Machine Protection System (MPS) is being designed and tested. This paper describes the progress and challenges associated with the MPS.

INTRODUCTION

PIP-II is being designed and constructed to be a CW-compatible, pulsed H^- SRF linac. It is an essential part of the planned program of upgrades to the existing Fermilab accelerator injection complex. To mitigate some risk and to validate the concept of the front-end associated with the PIP-II machine, a test accelerator (Figure 1) is under construction. The test machine is known as the PIP-II Injector Test (PIP2IT) [2]. It includes a 10 mA DC, 30 keV H^- ion source, a 2 m-long Low Energy Beam Transport (LEBT), a 2.1 MeV CW RFQ, along with a Medium Energy Beam Transport (MEBT) that feeds the first of 2 cryomodules. This increases the beam energy to about 25 MeV.

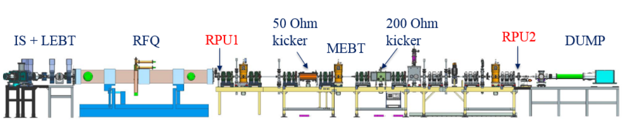

Figure 1: Schematic of PIP2IT facility.

A high Energy Beam Transport section (HEBT) takes the beam to a dump. The length of beam pulses in the machine is dictated by a chopper located between the last two solenoids in the LEBT. The chopper can provide 1 µsec - 16 msec pulses with a frequency that ranges from single shots to 60 Hz. The ion source, LEBT, RFQ, and initial version of the MEBT have been built, installed, and commissioned. Part of the ongoing R&D program associated with this setup includes the development and integration of a Machine Protection System into the complex capable of protecting the machine from beam induced damage while monitoring the chopper operation. An upgrade to quasi-CW operation is planned as a future mode of operation for the machine to deliver beam simultaneously to multiple users. This planned upgrade to CW operation implies that the total beam current and damage potential will be greater than in any present HEP hadron linac.

The MPS will ultimately be integrated as part of the entire Fermilab complex MPS responsible for protection of equipment in PIP-II and associated downstream machines from beam induced damage and excessive radiation damage. The system will therefore be integrated with legacy hardware and systems already operational and specific in scope. This integration process with the existing capabilities of the Fermilab facilities is part of the challenge associated with the design (see Figure 2). Since the main goal of the MPS is to protect the machines from beam induced damage; the system must inhibit the beam in case of excessive beam loss, equipment failures, or operator request. While achieving that objective, the system must also provide the ability to operate in a fail-safe manner with high availability. It must also manage beam intensity and permit limits as well as provide linac beam status to the accelerator complex control system.

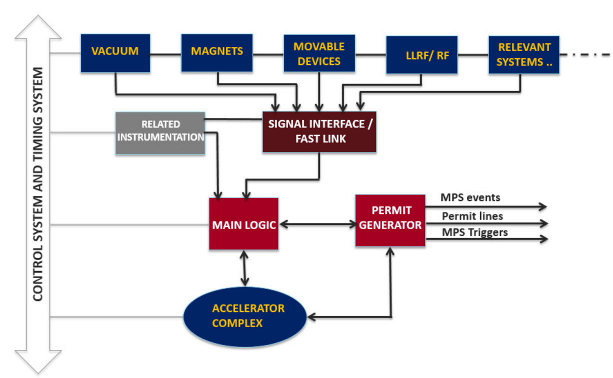

Figure 2: MPS integrated overview diagram.

The design will consider the redundant implementation of critical MPS components where possible to reduce probability of costly damage and corresponding downtime.

MPS PRIMARY DEVICES AND PERMITS

The PIP-II MPS will comprise of a logic system that

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CLARA GUN TEMPERATURE CONTROL USING OMRON PLC

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Abstract

STFC Daresbury Laboratory is currently commissioning Phase I of CLARA (Compact Linear Accelerator for Research and Applications), a novel FEL (Free Electron Laser) test facility focused on the generation of ultra-short photon pulses of coherent light with high levels of stability and synchronization. In order to maintain phase stability the CLARA gun requires a precision water temperature control system to maintain a gun cavity temperature within 0.028°C. This is achieved by mixing two water circuits with temperatures close to the desired set point. Two temperature measurement systems were evaluated for precision and reliability, the resultant system uses a single Omron PLC which provides all the precision read back and control loops. High resolution input modules and averaging achieve precision temperature monitoring while two PID loops control the coarse and fine temperature control. EPICS control is achieved using the FINS protocol communicating with a Linux IOC. This paper gives details of the system requirements and implementation and also describes initial results.

CLARA

CLARA [1] is a 250 MeV, 100-400 nm FEL test facility at Daresbury Laboratory. The purpose of CLARA is to test and validate new FEL schemes in areas such as ultra-short pulse generation, temporal coherence and pulse-tailoring. Some of the schemes that can be tested at CLARA depend on a manipulating the electron beam properties with characteristic scales shorter than the electron beam and require a 30 - 50 μm modulation of the beam energy acquired via the interaction with an infrared laser beam in a short undulator.

CLARA GUN

Seeded FEL experiments which require interaction between a short laser pulse and the electron bunch place extremely high demands on the RF gun stability (Figure 1). For example, the jitter of the launching phase of the beam in the magnetic bunch compression mode should be less than 300 fs, which, in terms of the S-band RF phase, is 0.32°. To provide such a phase stability the required cavity peak to peak temperature stability should be better than 0.028°C. This is still below the current start-of-the-art performance of thermal stabilisation systems which is 0.04°C [2].

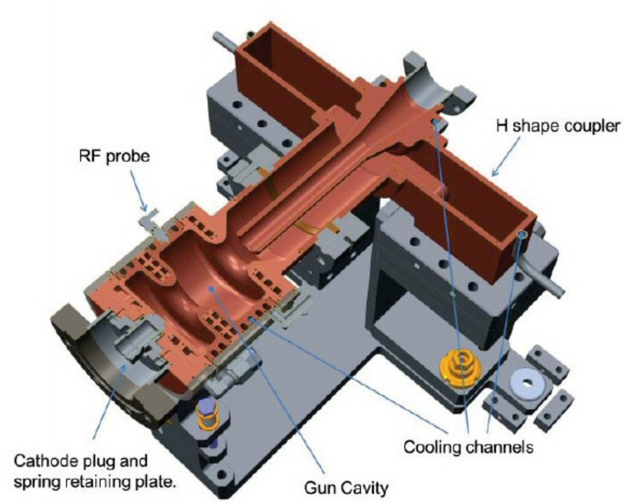

Figure 1: Overview of the gun cavity design.

GUN WATER SYSTEM OVERVIEW

Figure 2 shows a simplified EDM operator display. The process heater is a commercial unit which has its own internal control loop this is set to produce a temperature above the desired temperature, the control valve VP01 then mixes this with chilled water to produces a temperature a few degrees above the control point. Manual valves are set to mix chilled and heated water to a temperature just below the control point. The final stage is where VP02 mixes the two water temperatures close to the set point.

The gun flow and return are via a 12 way manifold with pressure flow and temperature measurements. The manifold also has remote controlled valves feeding the 12 water circuits within the gun. There are 21 temperature measurements in the system 17 having 0.1°C resolution and 4 have 0.001°C resolution. To prevent operation when the water flow or temperature is out of specification the system provides a hard wired interlock to the RF Modulator.

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A NEW TRANSVERSE AND LONGITUDINAL BUNCH BY BUNCH FEEDBACK PROCESSOR

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Abstract

We describe the development of firmware to support Longitudinal Bunch by Bunch Feedback at Diamond Light source. As well as feedback, the system supports complex experiments and the capture of detailed electron beam diagnostics. In this paper we describe the firmware development and some details of the processing chain. We focus on some of the challenges of FPGA development from the perspective of a software engineer.

INTRODUCTION

At Diamond Light Source (DLS) we have been working on multi-bunch feedback for more than a decade [1–7], this work being originally based on developments at the ESRF [8]. Up to now our work has been based on the Libera bunch-by-bunch platform [9], which is now obsolete and has limited capacity for further developments — at the time of writing the Virtex-II Pro FPGA at the heart of the Libera processor is 15 years old. With this platform we have focused on stabilising and measuring only transverse instabilities.

More recently we have been asked to provide support for measurement and stabilisation of longitudinal multi-bunch instabilities as part of an ongoing project to install normal conducting RF cavities [10]. It is anticipated that these may introduce longitudinal resonances and instabilities which will need to be managed.

We have therefore been working on a project to upgrade our TMBF (Transverse Multi-Bunch Feedback) system to run on more modern hardware and to add longitudinal capabilities to the system, so creating an LMBF (Longitudinal Multi-Bunch Feedback) processor. We have already reported [11] on our preliminary work on the new system and on the choice of hardware; we'll discuss this further below.

In this paper we will describe the architecture of the new LMBF (Longitudinal Multi-Bunch Feedback) processor based on our chosen hardware, and discuss some of the lessons learned during this development. From a software engineering perspective, development of a complex FPGA system presents some remarkable challenges, which we'll also discuss.

HARDWARE PLATFORM

The development of our new LMBF processor was driven by two motivations: to ensure that we are ready for any new longitudinal instabilities, and to increase the capabilities of our existing system [10, 11]. We also wanted to improve our knowledge and understanding of high speed processing hardware relevant to synchrotron diagnostics.

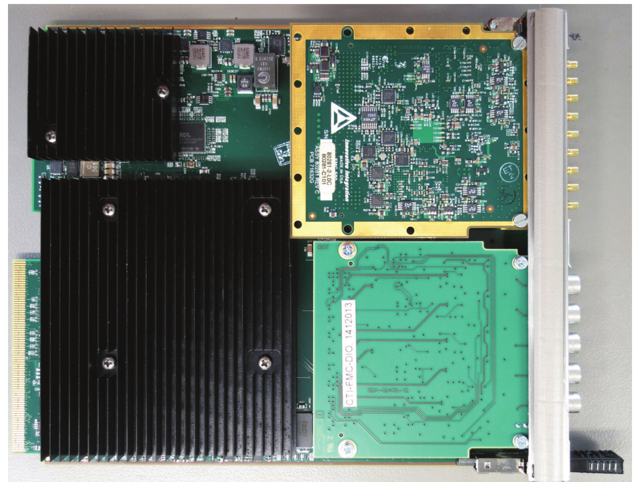

Figure 1: Photo of assembly of FMC-500 and Digital IO FMC on the AMC525 carrier, with FMC-500 at top right.

We started with an investigation to determine the appropriate hardware platform for this kind of development. Early on it was decided that we would need a powerful FPGA with FMC (FPGA Mezzanine Card) support. Initially we looked at self contained FPGA platforms, and even briefly considered creating our own, but in the end we converged on MicroTCA [12]. This platform provides us with a wide choice of crates and AMC (ATCA Mezzanine Card) processing modules with high speed interconnect. The same platform is being used for a joint development with ALBA of digital low level RF [13].

Having selected MicroTCA as our platform we then selected the following hardware. Figure 1 shows the digital processing hardware assembled ready for insertion in the MicroTCA crate.

FMC-500M (HPC) High Pin Count FMC providing dual channel 500 MS/s 14-bit ADC and dual channel 1230 MS/s 16-bit DAC [14]. This will support bunch-by-bunch operation at our machine RF frequency of 500 MHz, and can be driven by our machine clock.

FmcDIO5chTTLa Five port digital IO FMC [15]. This is used for miscellaneous triggering and other signals.

AMC525 Double width AMC card with two HPC FMC slots, 2 GB of fast on board DRAM and 128 MB of slower DRAM connected to a Virtex-7 690 FPGA, supporting an 8 lane gen3 PCIe connection over the MicroTCA backplane [16]. This is where all the FPGA firmware will run, and the fast backplane connection will allow us to do a lot of data processing in the associated CPU.

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EMITTANCE MEASUREMENT AND OPTICS MATCHING AT THE EUROPEAN XFEL

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Abstract

Electron beam quality described by the emittance or phase space moments are important for the operation of FEL facilities like the European XFEL [1]. For the operation these parameters need to be routinely measured. Based on such measurements machine setup can be optimized to match beam requirements. The beam parameters depend on parameters like quadrupole magnet strength or RF settings. While manual tuning is possible, we aim for highly automatized procedures to obtain such optimizations. In this paper we will present and discuss an overview of the different subsystems which are involved. These include image acquisition, analysis, and optics calculations as well as machine control user interfaces.

INTRODUCTION

An important measure of beam quality required for a FEL driver linac is the beam emittance. The machine settings, especially of the injector, needs to be tuned to optimize this parameter. In order to achieve this fast, efficient and reproducible measurement procedures are required. Related to emittance measurements is the determination of the beam optics. This optics is "matched" to the design based on such measurements using a set of upstream quadrupole magnets. These phase-space parameters are determined from beam spot-size measurements in different optics conditions, either at multiple positions or varying the magnet lattice, as described in [2]. Phase-space studies are done in a diagnostic section, which includes four-screen stations, a spectrometer arm, and a transverse deflecting RF structure (TDS) for longitudinal resolved studies. A unique feature of this diagnostics layout are fast kicker systems to kick individual bunches on off-axis screens (see Fig. 1). In this configuration individual bunches out of the train can be analysed while the remaining bunches continue eventually to the SASE user stations.

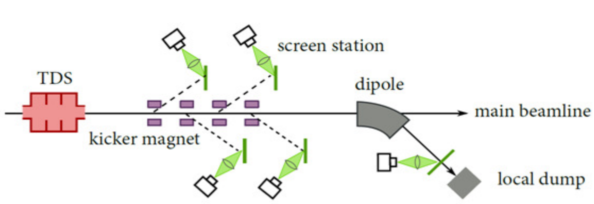

Figure 1: Overview of a diagnostic section of the European XFEL.

MEASUREMENT METHODS

There are several methods established to measure the emittance. Using the on-axis screens the full beam is intercepted by the screens and therefore prevent normal user operations. With the off-axis screens we can use individual bunches out of the full 2700 bunch train. In this measurement mode user operation is, in general, not interrupted.

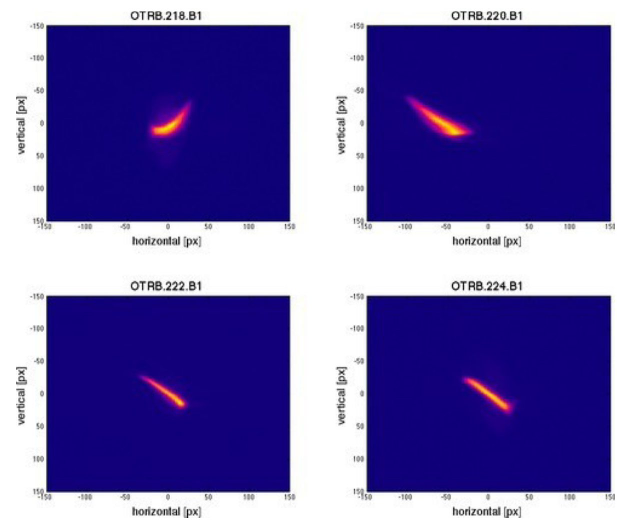

Figure 2: Example output of 4 on-axis screens.

Multi-Position Measurement

While an on-axis measurement four screens or wire scanners will be inserted into the beam one by one. In the case of screens the background noise has to be determined. After screen insertion the production of bunches will be stopped by turning off the injector laser and background images are acquired. An average of these background images are subtracted from subsequently acquired beam images. From a set of these processed images an average of beam parameters like the Gaussian width or RMS spot-size are calculated. After the successful acquisition, the screen will be moved out of the beam. This step will be done for all four screens. An example output for a measurement with four screens can be found in (Fig. 2). If wire scanners are used, each wire scanner will be moved through the beam one by one. Out of the profile of the wire scanner the beam parameters like the Gaussian width will be calculated. With the calculated beam parameters and the transport matrices from the optics model, the beam emittance at the reference point can be estimated. The outcome of this method is the machine operation is limited to one bunch due to radiation safety. While the measurement no other machine operation is possible. This methods take some time to move the screens. An overview about the screens at the European XFEL can be found in [3].

In order to speed-up the multi-position measurements the fast kicker system is used. In this configuration off-axis screens are used. These screens are installed with

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COMPENSATION CONTROLS FOR AN ELLIPTICALLY POLARISING UNDULATOR

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Abstract

At the Canadian Light Source (CLS) synchrotron, the addition of the Quantum Materials Spectroscopy Centre (QMSC) beamline requires the addition of an Elliptically Polarizing Undulator (EPU) insertion device to produce photons from the stored electron beam. Unlike the majority of such insertion devices, this EPU requires the production of photons of simultaneous arbitrary elliptical and linear phases, in addition to a range of energies. This EPU is also capable of creating perturbations of the stored electron beam sufficient to cause an interruption of an injection. In order to prevent this, compensation controls have been developed. These controls are accomplished with a combination of Experimental Physics and Industrial Control System (EPICS), mathematical models, and algorithms written in `C` and `MATLAB`.

INTRODUCTION

The Canadian Light Source (CLS) is a synchrotron radiation facility with an electron beam storage ring of 2.9 GeV. For the new Quantum Materials Spectroscopy Centre (QMSC) beamline, the Insertion Device (ID) is of the type Elliptically Polarizing Undulator (EPU) of an APPLE II manner, which uses four girders $Q_1 - Q_4$ as the frame for the magnetics as in Fig. 1. APPLE II EPUs are capable of creating photons both with elliptical polarization Φ_E and linear polarization Φ_L. However, in operation, generally only one of Φ_E and Φ_L are non-zero. This, combined with undulator gap, creates a system with two degrees of freedom.

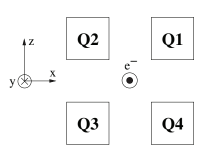

Figure 1: EPU Configuration.

The Dual-EPU for QMSC possesses two magnet arrays for producing photons of differing energies—effectively creating two EPUs which are shifted laterally, and must be used in a mutually exclusive manner—as depicted in Fig. 2. The high-energy array (EPU55) is not anticipated to pose significant issues. However, the low-energy array (EPU180) is capable of producing photons below 100 eV, for which beam optics can create distortions[1]. In order to compensate for this, EPU180 must be capable of generating photons of arbitrary superpositon of Φ_E and Φ_L, known as Universal Mode [1]. This results in a system with three degrees of freedom and additonal complexities.

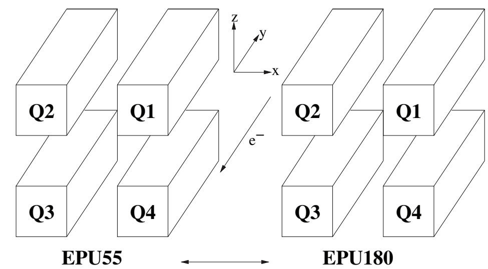

Figure 2: QMSC EPU Configuration.

In addition, the long spatial period of EPU180 also creates issues for the electron beam which may not be ignored. Tune shifts and a reduction in dynamic aperature would greatly reduce the ability of injected beams to join the stored beam. Current strips of the BESSY manner will be used in order to compensate for these effects [2].

Control Components

The QMSC EPU possesses twenty-four current strips for dynamic focusing, and four correction coils for compensation of the first and second field integrals. The compensation controls require the ability to set the current to each strip and coil individually. The differing compensations are:

- Universal Mode (Current Strips)
- Residual Focusing (Lattice Quadrupoles)[2]
- Skew Quadrupole (Current Strips)
- Normal Quadrupole (Current Strips)
- Multipole (Current Strips)
- Direct Entry (Current Strips)
- Field Integrals (Correction Coils)

The values that will be sent to each correction coil or current strip will then consist of a superposition of values from these differing compensations.

UNIVERSAL MODE

The Universal Mode is the most computationally taxing portion of the compensation controls, and it is anticipated that it will dominate the response time of the compensation controls. This software comprises two portions: software written in `MATLAB` to create a mathematical model of the magnetics of EPU180, and Universal Mode compensation

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[1] The period of EPU55 is 55 mm, while the period of EPU180 is 180 mm.

[2] The Residual Focusing is not yet implemented, and will be necessary to correct the vertical tune shifting which the current strips are incapable of accomplishing.

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OPTIMIZATION AND UPGRADE OF SLOW EXTRACTION CONTROL SYSTEM FOR HIRFL CSR MAIN RING*

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Abstract

The heavy ion beam from Heavy Ion Research Facility in Lanzhou (HIRFL) CSR Main Ring (CSRm) is slowly extracted by using a third-order resonance driven by sextupole magnets and delivered to various experimental facilities. The slow extraction is driven by the transverse radio frequency knockout (RF-KO) exciter. Many physics and radiation medicine experiments require high-quality spill-structure. In other words, the extracted spill should have flat structure and low ripple noise [1]. Therefore, a novel RF-KO exciter and spill feedback control system has been implemented and tested in CSRm.

INTRODUCTION

The HIRFL accelerator complex is illustrated in Fig. 1. The particles accelerated by CSRm are slowly extracted to external experimental terminals, or extracted in fast extraction mode to CSR Experiment Ring (CSRe). In slow extraction mode, many physical, material, biological, and medical experiments require high-quality spill that has flat structure and low ripple noise. For CSRm, the resonant slow extraction is driven by RF-KO exciter. In the new spill control system of CSRm, the host machines are employed to calculate amplitude modulation curve and spill duty factor, publish the control variables, and manage the various parameters that are often stored in the database. In addition, two FPGA boards are dedicated to control RF power amplifier and a pair of fast quadrupole (FQ) magnets.

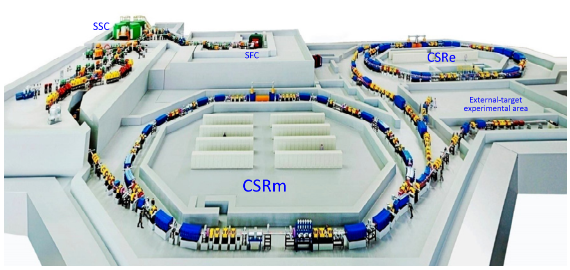

Figure 1: HIRFL accelerator complex.

SPILL CONTROL

In the HIRFL, the particles are extracted slowly out of the CSRm by using RF-KO exciter. The two FQ magnets are additionally used to achieve better spill quality. As shown in Fig. 2, the typical shapes of spill are achieved by RF-KO extraction without feedback unit at CSRm after upgrading. Fig. 3 shows the block diagram of the new spill control system. In the RF-KO method, the beam is partially moved into resonance by transverse excitation. The suitable parameters of the RF-KO exciter dose improve efficiency and spill quality reasonably. In the feedback unit, the spill signal is used to calculate the exciting signal for FQ magnets which is used to suppress the spill ripple noise and make rectangular-shaped spill structure.

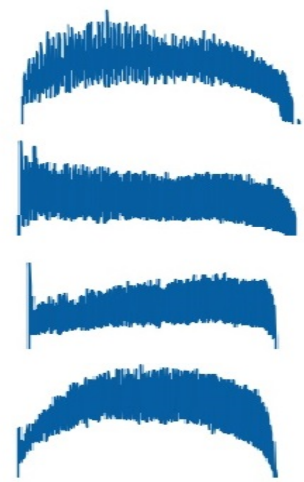

Figure 2: Typical spill shapes archived by RF-KO extraction without feedback control at CSRm. Here: Carbon beam, energy E = 190, 260, 330, and 400 MeV/u.

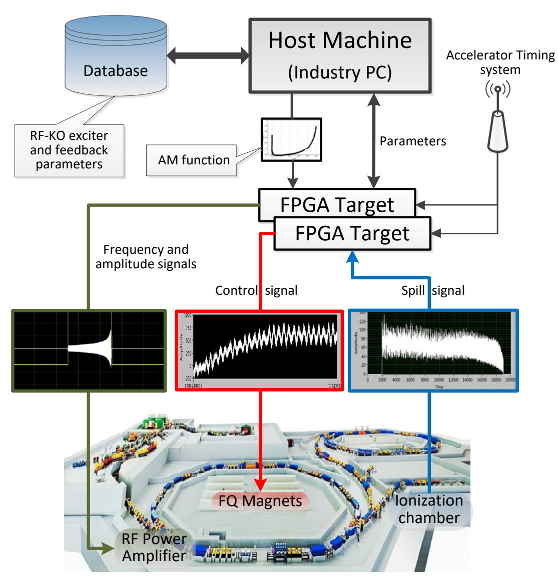

Figure 3: Block diagram of the spill control system.

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CONCEPT OF CAVITY SIMULATOR FOR EUROPEAN SPALLATION SOURCE*

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Abstract

At the European Spallation Source it is foreseen to use around 120 superconducting cavities operating at 704.42 MHz. Each cavity will require an individual LLRF control system, that needs to be tested before the installation inside the accelerator.

Testing of all systems using the real superconducting cavities would be very expensive and in case of a failure can lead to serious damages. To lower the testing cost and avoid potential risks it is planned to design and build a device that simulates the behavior of a superconducting cavity.

The cavity simulator will utilize fast data converters equipped with an RF front-end and a digital signal processing unit based on a high performance FPGA. In this paper conceptual design of hardware and firmware will be presented.

INTRODUCTION

Polish Electronics Group is a consortium of 3 Polish scientific institutes: National Centre for Nuclear Research, Warsaw University of Technology and Łódź University of Technology. It was established in order to contribute to the European Spallation Source project as an in-kind partner. PEG is responsible for assembly and installation of the LLRF control systems for superconducting elliptical cavities used in medium and high beta sections of the ESS linac. The consortium will also design and manufacture the following components of the systems: LO RTM, Piezo Driver, RTM Carrier and Cavity Simulator. [1].

The Cavity simulator is a device foreseen to test the LLRF control systems before they are commissioned in the accelerator. It simulates a behavior of a superconducting cavity together with a klystron/IOT RF power amplifier. The block diagram of the system simulated by the device is presented in Fig. 1 [2].

Basing on the input signals (RF drive and piezos' drive), the Cavity Simulator generates the following output signals:

- amplifier input,
- amplifier forward,
- amplifier reflected,
- cavity forward,
- cavity reflected,
- cavity probe,
- amplifier power supply modulator,
- piezo sensor.

The model of the cavity is implemented in a digital signal processing unit. Among others, the device simulates the following phenomena: cavity detuning, piezo compensation, Lorentz force detuning, beam current and influence of the amplifiers power supply modulator.

To operate with analog signals a set of data converters with a dedicated front-end is provided. The device is controlled remotely by a PC. The simplified concept of the Cavity Simulator is presented in Fig. 3.

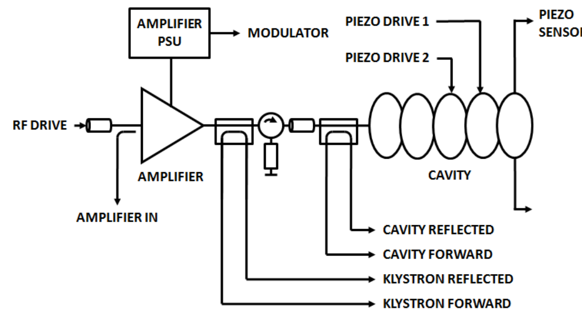

Figure 1: The block diagram of the system simulated by the Cavity Simulator

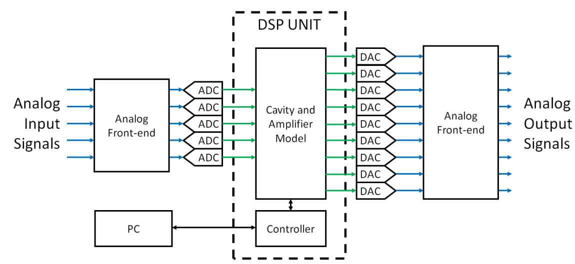

Figure 2: The simplified block diagram of the Cavity Simulator.

REQUIREMENTS

Based on the presented architecture and the specification of ESS LLRF control system a set of requirements for the Cavity Simulator was prepared.

The device shall operate at 704.42 MHz, the same reference frequency as the ESS LLRF control systems for medium and high beta cavities.

Three analog inputs are required: one for the RF drive signal and two for high voltage piezo actuator signals. The RF input must accept the maximum output power of a vector modulator module used in the ESS LLRF (Struck DWC8VM1 RTM). The maximum level of piezo driver input shall be ±100V. To simulate the impedance of the piezo actuator, each high voltage input shall have 2.2 uF input capacitance.

The Cavity Simulator shall have eight analog outputs: six RF outputs for the amplifier and the cavity signals, one for

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STATUS OF FAST ORBIT FEEDBACK SYSTEM IN TPS

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Abstract

TPS has provided its user service since 2016. To ensure stable beam can be delivered to users, the fast orbit feedback system were deployed to ensure the stable electron orbit. The system have been commissioning in the second quarter of 2016. Later, rf frequency adjustments are also included to compensate the path length changes due to ambient temperature variations, earth tides and etc. Improvement of the system has continued to solve various unexpected problems. This report will summarize the system configuration of the fast orbit feedback.

INTRODUCTION

The TPS is a state-of-the-art synchrotron radiation facility which consists of a 150 MeV S-band linac, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring. This synchrotron machine featuring ultra-high photon brightness with low emittance [1] requires beam position stability less than 1/10 beam size. FOFB is therefore implemented to achieve sub-micron orbit stability and it has been tested together with beamline commissioning since 2015. The orbit stability had been effectively improved with FOFB and it showed that the suppression bandwidth could achieve 250 Hz in both horizontal and vertical plane. Later, closed orbit correction methods by RF frequency correction have been developed to compensate for orbit path length changes. FOFB together with RF frequency corrections have been in routine operation since September 2016. The orbit stability has been effectively improved and can achieve sub-micron stability in both horizontal and vertical planes.

FOFB INFRASTRUCTURE

The design of the TPS storage ring has 24 cells, each cell is equipped with 7 BPMs and 7 horizontal/vertical correctors winding on the sexupoles as Fig. 1 shown. These kinds of slow correctors could provide about 500 μrad kick while their bandwidth could be limited only several tens of Hertz due to the eddy effect of the alumina vacuum chamber. This bandwidth is not sufficient to eliminate perturbation with frequency above several hundreds of hertz. Therefore, extra four horizontal/vertical correctors per cell are installed on the bellows site to obtain higher correction bandwidth. These horizontal/vertical correctors have fast response but smaller kick strength around 100/50 μrad. Thus the orbit feedback system would adopt two kinds of correctors simultaneously. The DC component of the fast correctors will transfer from fast to slow correctors smoothly and avoid saturation of the fast correctors as well as provide capability to suppress orbit disturbance.

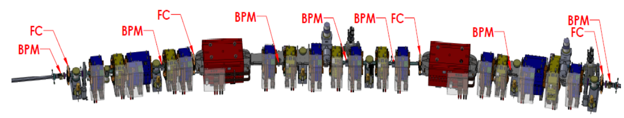

Figure 1: One cell of 24 double-bend cells for TPS lattice layout.

The overall infrastructure of FOFB is as Fig. 2. It is mainly implemented by three parts: BPM, feedback computation unit and corrector power supply control interface. TPS BPM electrical system will adopt the latest I-tech product: Brilliance+ [2]. It also offers a large playground for custom- written applications with VirtexTM 5, Virtex 6 in the gigabit data exchange module (GDX) to be used as orbit feedback computation. The corrector power-supply controller (CPSC) is designed for FOFB corrector control interface. This module is embedded with Intel XScale IOP and Xilinx Spartan-6 FPGA which will interface the fast setting from feedback engines. It was contracted to D-TACQ [3].

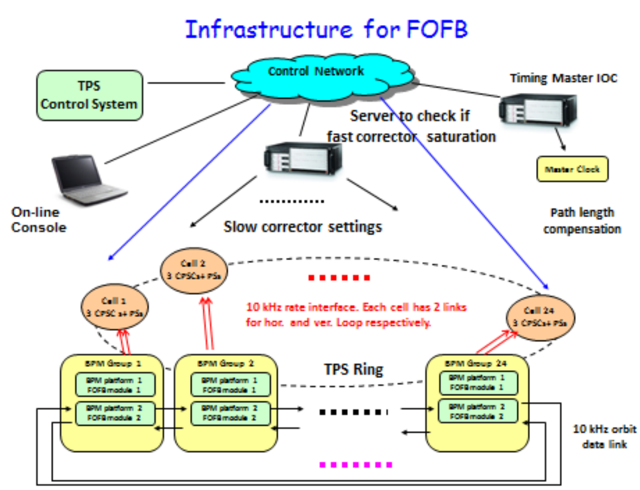

Figure 2: FOFB infrastructure.

BPM and GDX Interface

The TPS BPM electronics had commission with TPS beam commissioning in 2014 [4][5]. It consists of four kinds of modules: The timing module for clock locking and trigger; up to four BPM modules for receiving button pick-ups and signal processing, the inter-connection board (ICB) module for SW and HW interface; the GDX (Gigabit data exchange) module for FA data grouping and FOFB computation which could support at most 256 BPMs and 128 correctors feedback computation. The magnet correction output is transmitted to CPSC

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APPLICATIONS OF KALMAN STATE ESTIMATION IN CURRENT MONITOR DIAGNOSTIC SYSTEMS*

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Abstract

Traditionally, designers of transformer-based beam current monitor diagnostic systems are constrained by fundamental trade-offs when reducing distortion in time-domain beam-pulse facsimile waveforms while also attempting to preserve information in the frequency-domain. When modelling the sensor system with a network of linear time-invariant passive components, and a state-based representation based on first-order differential equations, we identify two internal dynamical states isolated from each other by the parasitic resistance in the transformer windings. They are the parasitic capacitance voltage across the transformer's windings, and the transformer inductor current. These states are typically imperfectly observed due to noise, component value variance, and sensor component network topology. We will discuss how feedback-based Kalman State Estimation implemented within digital signal-processing might be employed to reduce negative impacts of noise along with component variance, and how Kalman Estimation might also optimize the conflicting goals of beam-pulse facsimile waveform fidelity together with preservation of frequency domain information.

CONTROL THEORY BACKGROUND

Any linear time-invariant multi-input multi-output system might be represented in a so-called state-space representation [1], see equations 1 and 2.

$$\dot{x}(t) = Ax(t) + Bu(t) + Ed(t) \quad (1)$$
$$y(t) = Cx(t) + Du(t) + E_y d(t) \quad (2)$$

Where:

- ***x(t)*** is a vector of dynamical system states
- ***u(t)*** is a vector of system inputs
- ***d(t)*** is a vector of system disturbances
- ***y(t)*** is a vector of system outputs
- $\dot{\boldsymbol{x}}(\boldsymbol{t}) := \frac{d}{dt}\boldsymbol{x}(\boldsymbol{t})$
- ***A*** is a system dynamics matrix
- ***B*** is an input scaling matrix
- ***C*** is an output scaling matrix
- ***D*** is an input feedthrough scaling matrix
- ***E*** is a disturbance scaling matrix
- $\boldsymbol{E_y}$ is a disturbance feedthrough scaling matrix

The ***A*** matrix determines the systems *dynamical* behaviour while the ***B***, ***C***, ***D***, and ***E*** time-invariant matrices determine how the system interacts with its external environment. A canonical form of the state-based representation has the main diagonal elements of the time-invariant ***A*** matrix populated with the system's Eigenvectors and other elements zero.

In control-theory a **state-estimator** is an auxiliary system providing approximate values for internal variables of the target system using only measurements of inputs to, and outputs from, the target system. It is often possible to provide optimized system diagnostics, and also optimized system control, when enhanced estimates of the, often not directly measurable, internal states of the system are available. Equations (3) and (4) show the typical state-space representation for an axillary model-based state estimator. The emphasis with state estimator design is to formulate matrix ***K*** for stable feedback minimizing error in equation (5), which must satisfy differential equation (6).

$$\dot{\hat{x}}(t) = A\hat{x}(t) + Bu(t) + K(y(t) - \hat{y}(t)) \quad (3)$$
$$\hat{y}(t) = C\hat{x}(t) + Du(t) \quad (4)$$
$$e(t) = \hat{x}(t) - x(t) \quad (5)$$
$$\dot{e}(t) = (A - KC)e \quad (6)$$

A system is said to be **state-observable** if estimates for all internal states as time progresses can be provided contingent on knowledge of a model for the linear time-invariant system, initial conditions for its states, history of system inputs, and history of system outputs. In control-theory a necessary and sufficient condition for successful state-estimator design is that the rank of ***O*** in equation (7) based on the state-space representation of the target system must be the same as the rank ***N*** of ***A***.

$$O = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{N-1} \end{bmatrix} \quad (7)$$

The so-called Kalman Filter [2] is a famous model-based state-estimator feedback algorithm providing optimized iterative estimates of system states in the presence of noise, and in the presence of other uncertainties such as imprecise target system model identification. Its algorithm is proven to provide mathematically optimal state estimates when errors have known Gaussian stochastic distribution. The filter is implemented in two steps; first it produces current system state estimates along with their uncertainties, and second it updates iterative system state estimates using weighted averaging. The optimized ***K*** matrix for the Kalman filter is designed when solving the Algebraic Riccati Equation [3].

SIMPLIFIED CIRCUIT MODEL

A passive pulsed-beam current transformer has a parallel RLC simplified equivalent circuit with a band-pass behaviour transfer function [4]. In figure 1 we consider some additional details with $\boldsymbol{C_{sp}}$, $\boldsymbol{R_{scp}}$, and $\boldsymbol{R_{slp}}$ modelling the parasitic elements of transformer secondary Inductor $\boldsymbol{L_s}$[5]. The resistor $\boldsymbol{R_t}$ is added across the sensor's voltage

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AUTOMATED CONTOLS FOR THE HARD X-RAY SPLIT & DELAY SYSTEM AT THE LINAC COHERENT LIGHT SOURCE

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Abstract

The hard x-ray split and delay (HXRSnD) system at the Linear Coherent Light Source (LCLS) was designed to allow for experiments requiring two-pulse based x-ray photon correlation spectroscopy. The system consists of eight silicon crystals split between two optical branches, with over 30 degrees of freedom. To maintain system stability and safety while easing system operation, we expand the LCLS Skywalker software suite to provide a python-based automation scheme that handles alignment, operations and engineer notification. Core safety systems such as collision avoidance are processed at the controller and Experimental Physics and Industrial Control System (EPICS) layer. Higher level functionality is implemented using a stack of open-source python packages (ophyd, bluesky, transitions) which provide a comprehensive and robust operational environment consisting of virtual motors, plans and finite state machines (FSM).

INTRODUCTION

Between the various operational modes of the hard x-ray free electron laser (FEL) at the Linac Coherent Light Source (LCLS), delays in the 1 ps to 1 ns regime have been unattainable using multi-bunch techniques[1]. To help fill this gap, x-ray optics which split the beam while adding a predefined delay must be used. The hard x-ray split and delay (HXRSnD) system at LCLS fulfills this role by splitting the beam using Si(220) crystals, passing both halves through variable and static delay branches, then recombining them at the end of the enclosure.

The new HXRSnD system consists of almost 30 axes of motion and eight diagnostics for alignment and poses a significant challenge for basic operations since the most desired parameters such as energy and delay require coordinated motion between multiple motors in the system. Additionally, exposing the system in its entirety rather than in discrete states makes it prone to failure by permitting access to previously untested system states.

The HXRSnD system requires a fully automated controls system including the alignment, operations, and engineer notification. Introducing automation is especially prudent when considering projects such as the systems for LCLS-II, the future laboratory upgrade which will result in three new experimental soft x-ray hutches. To adequately prepare for LCLS-II, investing in automation opportunities such as the HXRSnD system proves invaluable as a test-bed for new controls frameworks that allow for full automation.

SYSTEM DESIGN AND HARDWARE

The HXRSnD system is divided into the towers, diagnostics, and pneumatics. There are four towers in the system labeled 1 through 4, with 1 and 4 being the farthest upstream and downstream towers respectively. Diagnostics are present before and after the enclosure, and between each of the silicon (Si) crystals. A system of pneumatics handles the flow and temperature of nitrogen (N_2) and helium (He) into the system.

After the beam has been split at the start of the enclosure, each half will travel through one of two paths: the delay, or channel cut branch. The delay branch is comprised of towers 1 and 4, along with the diagnostics between the tower crystals, and is capable of producing a delay range of -30 ps to 500 ps at 8 keV. The channel cut branch is comprised of towers 2 and 3, along with the diagnostics between them and remains at a fixed delay for a given energy.

Tower System

The towers require a high level of performance and are composed of a combination of servo motors and piezo stages (see Fig 1). Each delay arm is built on top of an Aerotech ANT180 linear stage for insertion/removal of the arm from the beam, with an Aerotech APR150DR-135 positioning the arm on the granite table. The Si crystals rest on top of two Aerotech ANT95-180-R stages which adjust the crystal angles with respect to each other. One of the ANT95-180-R stages is placed on a custom stage built using an Aerotech BMS35 motor, while the other is static, allowing for the time delay between the two branches to be adjusted. Each of the crystals is mounted on top of an Attocube ECGt5050 goniometer and Attocube ECSz5050 vertical translation stage. An Attocube ECSx5050 linear translation stage is used for insertion of a Hamamatsu S3590-19 PIN diode for measuring the beam intensity at the delay crystal. The channel cut branch towers are built using Aerotech ANT95-100-L linear stages for insertion and removal of the crystals from the beam, and ANT95-180-R rotation stages for angular adjustment.

Diagnostics

In addition to the servo motors and piezo stages making up the delay and channel cut branches, beam diagnostics can be inserted and removed along each branch, as well as at the input and output of the system. Hamamatsu S3590-19 PIN diodes are used for beam intensity measurements, while Mako G192B PoE CCD detectors are used for beam profile

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CONTROL AND INTERLOCK SYSTEMS FOR THE LIGHT PROTOTYPE

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Abstract

LIGHT (Linac Image Guided Hadron Technology) is a particle therapy system[1] developed by Advanced Oncotherapy plc. Accelerator, control and interlock systems are developed by its subsidiary A.D.A.M. SA, a CERN spin-off. The system is being designed to accelerate protons up to 230 MeV using a modular and compact 25-meter-long linear accelerator. It is being designed to operate in pulsed mode where beam properties (energy, pulse charge and spot size) can be changed at 200 Hz.

A proof-of-concept accelerator is being assembled and tested at CERN (Geneva, Switzerland). Control and interlock systems are developed using an exploratory prototyping approach and COTS hardware. Requirements for the final LIGHT control and interlock systems are iteratively clarified through creation and refinement of these prototypes. We will continue to support the proof-of-concept accelerator activities while starting to design the final LIGHT control and interlock systems in parallel, building upon the knowledge acquired with the proof-of-concept accelerator. The matured final LIGHT control and interlock systems will gradually replace the prototypes to automate procedures and test the system before deployment.

INTRODUCTION

ADAM S.A. is a CERN spin-off founded in 2007 in Geneva (Switzerland) developing applications of detectors and accelerators to medicine and is a subsidiary of London-based Advanced Oncotherapy PLC. ADAM S.A. is developing the linear accelerator to be used in the Linac for Image Guided Hadron Therapy (LIGHT) project of Advanced Oncotherapy PLC [1].

Current proton therapy solutions mostly rely on synchrotron and synchrocyclotron accelerators for accelerating protons. Driven by the recent advancements in linear accelerator technology, ADAM S.A. has designed a new linear proton accelerator.

The LIGHT prototype is situated in Geneva, Switzerland (building 2250, Point 2, CERN), which hosts a control room, a mechanical and electronic workshop, a rack room and a shielded space for the accelerator referred to as a bunker, as depicted in Figure 1. The complete LIGHT prototype is anticipated to produce beam up to 90 MeV. The rack room placed at the bunker wall hosts 18 racks for electronic equipment.

The control and interlock systems for the LIGHT bunker support conditioning and beam commissioning activities for the accelerator. Additionally, CERN rules and

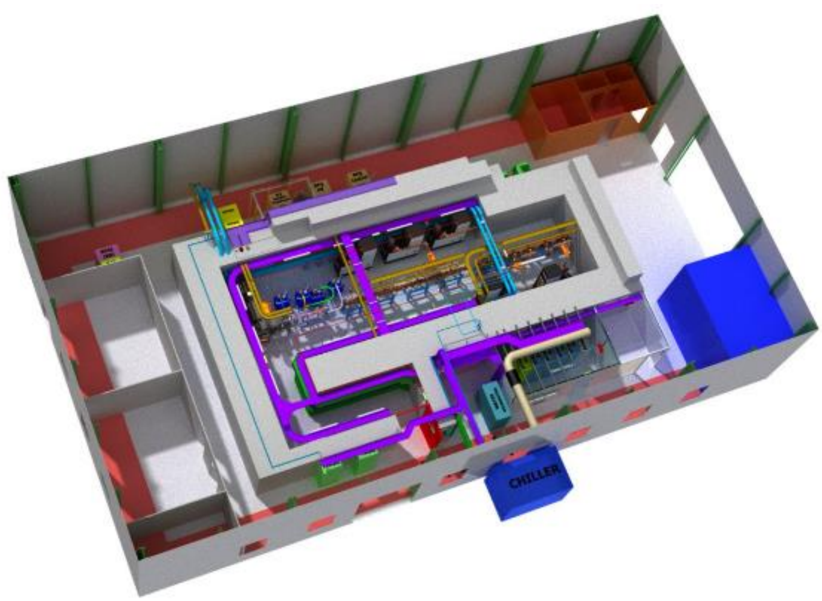

Figure 1: Building layout for the LIGHT Prototype in Geneva, Switzerland (building 2250, Point 2, CERN).

[1] The LIGHT Proton Therapy System is still subject to conformity assessment by AVO's Notified Body as well as clearance by the USA-FDA

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PRELIMINARY SCANNING INTEGRATION AT MAX IV BEAMLINES

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Abstract

The MAX IV Laboratory is in a stage where beamlines are starting to welcome users that will collect data utilizing various scanning methods. This paper focuses on the different motion and synchronization techniques, hardware integration, software solutions, data acquisition and experiment supervision at MAX IV beamlines.

INTRODUCTION

The objective of a scan is to vary certain physical parameters of a machinery while acquiring sample images/data together with other relevant attributes for metadata purposes and eventual result adjustments/corrections. Step and continuous scans plus their variations (hybrid scans) are the most common.

Step scans are mostly position based. A scan macro defines a group of motors with their position set points, group of acquisition devices, step period and amount of steps. Once the scan is launched, motors follow the defined trajectory and the group of detectors/acquisition devices collect data for each set point. Step scans are generally software based, e.g. a program manages each step's transitions and acquisitions.

Continuous scans are a bit more complex. The data acquisition is carried out as, at least, one of the motors is moving continuously along a predefined stroke. That implies the need of hardware to associate the data points to the position of the motors where that data was collected.

If the scheme is time based, that hardware will take not only the role of triggering the acquisition devices in the scan, but also to sample the positions of the motors at each point.

If, on the other hand, a position based scheme is used, that hardware will have to monitor the position of the moving motor and generate triggers as target positions along the stroke are reached.

The selection of the scheme to be used, either time or position, will be done by the availability of suitable electronics, scan timing performance, error budgets and the nature of the experiment itself.

HARDWARE

A variety of hardware elements are present in the data acquisition setups in synchrotron beamlines. Motion controllers steering actuators like steppers or piezoceramic stacks in closed loop against encoders based on optic, magnetic, interferometric and other effects run across a predefined trajectory, while different detectors like CCDs, electrometers, ADCs, counter cards and other electronics acquire data gated by some hardware unit that at the same time can distribute other digital signals to open shutters and valves.

Motion Controllers

Beyond 75% of the axes in MAX IV Laboratory are stepper motors. IcePAP [1] has been chosen as our standard motion controller. This motion controller offers multi-axes synchronization for a wide range of steppers allowing at the same time for seamless control of external drivers of other motor technologies (e.g. Digitax ST servo drivers etc.) in a single electronic card, simplifying installation and maintenance. The driver can output its position reference or any encoder input to synchronize with other motion controllers or to capture position data. Furthermore, a set of digital I/O enables to both, output internal states in the driver to external hardware and to trigger internally generated movements.

The scenario for piezoelectric actuators is a bit more fractioned as there are different techniques under this term. The different piezo electric linear stacks, slip-stick motors, walkers and the incompatibilities between drivers, that vendors offer for them, create a slowly growing set of different controllers that often are not thought with integration in a complex data acquisition setup like a synchrotron beamline in mind and that furthermore increase required support from the different teams involved.

To mention a few, Physik Instrumente (E-625, E-725 series), Smaract MCS, Attocube ECC are already present in some of the MAX IV Laboratory setups. The diversity in communication buses, I/O-s, internal resources, features implementation, calibration requirements and heterogeneous offer of available actuators forces to study carefully the current requirements and their possible future evolution before purchasing.

Encoders

Encoders are not only used in setups to close the different actuators position loops but also as a source of data that is captured together with that of the rest of detectors. That set specific requirements on the motion controllers or on external electronics used to capture that data.

A number of different technologies are used in synchrotron beamlines to measure position, optical and magnetic encoders, strain gauges and interferometers. For scanning purposes, the nature of the transducer itself is as important as the signal scheme used to bring the data into the control system. Incremental and absolute (SSI, BISS-C, EnDat) encoders are the most common and are compatible with most motion controllers but other schemes based on simple analog voltages or currents can appear and require additional solutions.

Other Hardware

Industrial PC cards like counters and ADCs are used for a number of purposes within the measurement setups as the examples below describe. Among others, acquiring analog

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MicroTCA.4 INTEGRATION AT ESS: FROM THE FRONT-END ELECTRONICS TO THE EPICS OPI

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Abstract

The European Spallation Source (ESS) is a collaboration of 17 European countries that is building a leading neutron research center in Lund, Sweden. The ESS facility will have the most powerful neutron source in the world, providing 5 MW of beam power. The Integrated Control Systems Division (ICS) is responsible for all the control systems for the whole facility. For the accelerator control, ICS will provide different hardware platforms according to the requirements of each specific system. For high performance systems, demanding high data throughput, the hardware platform is the MicroTCA.4 standard. This work presents the software stack that makes the integration of a high-end MicroTCA hardware into the ESS Control System, with the implementation details of the FPGA firmware framework, kernel and userspace drivers, EPICS driver and finally the EPICS IOC that integrates the MicroTCA boards.

FRONT-END TO USERSPACE

For the ESS Control System, MicroTCA platform has been chosen as standard hardware for systems that demand fast acquisition rate and online processing. With the flexibility provided by Advanced Mezzanine Cards (AMC) carriers and a selection of mezzanine boards, this platform can meet the most user requirements at the facility. ICS plan is to provide a reduced standard set of hardware in order to optimize the long term support and maintenance of the software and hardware that comprises the MicroTCA ecosystem.

Data Acquisition Hardware

The main board of this set of hardware [1] is the AMC carrier IFC1410, equipped with a Xilinx Kintex Ultrascale FPGA and a QorIQ T2081 CPU, manufactured by IOxOS Technologies. The IFC1410 also has two HPC VITA 57.1 slots for FPGA Mezzanine Card (FMC) units. The combination of FMC cards and Rear Transition Modules (RTM) to the AMC board gives the flexibility to configure an acquisition system. The on-board T2081 CPU allows a user to run an EPICS IOC directly on the board, thus increasing the modularity of the hardware platform in the sense of control system integration and distribution. The Figure 1 shows the IFC1410 board, without any FMC attached to it.

For analog signals the main FMC boards supported by ICS are ADC3110, ADC3111 and ADC3117, from IOxOS Technologies. The ADC3110 implements eight analog inputs using 16-bit ADC up to 250 MSPS with AC coupled input stages. The ADC3111 has the same characteristics as the ADC3110 but with DC coupled input stage. The ADC3117 implements 20 analog inputs (DC coupled) using a 16-bit ADC up to 5 Msps and also has two analog outputs driven by a 16-bit DAC with a range of ± 10V.

Figure 1: IOxOS IFC1410 MicroTCA board.

The IFC1420 AMC is designed for applications that require analog signal conditioning that is not possible to implement in an FMC card, due to the reduced area available, but can be achieved using a Rear Transition Module (RTM). The IFC1420 has the same FPGA and CPU model of the IFC1410 but with a special mezzanine card that occupies one of the FMC slots and has 10 analog input channels routed to the RTM interface.

Currently ESS has been using the SIS8300 digitizer board, from Struck [2]. This board is a MicroTCA AMC carrier with on-board 10-channel ADC (16-bit @ 125 MSPS) and two 16-bit DAC for fast-feedback implementations, also routed to the RTM interface.

FPGA Firmware Application

The basic firmware application that is available for the IFC1410 FPGA is a waveform digitizer that acquires analog signals from the FMCs attached to the board. This application can be used for standard data acquisition on the CPU side and can be modified to add user-specific digital processing blocks and functions. The main features of the basic application are:

- Waveform digitizer with data buffering using the FPGA memory blocks.
- Waveform digitizer with storage in external DDR3 memory.
- Independent trigger function for both FMCs.
- Parallel acquisition for all channels.

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GROUND VIBRATION MONITORING AT CERN AS PART OF THE INTERNATIONAL SEISMIC NETWORK

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Abstract

The civil engineering activities in the framework of the High Luminosity LHC project, the Geneva Geothermie 2020 [1] and the continuous monitoring of the LHC civil infrastructures triggered the need for the installation of a seismic network at CERN. A data acquisition system has been deployed in 3 places at CERN: ATLAS, CMS and the Prévessin site. The system is sending all the raw data to the Swiss Seismological Service (SED) [2] and performs FFT on the fly to be stored in the LHC database.

INTRODUCTION

In the future decades, the mechanical stability of high energy accelerator components, in particular of magnetic elements guiding and focusing the beam, will become crucial: high luminosity [3] typically requests smaller beam sizes, thus requiring an improved vibration stability of the structures and a better knowledge of the environmental mechanical noise to determine any detrimental effect on the accelerator performances and eventually correct for that. The vibration stability of the structures is linked to the dynamic behavior of the structure itself and the environmental conditions where the structure is installed. A seismic wave striking the LHC will induce beam position (orbit) changes all along the circumference. If the position change is too large and too fast, the resulting beam loss could lead to a beam abort. For small earthquakes (that do not induce mechanical damage to accelerator components) the LHC protection system is able to safely abort the beams without any risk of damaging the accelerator components. However, the repetition of beam aborts will affect the integrated luminosity, i.e. the availability for production of physics data, of the accelerator and generate extra operation costs.

In view of future sensitive projects such as the HL-LHC [3] civil engineering operation and the geo-thermal exploitation in the Geneva canton, CERN in collaboration with the Swiss Authorities decided to deploy a seismic network to evaluate their impact on the LHC machine operation. The goal of the network is to collect the seismic activity background level in 2017 as reference before the main activities described previously start and will continue over the next decade. A study mandated by the Geneva canton to evaluate the impact of the possible micro seismicity induced by geothermal exploitation on the CERN installation gave the following result; there is a probability of local earthquakes: Monthly, magnitudes may reach up to ~3, but most earthquakes are expected to be limited to magnitude ~2 with a weekly frequency. In the geothermal exploitation framework and following the Resonance SA study, the Service Industriel de Genève (SIG) [4] has decided to densify the local seismic network in the Geneva canton to optimize the predictive model and localize the best site for geothermal exploitation. Thanks to the new stations installed at CERN, more low magnitude seismic events should be recorded with a better spatial resolution. As an example, the LHC beam orbit oscillations on 13th November 2016 between 5am and 7pm GMT (UTC+1) are shown in Figure 1. The beam position is influenced by the moon gravity and by a series of earthquake waves which propagated through the Earth's crust from New Zealand. (with a maximum magnitude of Mw 7.9 at 12:03am GMT).

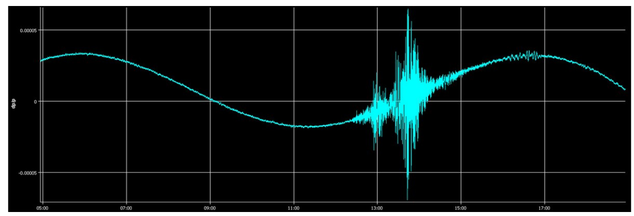

Figure 1: LHC beam horizontal orbit oscillations.

This paper presents the requirements, the design, the validation tests and the installation of the LHC seismic network deployed at CERN beginning of 2017 in collaboration with the Swiss Seismological Service (SED).

REQUIREMENTS

Seismic Wave on LHC

The impact of a ground wave travelling across the LHC depends on the wave amplitude and wavelength and its orientation in relation to the ring. The consequence of the passage of a seismic wave across the LHC while it is in operation may be divided into 3 categories:

- The amplitude is very small (< 0.1µm), the passage may not even be detected.
- The amplitude is large enough to temporarily disturb the beam during the passage of the wave and will lead to a small loss of data for the experiments
- The combination of amplitude and wavelengths are strong enough for the beam movements to cause large particle losses, leading eventually to a beam abort by the Machine Protection System (MPS) [5]. In that case it will take a few hours to restore a quality of beam to a level suitable for the data acquisition for the LHC experiments. Such events should be extremely rare in order not to affect the LHC uptime and the data acquisition periods. A rate of one per week can already be considered to have a significant impact.

Frequency-amplitude Impact on LHC

The CERN seismic network should measure both the low amplitude vibrations of the LHC during its normal operation and the high amplitude vibrations due to, for example, HL-LHC related excavation works, near source earthquakes triggered by the geothermal project or teleseismic earthquakes. One has to decide the boundaries inside which ground motion will be measured. The upper limit was fixed

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WALL CURRENT MONITOR USING PXI AND LABVIEW AT CERN

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Abstract

The new data acquisition system for the PS ring wall current monitors installed in the PS is able to perform high frequency measurements of a beam bunch up to a frequency of 2.7 GHz. This is an important improvement, since the oscillating signal within the bandwidth 500-700 MHz, is related to losses of a beam bunch. The losses could be eventually reduced by measuring the frequency and classifying the cause of the oscillations. The PXI-5661 is used to carry out spectral analysis of this signal. The acquisition is performed on a PXI running LabVIEW Real-Time and synchronized using a trigger from the accelerator timing system.

INTRODUCTION

A wall current monitor (WCM) [1] is a device to measure the instantaneous value of the beam current (Figure 1 together with its working principle). As the beam travels through the vacuum pipe, it is accompanied by a current flowing along the inside of the pipe's wall, in the opposite direction of the beam current, which can be measured.

A new acquisition system for the CERN Proton Synchrotron (PS) ring wall current monitors has been installed to be able to perform higher frequency measurements of beam bunch transverse and longitudinal oscillations. The losses and instabilities can be understood and eventually mitigated by measuring the frequency and classify the impedance sources exciting the oscillations.

REQUIREMENTS

The main goal of this project is to acquire and view the wall current monitor data in time and frequency domains and to be able to identify different type of beam instabilities. A LabVIEW application running on a PXI real-time target is used to perform continuous and triggered data acquisition of a beam bunch and display the data on a viewer for the users.

Longitudinal Instabilities

The main limitations to the brightness of the beam of the PS for the future HL-LHC [2] beams are in general related to the longitudinal coupled bunch instabilities [3]. These oscillations occur in the relative low frequency domain, 0-20 MHz, and are related to the ten 10 MHz RF cavities impedance. Note that the purpose of these RF cavities is to accelerate the beam, which means that they are indispensable and their number cannot be reduced to mitigate the instability.

Principle of the Wall Current Monitor

The wall current monitor can measure the instantaneous voltage within a bandwidth of 100 kHz to 4 GHz of the beam current. In the PS at CERN three kind of Wall Current Monitors are present, which measure the following signals: vertical, horizontal and sum pick up voltages. Each signal could be used to identify beam oscillations, thus a different instability.

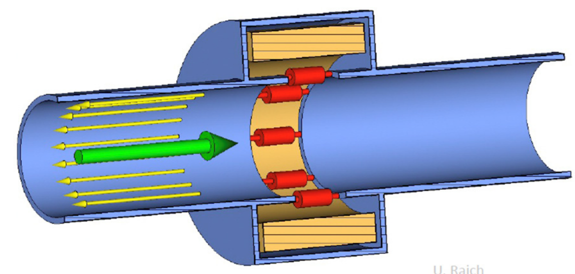

Figure 1: A schematic overview of a WCM. The green arrow represents the beam current, which is accompanied by its own image current (yellow arrows). A set of resistors (the red cylinders) generates a measured voltage. Ferrites, which are electrically insulators, (light brown section) forces the image current to flow through the resistors.

WALL CURRENT MONITOR OVERVIEW

The WCM application is deployed on a PXI system, which can be triggered by using a Control Timing Receiver (CTR) [4] card and the timing library ported to LabVIEW RADE [5] (Figure 2). The Target application is integrated in the CERN accelerators control system to profit of services such as the CERN accelerator logging [6] or to simply give the possibility to other applications in the Cern Control Center (CCC) to access the data published by the target application. The HOST application has been developed in LabVIEW using the RADE framework.

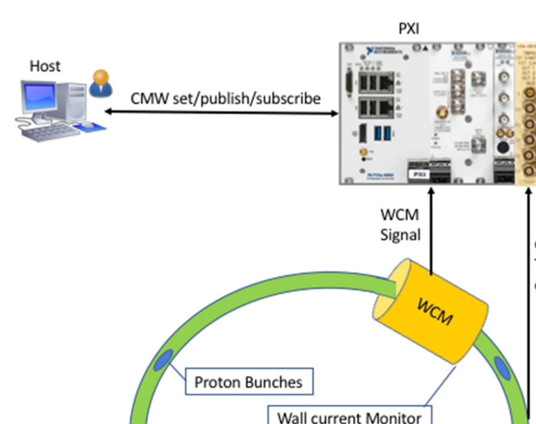

Figure 2: System overview.

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DISTRIBUTING NEAR REAL TIME MONITORING AND SCHEDULING DATA FOR INTEGRATION WITH OTHER SYSTEMS AT SCALE

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Abstract

The MeerKAT radio telescope control system generates monitoring and scheduling data that internal and external systems require to operate. Distributing this data in near real time requires a scalable messaging strategy to ensure optimal performance regardless of the number of systems connected. Internal systems include the MeerKAT Graphical User Interface (GUI), the MeerKAT Science Data Processing (SDP) subsystem and the MeerKAT Correlator and Beamformer (CBF) subsystem. External systems include Pulsar Timing User Supplied Equipment (PTUSE), MeerLICHT and the Search for Extraterrestrial Intelligence (SETI). Many more external systems are expected to join MeerKAT in the future. This paper describes the strategy adopted by the Control And Monitoring (CAM) team to distribute near realtime monitoring and scheduling data at scale. This strategy is implemented using standard web technologies and the publish-subscribe design pattern.

INTRODUCTION

MeerKAT [1] is a mid-frequency "pathfinder" radio telescope and precursor to building the world's largest and most sensitive radio telescope, the Square Kilometer Array (SKA). MeerKAT builds upon its own precursor namely KAT-7, a seven-dish array currently being used as an engineering and science prototype.

MeerKAT CAM [2] has a number of systems connected which require a constant stream of near real time sensor data updates in order to operate. There are internal systems including the GUI, the SDP subsystem and the CBF subsystem. There are also external systems including PTUSE, MeerLICHT and SETI. Many more systems are scheduled to be connected to CAM in the coming months and years. As the demand for live sensor data increases, CAM must be able to distribute sensor data to all of the interested systems without negatively impacting the performance of the running CAM system.

In the existing implementation, users would connect to CAM webservers using a Python client [3] and subscribe to sensor data that they were interested in. For each such connection, a Karoo Array Telescope Communication Protocol (KATCP) [4] connection is created to each component of interest between the CAM webservers and the CAM system. This design puts a high load on the CAM webservers as well as the CAM system.

In order to fix this bottleneck, the CAM software engineering team decided to combine our current monitoring messaging system with an existing high performance messaging system that allows for the use of a publish-subscribe pattern to enable a scalable distribution of near real time sensor data.

Several messaging platforms were evaluated. NATS [5] was found to be the most suitable to our needs. CAM is also using NATS as a messaging system to archive historical sensor data [6]. We will not be discussing the archiving of historical sensor data in this paper.

DATA DISTRIBUTION

The CAM system is distributed over multiple virtualized machines [7], referred to as CAM nodes. Each CAM node has a local NATS instance which is connected to all other NATS instances in the CAM system to form a messaging cluster. All the CAM components, which run on CAM nodes, publish messages to the local NATS instance and the NATS cluster routes the messages to the appropriate subscribers.

A group of webservers runs on one of the CAM nodes, this node is named the portal node and is collectively known as Katportal. Katportal acts as the main interface for all subscriptions by exposing websocket endpoints. Interested parties connect to the websocket interfaces and execute Remote Procedure Call (RPC) methods to subscribe and unsubscribe to subjects on the NATS messaging system. When the websocket closes all subscriptions are automatically pruned, therefore, connecting clients need to re-subscribe to subjects after a disconnect has occurred. Subjects can be individual sensor names, aggregated subjects that logically combine numerous individual subjects or application specific subjects.

Additionally, Katportal publishes to application specific subjects on NATS. These subjects include live observation scheduling data, current date and time (including local sidereal time and the current Julian date), alarms, user authentication and aggregated sensor subjects. Application specific subjects makes it more efficient for systems interested in a logical subsection of CAM to subscribe to certain types of data, which could be published as various different subjects. For example; the MeerKAT GUI [8], the operator control interface known as Katgui, will only subscribe to the observation scheduling subject in order to receive messages for all scheduling related updates. An example of an external system that requires observation scheduling data updates, is the MeerLICHT optical telescope. MeerLICHT aims to provide a simultaneous, real-time optical view of the radio (transient) sky as observed by MeerKAT.

Aggregated subjects are created specifically for use by Katgui. These subjects typically serve to update one specific

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YCPSWASYN: EPICS DRIVER FOR FPGA REGISTER ACCESS AND ASYNCHRONOUS MESSAGING

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Abstract

The Linac Coherent Light Source II (LCLS-II) is a major upgrade of the LCLS facility at SLAC, scheduled to start operations in 2020. The High Performance Systems (HPS) defines a set of LCLS-II controls sub-systems which are directly impacted by its 1 MHz operation. It is formed around a few key concepts: ATCA based packaging, digital and analog application boards, and 10G Ethernet based interconnections for controls. The Common Platform provides the common parts of the HPS in term of hardware, firmware, and software. The Common Platform Software (CPSW) provides a standardized interface to the common platform's FPGA for all high-level software. YAML is used to define the hardware topology and all necessary parameters. YCPSWASYN is an asynPortDriver based EPICS module for FPGA register access and asynchronous messaging using CPSW. YCPSWSYN has two operation modes: an automatic mode where PVs are automatically created for all registers and the record's fields are populated with information found in YAML; and a manual mode where the engineer can choose which register to expose via PVs and freely choose the record's filed information.

INTRODUCCION

The high repetition rate (1 Mhz) of the next generation Linac Coherent Light Source II (LCLS-II) has brought requirements that can be achievable only with FPGA-based solutions. In that sense, the High Performance System (HPS) was born [1]. As parts of the HPS, the common platform contains all the common hardware, firmware and software that are common to all applications.

YCPSWASYN is a general-purpose EPICS module for register access and asynchronous messaging with the FPGA. The module is based on asynPortDriver, and uses the Common Platform Software (CPSW) as communication layer with the hardware, which is described using YAML files.

THE HIGH PERFORMNCE SYSTEM

The 1MHz operation rate of LCLS-II has set new requirements for controls that are no longer achievable by software application, as was done for LCLS-I. The adopted solution was to implement the control systems with real-time requirements into FPGA-based system. This FPGA-based solution is called the High Performance System (HPS).

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The HPS Comon Platorm

As all sub-system using the HPS will have a set of similar requirements, the Common Platform encompasses all the common areas: Intelligent Platform Management Interface (IPMI), Timing Network, Machine Protection System (MPS) network, and EPICS network.

The HPS common platform is based om Advanced Telecommunication Computing Architecture (ATCA). Each sub-system will use an ATCA Advanced Mezzanine Card (AMC) carrier board which contains all the common platform blocks. The AMC carrier supports two doublewide, full height AMC mezzanine cards. An AMC card is where the application specific hardware exists for a given HPS sub-system. Figure 1 shows a block diagram of the HPS ATCA carrier and AMC card.

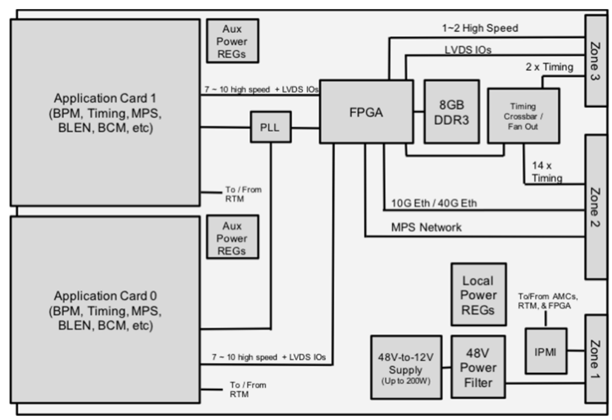

Figure 1: The HPS hardware block diagram.

The help minimize cabling, the ATCA back plane is highly utilized. We are using a dual-star back plane. In slot#1 (1st star connection), we use a Commercial Off The Self (COTS) Ethernet switch to connect Ethernet to all the AMC carriers via the back plane's zone2 interface. In slot#2 (2nd star connection), we use an AMC carrier to connect all the other AMC carriers to the timing and MPS networks via the back plane's zone2 interface as well. The slot#2 AMC carrier's external connection to the timing and MPS networks is via a Rear Transition Module (RTM). The ATCA Zone1 back place interface provides the AMC carriers with -48VDC power (up to 300W) and an IPMI network interface. Figure 2 shows a block diagram of the crate network connections.

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DESIGN OF THE FRONT-END DETECTOR CONTROL SYSTEM OF THE ATLAS NEW SMALL WHEELS*

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Abstract

The ATLAS experiment will be upgraded during the next LHC Long Shutdown (LS2). The flagship upgrade is the New Small Wheel (NSW) [1], which consists of 2 disks of Muon Gas detectors. The detector technologies used are Micromegas (MM) and sTGC, providing a total of 16 layers of tracking and trigger. The Slow Control Adapter (SCA) is part of the Gigabit Transceiver (GBT) - "Radiation Hard Optical Link Project" family of chips designed at CERN, EP-ESE department [2,3], which will be used at the NSW upgrade. The SCA offers several interfaces to read analogue and digital inputs, and configure front-end Readout ASICs, FPGAs, or other chips. The design of the NSW Detector Control System (DCS) takes advantage of this functionality, as described in this paper.

THE NEW SMALL WHEEL UPGRADE OF THE ATLAS MUON SPECTROMETER

The ATLAS experiment will be upgraded during the next LHC Long Shutdown (LS2). The flagship upgrade is the New Small Wheels (NSW), which consists of 2 disks of Muon Gas detectors. The detector technologies used are Micromegas (MM) and sTGC, providing a total of 16 layers of tracking and triggering. Shown in Fig.1 is an expanded view of the NSW.

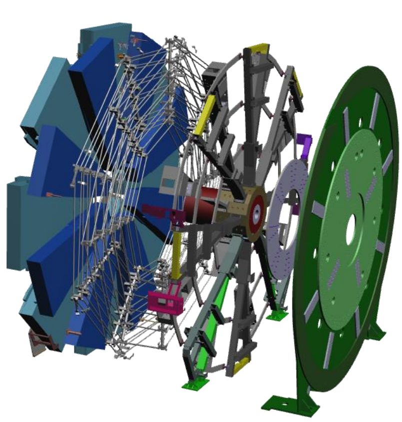

Figure 1: An exploded view of the NSW. From left to right: The detector sector envelopes, the alignment system, the structure and the New JD (shielding and support).

SCA FUNCTIONALITY

The SCA ASIC offers several interfaces to read & control analogue/digital levels, and configure front-end Readout ASICs, FPGAs, or other chips.

The interfaces offered by the SCA are:

- 1 ADC channel, providing 31 input lines and one on-chip temperature sensor
- 1 JTAG serial bus master channel, with programmable transaction length and frequency
- 1 Digital I/O pin interface, which gives access to 32 general purpose pins (can be individually set as input or output and can generate interrupt requests)
- 16 independent I2C master serial bus channels (transfer rates 100kHz-1MHz)
- 1 SPI serial bus master with 8 individual slave select lines (programmable transaction length and frequency)
- 1 DAC interface, giving access to 4 converters with 8-bit resolution and with input range 0..1V

As described in the next sections, the above interfaces prove extremely useful for the detector control.

THE GBT-SCA IN THE NEW SMALL WHEEL

There is a big number of SCAs in the NSW ecosystem (almost 7000), each of which will be placed on a separate PCB. Given the embedded nature of this functionality, the control data needs to follow the main path like the signal and timing data.

Concerning SCA downstream connections, there will be many cases that the SCA connects to 8 front-end chips. This creates complexity at the level of the software development since parallelization of the data upload becomes a necessity but not a given.

COMMUNICATION PATH

The communication chain starts in the control room with an OPC-UA client, which talks to a quasar-based [4] OPC-UA server in the service cavern. The server, in turn, communicates the data through a front-end link exchange and a fiber cable to arrive to the on-detector electronics (Fig. 2). Some details are given in the following subsections.

* For the ATLAS Muon Collaboration

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THE SKA DISH SPF AND LMC INTERACTION DESIGN: INTERFACES, SIMULATION, TESTING AND INTEGRATION

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Abstract

The Square Kilometre Array (SKA) project [1] is responsible for developing the SKA Observatory, the world's largest radio telescope ever built: eventually two arrays of radio antennas - SKA1-Mid and SKA1-Low - will be installed in the South Africa's Karoo region and Western Australia's Murchison Shire respectively, each covering a different range of radio frequencies. In particular, the SKA1-Mid array will comprise of 133 15m diameter dish antennas observing in the 350 MHz-14 GHz range, each locally managed by a Local Monitoring and Control (LMC) system and remotely orchestrated by the SKA Telescope Manager (TM) system. All control system functionality run on the Tango Controls platform. The Dish Single Pixel Feed (SPF) work element will design the combination of feed elements, orthomode transducers (OMTs), and low noise amplifiers (LNAs) that receive the astronomical radio signals. Some SPFs have cryogenically cooled chambers to obtain the sensitivity requirements.

This paper gives a status update of the SKA Dish SPF and LMC interaction design, focusing on SPF, LMC simulators and engineering/operational user interfaces, prototypes being developed and technological choices.

SKA DISH

SKA-MID1 Dish array is composed of 15-m Gregorian offset antennas (Dish element)[2] with a feed-down configuration equipped with wide-band single pixel feeds (SPFs) for the bands 1 (0.35-1.05 GHz), 2 (0.95-1.76 GHz) and 5 (4.6-13.8 GHz) of SKA frequency. The array will consist of 133 dishes plus the 64 MeerKAT dishes, arranged in a dense core with quasi-random distribution, and spiral arms going out to create the long baselines that go up to 200km.

Four sub-elements can be identified in the SKA-Mid1 dish element (see Figure 1): the *Dish Structure (DS)*, the *Single Pixel Feed (SPF)*, the *Receiver (Rx)* and the *Local Monitoring and Control (LMC)*.

The *Dish structure* features the following components: an offset Gregorian reflector system with a feed-down configuration to optimise system noise performance, a fan-type feed indexer at the focal position which allows for changing between the 5 frequency bands by moving the appropriate feed into position, a pedestal providing a RFI shielded cabinet for housing digital electronics and computing equipment hosting other sub-elements' controllers, hardware for antenna movement control and monitoring (Antenna Control Unit or ACU), power distribution to all sub-elements, networking equipment, lightning protection and earthing, cooling ventilation for all the equipment mounted in the RFI shielded compartment itself.

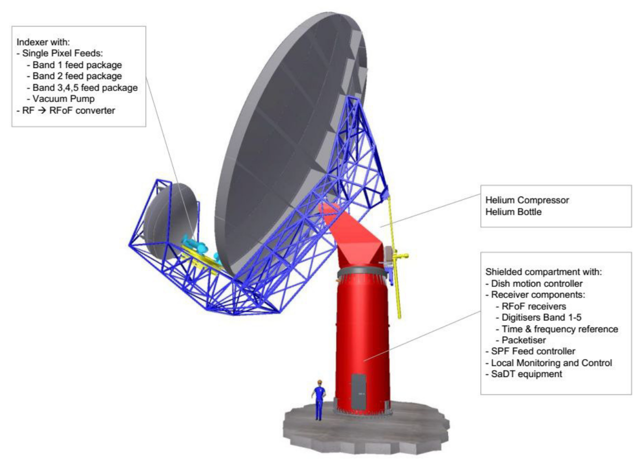

Figure 1: SKA DISH overview.

The *Receiver (Rx)* includes the following components: RF over fibre transport to the antenna pedestal where the digitisers are located, Digitizers performing some RF conditioning (filtering and level control), digitisation, packetizing and transmission to SKA Central Signal Processor (CSP), the Master Clock timer which receives time and frequency reference inputs externally and generates timing and frequency references and a Central controller that acts as single point of control and monitoring to the LMC sub-element.

Dish Local Monitor and Control (LMC) is the subsystem for each dish antenna that deals with the management, monitoring and control of the operation as orchestrated by the Telescope Manager (TM). It consists of a commercial off the shelf controller that serves as a single point of entry for all control and monitoring messages to the outside. Besides configuring the static configurations of the various sub-elements, it also relays the real-time pointing control and applies local pointing corrections. For the monitoring, it aggregates and filters monitoring data as set up from the external (central) controller. The

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SYNCHRONOUS MOTION WITH S7-1500 PLCS IN NEUTRON INSTRUMENTS

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Abstract

Control systems of neutron instruments are responsible for the movement of a variety of mechanical axes. In the TANGO based control systems developed by Forschungszentrum Jülich for neutron instruments, Siemens S7-300 PLCs with single axis stepper motor controllers from Siemens or Phytron have been used for this purpose in the past. Synchronous coordinated movement of several axes has been implemented with the FM357-2, a dedicated multi-axis modules for the S7-300 with NC functionality.

In future, the recent S7-1500 PLC family shall be used for motion tasks. With the S7-1500, stepper motor control is possible with low-cost fast digital outputs, so called PTOs (pulse trade outputs). The integrated motion functions of the S7-1500 directly support synchronous movement. The function block interface defined by PLCopen serves as a homogenous programming interface which is independent of a specific motion controller.

For the single crystal diffractometer HEiDi at the research reactor FRM-II a prototype for the replacement of a S7-300 with FM357-2 has been implemented based on a S7-1500 PLC and a PTO module.

INTRODUCTION

Stepper motor and servo controllers are typically implemented as dedicated hardware modules. Due to the increase in computing power, these functionalities also can be implemented by PLC CPUs based on low cost fast digital (so called PTOs: pulse trade outputs) and analogue outputs, requiring external stepper or servo drivers. The hot single crystal diffractometer HEiDi [1], which is operated by the Institute of Crystallography, RWTH Aachen University, and JCNS, Forschungszentrum Jülich, has been equipped with the multi-axis function module FM357-2 for the synchronous movement of the 4-axes-diffractometer unit during measurement. It is intended to replace the old S7-300 with the FM357-2 module at HEiDi by an S7-1500 System with the technology module TM PTO 4 (with 8 pulse trade outputs). The next sections give an overview the instrument HEiDi as well as the so-called "Jülich-Munich Standard", since the overall control system software and hardware architecture of HEiDi conforms to this standard. After an introduction into the S7-1500 motion functionality the implementation of a test system for the coordinated movement of axes is described and first measurement results are presented.

THE "JÜLICH-MUNICH STANDARD"

The "Jülich-Munich standard" [2] is a framework for the selection of technologies and components at each level of the control system. The definition of this framework was motivated by synergy effects and the reduction of spare parts on the shelf. A guiding principle for the framework was to minimize the development efforts and to acquire as much from the market as possible. A key component of the framework is the consistent use of industrial technologies like PLCs, fieldbus systems or decentral periphery in the front end. Main motivations are:

- low prices induced by mass market
- inherent robustness
- long term availability and support from manufacturer
- powerful development tools

A control system according to the Jülich-Munich Standard is organized hierarchically into the following levels:

Field level: The field level is the lowest level, at which devices that are not freely programmable reside, like motor controllers, SSI controllers, PID controllers, analogue and digital I/O modules, or measurement equipment. For all industrial type of I/O modules PROFIBUS DP or PROFINET based decentral periphery is recommended. Siemens ET200S is the preferred one. The ET200S modules 1STEP and 1STEP-DRIVE are the predominantly used stepper motor controllers.

Control level: The control level resides on top of the process level. Devices at the control level are freely programmable. They must meet real time requirements and guarantee robust operation in a harsh environment. At the control level Siemens S7 PLCs are used, because they dominate the European market.

Process communication: Process communication covers the communication of devices at the field and control level with supervisory controllers or computers. For lab equipment GPIB and proprietary RS232/RS485 connections are unavoidable. For industrial automation equipment PROFIBUS DP and PROFINET are the recommended choices. They are the dominating fieldbus systems in Europe and naturally supported by S7 PLCs and many other devices. A major reason for their success is the technological and functional scalability based on a common core as well as the programming model, which easily maps to PLC operation.

Experiment Computer: For economic reasons, all experiment computers should be PCs. Linux, being well established in the scientific community, is the only supported operating system. CentOS is the preferred distribution at JCNS. Direct device access is typically implemented on industrial PCs, mainly CompactPCI systems. CompactPCI allows deploying a variety of existing software in a mechanically more robust platform that fits into 19" racks.

Middleware: Since the framework aims at an inherently distributed system, software support for the transparent distribution of services between systems is required. For

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INDUSTRIAL STEPPING MOTORS INTEGRATION IN THE UNICOS-CPC FRAMEWORK

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Abstract

A large number of movable devices are present in the field of accelerators and must often be integrated in a control system. Typical examples of these systems are phase shifters and magnetic dipoles among others. The standard industrial control system UNICOS-CPC (UNified Industrial COntrol System for Continuous Process Control) provides a set of generic device types which matches the majority of the industrial equipment employed in process control. This new development extends it with additional device types for precise positioning equipment based on stepping motors.

The paper focuses on how the integration on UNICOS was fulfilled, the potential use of the solution and the automatic integration with the CERN real-time FESA (FrontEnd Software Architecture) framework. Finally, it illustrates a couple of use cases that already incorporate the solution: the CTF3 facility, the two-beam acceleration scheme envisioned for CLIC (Compact Linear Collider) and the EuroCirCol project for the measurements of the beam screen prototype for the FCC-hh (Future Circular Collider proton-proton).

INTRODUCTION

A stepping motor is an electric device capable of positioning objects in discrete regular steps with great accuracy and reliability. It can be controlled from several types of hardware including: industrial computers, specific electronics or, as in this publication proposed case, PLCs. A large number of movable devices are present in the field of accelerators and must often be integrated in a control system. This paper proposes integration through a standard device within the UNICOS-CPC (UNified Industrial COntrol System for Continuous Process Control) framework [1].

At CERN there were several legacy installations which were using control solutions based on standard PLCs with a wide variety of technical approaches. Our engineers were frequently called for support on those installations and thus a standard for stepping-motor integration in the UNICOS framework was proposed.

Another requirement was the integration of such devices to the standard accelerator control systems at CERN which are based on the FESA (Front-End Software Architecture) framework [2].

In this paper, we will go through the steps needed to include the stepping motor device as a new field device type in the UNICOS framework, its integration on the control systems and its application in real installations.

HARDWARE ARQUITECTURE

The selected solution is based on PLC hardware architecture with Siemens components. A distributed station *ET200S* is connected to a *S7-300* series Siemens PLC. The specific controller *1STEP-5V*, placed in the *ET200S*, is an electronics card with its own custom logic and is in charge of producing the signals to control the motor. It has a dedicated input where a reference switch is connected. As this input has a faster scan cycle than the normal digital inputs of the PLC, this enables increased precision in the detection of the reference position. In some installations, the end switches limiting the movement of the device are also connected to this same input. Pulses emitted by the card and signals indicating the turning direction are sent to the power module, which decodes them and gives the motor the electrical power to turn.

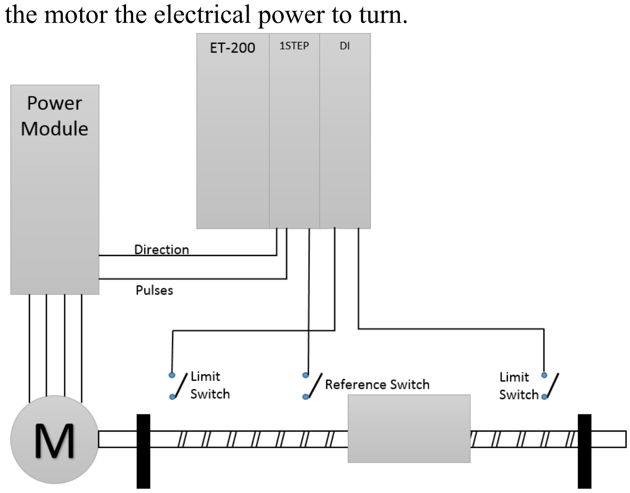

Figure 1: Hardware scheme of a typical installation.

The wiring of the setup depends on the desired mode of operation and the instrumentation installed. The recommended and fundamental configuration is based on using two end switches and a reference switch in between. The end switches are connected to digital inputs of the PLC I/O card. The reference switch is connected to the specific input of the controller card. Another possible configuration uses only two end switches, taking one of them as reference and connecting both of them to the controller card. In this configuration there is no need for digital input cards, making the final set simpler, but this is only possible with the second generation of controller cards.

INTEGRATION IN THE UNICOS-CPC FRAMEWORK

The first step to integrate the object in to the UNICOS-CPC framework was designing the device according to the UNICOS device model. This needs a device type

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INTEGRATION OF PLC AND PXI CONTROL SYSTEMS

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Abstract

Engineers are often challenged with the need to integrate several technologies to find optimal solutions when designing new control architectures. Generally, the technical solutions chosen require the combination of various industrial products such as PXI systems for applications requiring fast acquisition, analysis and reaction times, while PLCs are commonly used for their reliability and their ability to withstand industrial environments. The needs to exchange information between these different technologies can today be solved by using industrial fieldbuses such as Profibus DP or Profinet IO. This paper describes the technical aspects of the two options, focussing on their advantages and constraints. The experience gained with integrating PXI and PLC systems as part of the 2016 consolidation project of the control of the kicker systems of the Antiproton Decelerator (AD) at CERN will be presented.

INTRODUCTION

In the late 1980s, the PLC-based automation systems became increasingly popular in the manufacturing industry aiming to improve their productivity. The need to reduce costs and downtime while ensuring a high level of flexibility has led to the search for innovative decentralized solutions. Some automation manufacturers decided to join their efforts on a "fieldbus" project to find out a homogenous common solution. The Profibus standard was born. Today, the PI Organisation (Profibus and Profinet International) count over 1400 member companies worldwide [1]. Subsequently, a protocol based on the Ethernet, the Profinet, was designed with a first version available from 2001 onwards [2]. Meanwhile, National Instrument (NI) developed the PXI technology (PCI eXtensions for Instrumentation) for fast measurement applications as electronic testing equipment. The need to add fast measurement devices to a manufacturing plant is today essential and a communication channel between the two is therefore mandatory. Because PLCs have already their own industrial communication solutions and are generally the core of plant processes, the PXI based solutions have to become compatible and adapt to the industrial communication standards.

CONTEXT

The Accelerator Beam Transfer group (TE-ABT) at CERN, which is responsible for all beam injection and extraction systems across the accelerator complex, has a control architecture based on a slow control, fast control and timing control. With the introduction of PXI based solutions to replace old electronics for the fast control, a study of industrial communication solutions based on fieldbuses was carried out in order to ensure a homogeneous exchange of data between the slow control and the fast control. However, the modernisation of the slow control with off-the-shelf components had already been done using Siemens PLCs, leading to Profibus DP and Profinet IO as possible choices.

The Control group (BE-CO) at CERN provides a communication solution that could also be consider to build a communication channel between a PLC and a PXI through their Front-End Software Architecture (FESA). Unfortunately, the choice of such a solution would lead to additional software layers, more complexity and dependence on external services, which would not allow the exchange of critical data such as interlocks.

FIELDBUS

Definition

A *fieldbus* is a digital, serial, multidrop, data bus for communication with industrial control and instrumentation devices such as -– but not limited to - transducers, actuators and local controllers [3].

Profibus DP[1]

Profibus DP, for **Pro**cess **Fi**eld **Bus** **D**ecentralized **P**eriphery, is a fast and deterministic master-slave fieldbus standardized in IEC 61158 and compliant with the OSI model (Open Systems Interconnection) standard, which make uses of only three separate layers of the OSI model [4]. The physical layer defines the data transmission technique, the three main ones being: the RS485, the optical-fibre and Manchester Bus Powered. The data link layer specifies the communication functions. Today, three version exists, DP-V0 that ensure the basic functions with cyclic data and diagnostics transmission, DP-V1 adding acyclic data transmission for process oriented services (configuration, alarms), and, DP-V2 for isochronous needs (Direct slave communication, motion applications). Finally, the application layer is specific to the manufacturer.

In Profibus terminology, a *device profile* defines functionalities and services a device has to be able to deliver and perform. A profile is always encapsulated in a standardized General Station Device (GSD) file, which allows the user to integrate any device into its automation project.

Profinet IO

Profinet IO, for **Pro**cess **Fi**eld **Net**, is a full duplex network for industrial automation applications build on standard Ethernet technology and compliant with CEI 61158 and CEI 61784 [5].

The communication networks used in the industry must ensure data transfer between different devices in real time in order to guarantee the response time of the processes.

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[1] The Profibus and Profinet fieldbuses exist in several variants. This paper will consider only the Profibus DP and the Profinet IO versions without safety frames.

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LCLS-II CRYOMODULE AND CRYOGENIC DISTRIBUTION CONTROL*

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Abstract

LCLS-II is a superconducting upgrade to the existing Linear Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory. Construction is underway with a planned continuous wave beam rate of up to 1 MHz. Two cryogenic plants, a distribution system, and 37 cryomodules with superconducting cavities will operate with liquid helium at 2.2K. The process is controlled with networked Programmable Logic Controllers (PLC) and the Experimental Physics and Industrial Control System (EPICS) as an integrated system that work in concert for controlling valves, pressure, flow, and temperature. Interlocks and critical process information are communicated with the low level radio frequency (LLRF), vacuum, and magnet systems. Engaging the controls community proved vital in advancing the controls architecture from a conventional design to a centralized, reliable, and cost-effective distributed platform. The date for first light is in 2020.

INTRODUCTION

Two cryogenic plants, designed by the Thomas Jefferson National Accelerator Facility, supply helium to the LCLS-II linear accelerator (LINAC) cryogenic control system. SLAC is responsible for the LINAC control system and the EPICS integration to the plant [1]. The controls design includes:

- EPICS Supervisory Control of the cryogenic plant, distribution system, and cryomodules.
- 2 sets of centralized, redundant PLC processors and EtherNet/IP modules for cryomodule and distribution system.
- PLC 1 GB/s interface to EPICS.
- Device-level Ring (DLR) communication with Distributed I/O and LLRF Input/Output Controller (IOC) Servers.
- Profibus Decentralised Peripherals (DP) communication to temperature monitors.
- Profibus Process Automation (PA) communication to valve positioners.
- Over 100 devices distributed over 4 rings.
- Interfaced systems: LLRF, Magnet, Vacuum.
- Interfacing and controlling: cryogenic valves, pressure transducers, liquid level monitors, temperature monitors, and heaters.

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CONTROLS ARCHITECTURE

The system controls and monitors instrumentation in the cryomodule and distribution system; the instrumentation quantities are shown in table 1 below [2].

Table 1: Instrumentation Signal Count

Instrument	Quantity
Pressure	106
Temperature (sensor)	1500
Liquid level	74
Valves	84
Heaters	520
Voltage Taps (conditioned)	315

Collaborative feedback from fellow laboratories helped build the architecture for controlling the LCLS-II cryomodule and distribution system. This lead to the adoption of centralized processing and commercially available off-the-shelf hardware.

Centralized Redundant Processing

The cryogenic plant supplies helium through two distribution boxes. One distribution box supplies the upstream 17 cryomodules and one distribution box supplies the downstream 20 cryomodules. The controls architecture mirrors this mechanical design by having the PLC processing located in two centralized locations. These centralized processing locations have the complete PLC programs that support the control functions for the instrumentation described in this document. Figure 1 shows one of the two sets of redundant chassis architecture. Two chassis contain the same Rockwell ControlLogix hardware: PLC 1756-L83E processor, Ethernet modules, and redundancy control modules are located near both distribution boxes. The primary chassis fails over to the secondary chassis when a fault occurs in one of the modules located in the chassis. The EtherNet/IP modules support communications to the DLR and the PLC's in the cryogenic plant. The 1 GB/s interface on the PLC CPU supports communication to the EPICS IOC.

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CONCEPTUAL DESIGN OF VACUUM CONTROL SYSTEM FOR ILSF*

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Abstract

Many The Iranian Light Source Facility (ILSF) is a new 3 GeV third generation synchrotron light source facility with circumference of 528 m, which is in the design stage. In this paper conceptual design of vacuum control systems presented. The control system architecture, Software toolkit and controller in device layer are discussed in this paper [1].

INTRODUCTION

The Iranian Light Source Facility Project (ILSF) is a 3 GeV third generation light source with a current of 400 mA which will be built on a land of 50 hectares area in the city of Qazvin, located 150 km West of Tehran. The ILSF storage ring has been designed to be competitive in the future operation years. Iranian Light source facility vacuum control system, contain of controller for Pumps specially ion pump and gauges to read pressure. To implement a successful and reliable system to obtain pressure about 1 $nTorr$ and keep it in storage ring, the vacuum system must be based on distributed intelligence with proper process variable update rate. This paper explain conceptual design of vacuum control system. A summary of ILSF major parameters are listed in the Table 1 [1].

Table 1: Main Parameters of the ILSF Storage Ring

Parameter	Unit	Value
Energy	GeV	3
Circumference	m	528
Emittance	nm.rad	0.27
Current	mA	400
Length of straight section	m	7
Number of straight section	-	20
RF frequency	MHz	100

For current machine design, the concept of antechamber has been chosen. The vacuum chambers will be made of stainless steel and will be baked out before installation. 580 ion pumps, 180 TPS and 100 NEG pump have been foreseen for the storage ring. Different computational methods have been developed to help designers to achieve the necessary low pressure throughout small aperture magnet vessels. Several methods have been employed to calculate pressure profile in different working modes of storage ring. Calculations have shown that the maximum pressure in storage ring will be lower than 1.8×10-9 mbar during operation time.

The interface of each vacuum controller is in the Table 2.

Table 2: Controlling Interface for Vacuum Sub System

Devices	Interface
Ion Pomp controller	Ethernet
Roughing pump controller	PLC
NEG pump controller	PLC
Cold cathode gauges controller	Ethernet
Pirani gauge controller	Ethernet
Valve controller	PLC
Thermometer controller	PLC
Residual gas controller	Ethernet

NETWORK CONTROLLER AND TOOLKIT

All devices and vacuum components in control level should support Ethernet protocol to send data to control room and receive operational commands through the network. However, using well-known protocols increases the risk of penetration into the system.

Controller should designed in such a way to have a minimum latency in send and receive commands from control room.

Since Ethernet protocol is main network line, the mentioned devices must support this protocol or in case of devices which are provided by companies outside of ILSF and do not support main protocols, taking advantage of a converter could be a solution.

Open source and wide usage are the two main factors which have led us to choosing EPICS as a control system toolkit for ILSF.

VACUUM CONTROLLER DESIGN

In order to increase respond time and system reliability, and also to reduce network control traffic, the vacuum system is designed on the basis of distributed control system in which the process of control take place in each controller individually and the results of events or sensitive process variables are being sent to man-machine interface.

Since vacuum system is not majorly involved in data analysis, the main concern in designing the system is focused on its maintenance and prolonging its life time. This clearly indicates the significance of establishing a vacuum control system in favor of layer approach. In other words, the priority is to establish the vacuum control system based on the hardware layer instead of the software layer.

In this system the vacuum equipment is located in the field level and connected to the controllers which lays in safe area and control level and are hart of control by cables.

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CONCEPTUAL DESIGN OF POWER SUPPLY CONTROL SYSTEM FOR ILSF

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Abstract

The Iranian Light Source Facility (ILSF) project is a first large scale accelerator facility which is currently under planning in Iran. On the basis of the present design, circumference of the 3 GeV storage ring is 528 m. Beam current and natural beam emittance are 400 mA and 0.27 nm.rad respectively. The facility will be built on a plot of land the size of 100 hectares in the city of Qazvin, located 150 km West of Tehran. In this paper the conceptual design of power supply control system is presented.

INTRODUCTION

Synchrotron radiation, as a versatile research tool, has experienced an unprecedented expansion. Nowadays, a large and continuously growing community of researchers representing a variety of disciplines depends on light sources as an essential part of their research programs. In spite of innumerable applications of synchrotron radiation, a large portion of the world namely Middle East is unfortunately poor on modern synchrotron light source facility.

Following SESAME project which was dedicated by UNESCO to the Middle East countries [1], several countries of the region such as Armenia [2] and Turkey [3] have planned to have their own synchrotron radiation facility.

The Iranian Light Source Facility (ILSF) project [4] was initiated in 2003 and formally approved by the Iranian government in 2008 [5-6].

At the end of 2009, Institute for Research in Fundamental Sciences (IPM) was selected to plan, construct, equip, and exploit the facility.

The ILSF is conceived as a national synchrotron light source to provide a powerful source of x-ray for the users and cover requirements of the experimental science in several fields.

The figure of merit of the ILSF storage ring follows modern synchrotron light sources design trend. To have a competitive leading position in the future, the ILSF is designed to emphasize small emittance electron beam (below than 0.27 nm.rad), high photon flux density, brightness, stability and reliability.

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OVERVIEW OF ILSF P.S.

This section is presented to check out the ILSF booster Table 1 and storage ring Table 2 power supply specifications.

Table 1: ILSF Booster Ring Power Supplies

Booster Ring P.S.	Dipole	Quadrupole	Sextupole
Output current	484A	202.4 A	22.82 A
Output voltage	1135.41V	401.45 V	101 V
No. of Power Supplies	1	1	1

Table 2: ILSF Storage Ring Power Supplies

Storage Ring P.S.	Dipole	Quadrupole	Sextupole(S4)
Output Current	364.3A	132.3A	125 A
Output Voltage	640V	15 V	1108.8 V
No. of Power Supplies	2	240	6

OVERVIEW OF POWER SUPPLY CONTROL SYSTEM

The P.S. control system consists of three parts:

- ✓ Internal Control Module
- ✓ Analog to Digital Converter
- ✓ Digital to Analog Converter or High Resolution PWM

Figure 1 proposes an architecture of digital current regulator intended to be used to control the power supplies of the Iranian Light Source Facility. It is based on a high-precision Digital to Analog Converter and a high performance digital control system. This control structure will be used to control the current of the most types of power supplies either in Storage or Booster Ring.

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SOFTWARE AND GATEWARE DEVELOPMENT FOR SIRIUS BPM ELECTRONICS USING A SERVICE-ORIENTED ARCHITECTURE

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Abstract

The Brazilian Synchrotron Light Laboratory (LNLS) is in the final stages of developing an open-source BPM system for Sirius, a 4th-generation synchrotron light source under construction in Brazil. The system is based on the MicroTCA.4 standard comprising AMC FPGA boards carrying FMC digitizers and a CPU module. The software is built with the HALCS framework [1] and employs a service-oriented architecture (SOA) to export a flexible interface between the gateware modules and its clients, providing a set of loosely-coupled components favoring reusability, extensibility and maintainability. In this paper, the BPM system will be discussed in detail focusing on how specific functionalities of the system are integrated and developed in the framework to provide SOA services. In particular, two domains will be covered: (i) gateware modules, such as the ADC interface, acquisition engine and digital signal processing; (ii) software services counterparts, showing how these modules can interact with each other in a uniform way, easing integration with control systems.

INTRODUCTION

Many particle accelerators and high-energy physics experiments are based on a distributed industrial control system, such as: EPICS [2], Tango [3], DOOCS [4]. In order to fulfill the requirements of such demanding installations in terms of scalability, decoupling, reliability and evolution, their foundation lies on a two or three-tier architecture, effectively decoupling the so called *Front-End Controller* (*FEC*) layer, *Client Application* layer and, in the case of a three-tier architecture, *Middle-Layer Services* layer.

Hence, to accomplish these goals, two concepts are generally employed: (i) an *entity* that abstracts a given functionality, being either an actual equipment or an abstract computing service; (ii) a *contract*, specifying how to communicate with this entity in order to explore that exported functionality.

Examples of the *entity* concept are clear by looking at the existing control system toolkits, such as: *Input-Output Controller* (IOC) for EPICS and *Device Server* for Tango and DOOCS. As for the *contract* concept, EPICS defines the *Channel Access* protocol for EPICSv3 and the *PVAccess* protocol for EPICSv4, Tango establishes the contract on top of existing Message-based middleware technologies like ZeroMQ [5] and CORBA [6], and lastly, DOOCS uses the ONC/RPC protocol [7].

As a natural advancement of the underlying modern control system architecture, many applications have been developed by following what is called *Service-Oriented Architecture* (SOA) principles [8] [9], such as: loose-coupling between parts of the system, a standard contract between the parts, reusability, service abstraction, service autonomy, among others. Examples of this can be seen in [10–15].

By using the same SOA principles over which high-level applications have been successfully employed over the years, development and integration of systems using modular platforms like MicroTCA [16], can be leveraged by the use of the same approach. Specifically, but not limited to, applications that make use of FPGA chips can benefit a lot from this approach, so that even micro-modules can be abstracted as an *entity* and controlled by a common *contract*, favoring reusability and maintainability.

In the next sections, the tools that provide this abstraction, as well as the benefits and challenges, are going to be discussed.

SOA ARCHITECTURE FOR LOW-LEVEL SYSTEMS

Traditional SOA principles are based on ideas that favor independent design and evolution of each part of a system. In many cases, however, low-level systems controlling an embedded or external hardware device lack these features, even though they tend to follow a modular design philosophy.

The reason behind this might be due to the intrinsic tightly-coupled characteristic of these systems and the difficulties in achieving the end metrics, namely: latency of operations, number of operations per second and system scalability. Taking full advantage of the SOA principles in this case is harder, but not intangible, as the key idea is to dissociate the performance-driven part of the system, in which a more tightly-coupled design might be inevitable, from the actual architecture of the system, in which the actual properties and the interrelationships between the system's entities are described. The former generally needs to use a more complex protocol and abstractions, while the latter has the freedom to use SOA principles to increase modularity, maintainability and reuse.

Topology for Low-Level Systems

In a generic way, low-level systems, particularly FPGA-based with a CPU attached to it (either via PCIe, Ethernet or an internal bus), can be described in two parts. The first one is composed by the specific hardware to perform the end application, along with its peripherals, FPGA, ADCs, DACs and others. The second part is denoted by a controlling agent (typically a software composing a *FEC*) interacting with the hardware and providing an abstraction to other systems.

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INTRODUCING FAST INTERLOCKS IN THE UNICOS-CPC FRAMEWORK

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Abstract

The CERN UNified Industrial COntrol System framework (UNICOS) with its Continuous Control Package (UNICOS-CPC) is the CERN standard solution for the design and implementation of continuous industrial process control applications. The need of adapting the framework capabilities to the different processes at CERN has brought new challenges. Reacting as fast as possible to an interlock situation to protect equipment is a new requirement which has been introduced in UNICOS-CPC.

This paper presents the challenges, design and test results of the seamless integration of fast interlocks capabilities in the current UNICOS-CPC package based on conventional PLCs (Programmable Logic Controllers), with a heightened level of flexibility and maturity. The first implementation is employing SIEMENS PLCs but the underlying technique is extensible to the other UNICOS-CPC compliant platforms.

INTRODUCTION

UNICOS is a CERN framework to develop industrial control applications and UNICOS-CPC is the framework package devoted to continuous process control. It provides developers with means to design and develop full control applications and operators with ways to interact with all items of the process. In addition UNICOS-CPC offers a suite of tools at the supervision level to diagnose the process and the control system itself. [1]

The methodology to develop process control applications proposed by UNICOS-CPC is based on the model provided by the ISA-88 standard for batch control systems. The basis of these standards embraces the methodology known as "Modular Functions", which supports multi-use instances to minimize and simplify the coding. The standard defines a hierarchy of objects that standardize the interaction between the layers, thus simplifying the overall system. These objects are classified according their functionality (i.e. Input/Output, Interface, Field and Control Objects) and are used as a common language by process engineers and control system programmers to define the functional specification of the process control.

In addition to the method, offline tools have been produced to automate the instantiation of the objects in both supervision and process control layers, and generate the Programmable Logic Controller (PLC) programs.

The UNICOS-CPC package can be deployed to different platforms. For the control layer, Siemens and Schneider PLCs are supported together with controllers compatible with Codesys development environment. At the supervision layer, the Siemens Supervisory And Data Acquisition (SCADA) WinCCOA is used and it also includes a full library for Siemens and Schneider local operator panels.

Fast Interlocks

Fast interlocks are defined as critical events in the process that require detection, evaluation and a response by the control system in a time window that cannot be achieved by a standard PLC application. They are used to set the equipment under control in a safe state in response to an abnormal situation. In addition to evaluating and responding to those events, it is necessary to provide an accurate time stamp of the event which will be used to diagnose the root cause.

TSPP

The Time Stamp Push Protocol (TSPP) is an event driven communication protocol for process control. TSPP provides both, optimized data transfer from the PLC to the SCADA and time-stamped data at source.

The protocol detects data changes, associates the time stamp and then sends it in a single telegram. The time stamp allows better diagnostic capabilities than classic polling data.

TSPP is designed to send three distinct types of time stamped data: Events (Boolean changes in the state of the UNICOS-CPC objects), Status (analogue changes of the objects) and Watchdog (connection alive message). The three types of TSPP data buffers are managed in parallel but only one send-channel is used. To manage this mechanism, a first in – first out (FIFO) queue has been designed.

Events are individually time-stamped, buffered and then sent to the SCADA, which allows a comprehensive event analysis in case of failure. However, statuses are time-stamped in blocks and sent to the data server without buffering, therefore only the most recent status values are ensured.

On Siemens PLCs the protocol is implemented using a standard S7 communication function, BSEND, which sends large amounts of data to the SCADA layer (WinCC OA).

CRITICAL EVENT DETECTION

The UNICOS-CPC standard application time granularity is the one imposed by the PLC sampling time, which depends mostly on the application size. In general, the PLC sampling time does not comply with the fast interlocks time requirements. Two implementation solutions for the detection of critical events have been evaluated.

Hardware Interrupts

The hardware catalog of Siemens provides a set of input modules with hardware interrupt capabilities, a program which is adapted to suit the event can be called in real time. If an alarm-triggering event occurs during the main PLC program processing, the operating system calls the alarm

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MARS: EASING MAINTENANCE AND INTERVENTIONS FOR CERN CONTROLS

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Abstract

Industrial control systems for the CERN technical infrastructure and accelerator complex consist of a myriad of devices and components geographically distributed around the CERN facilities. In the event of an intervention in such systems, the on-call engineer or the system expert needs detailed information about the nature of the problem, e.g. what device, what problem, intervention procedures, and contextual data like the location of the device, current access conditions to this place, the list of access rights required and whether he/she is granted with these rights. This is of special relevance when the person responsible for the intervention has only limited knowledge of the control system as it is the case for some on-call services. At CERN, this information is scattered over a number of data sources. This paper presents MARS (Maintenance and Assets for contRolS), a web-based tool designed to federate data from heterogeneous sources with the aim of providing support for interventions and maintenance activities. The information can be displayed in a single web page or be accessed through a REST API.

INTRODUCTION

The Industrial Controls and Safety systems group of the Beams Department (BE-ICS) at CERN provides turn-key solutions for controls, as well as safety and access controls systems for the experiments, accelerator complex and technical infrastructure. In the domain of industrial controls, BE-ICS develops full controls systems ranging from PLCs or front-end computers executing real time tasks, to supervisory applications using the commercial SCADA package WinCC Open Architecture (OA) [1] from Siemens/ETM. All these controls applications are made using common building blocks from the two industrial controls frameworks developed on top of WinCC OA, JCOP (Joint COntrols Project) [2] and UNICOS [3].

Although all these applications are built from standard components, they can be very different depending on the functionality required and the domain where they are deployed. This also applies to the technologies chosen from the BE-ICS catalogue to implement the applications, e.g. Siemens vs. Schneider PLCs, Modbus vs. OPC Unified Architecture, Oracle Archiving vs. file archive, etc. Typically, specialists in different technologies or layers of the control system, e.g. PLC and SCADA developers, work together in the development of these applications.

Most of these applications have a very long lifetime, typically the LHC lifetime, which given the large turnover of people at CERN, in some cases, it may represent a challenge to ensure that the detailed knowledge about the application is preserved.

BE-ICS is currently responsible for the development and maintenance of more than 200 SCADA applications running on around 100 Linux servers. These applications comprise more than 400 PLCs from both Siemens and Schneider and around 40 front-end computers. These controls devices are geographically distributed around the CERN premises.

The large number of applications, the variety of technologies used, as well their geographical distribution represent a major challenge for on-call services that have to provide coverage to all these applications and control devices. The industrial controls standby service is formed by members of BE-ICS who are specialized in a particular set of technologies and who participate in the development of a number of applications. Having the knowledge about every single application provided by BE-ICS and all technologies involved in their development would be impossible. Moreover, besides the technical knowledge, a lot of contextual information is also required in order to perform interventions in the controls applications. The following are some of the most common questions to be addressed prior to an intervention:

- What is the device affected and what problem is?
- What are the procedures to follow? Where to find them?
- Where is the device located? How can I access this location? Do I have all necessary access rights?
- What are the dependencies with other systems?
- What software runs on this device? What version of the program? Where do I get a copy from?
- What is the device made of? Where do I get spare parts from?

However, the information required to reply to these questions is scattered over multiple sources with no clear relations between them as it will be described in the next section.

ASSET INFORMATION MANAGEMENT

CERN's technical infrastructure is maintained by many specialists and experts in different domains like cooling and ventilation, electricity, cryogenics and computing infrastructure. Each expert group is responsible for the documentation, configuration and handling of their equipment. Different systems and databases are used for specific tasks, thus leading to have information about assets, their functionality and use scattered in different data sources. Each data source is used to describe a specific aspect of an asset in detail, but only the combination of all data will give a complete picture for an equipment.

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RENOVATION AND EXTENSION OF SUPERVISION SOFTWARE LEVERAGING REACTIVE STREAMS

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Abstract

Inspired by the recent developments of reactive programming and the ubiquity of the concept of streams in modern software industry, we assess the relevance of a reactive streams solution in the context of accelerator controls. The promise of reactive streams, to govern the exchange of data across asynchronous boundaries at a rate sustainable for both the sender and the receiver, is alluring to most data-centric processes of CERN's accelerators. Taking advantage of the renovation of one key software piece of our supervision layer, the Beam Interlock System GUI, we look at the architecture, design and implementation of a reactive streams based solution. Additionally, we see how this model allows us to re-use components and contributes naturally to the extension of our tool set. Lastly, we detail what hindered our progression and how our solution can be taken further.

INTRODUCTION

A common issue with software systems for which maintenance and evolution stretched over years and multiple core developers is the emergence of a cluttered architecture. It occurs even in seemingly simple cases such as supervision software, where the base use-case is the acquisition, processing and exposition of data from operational devices.

The Beam Interlock System supervision GUI is one such example and as part of its renovation, a particular attention was paid to render its architecture more robust both in the short and longer terms. Reactive streams appeared as a promising solution to this endeavor:

- They provide an adequate model to the primary supervision software need, the transformation and consolidation of acquired data, which is then delivered to tailored user interfaces
- They can allow for flexible designs, which nevertheless promote coherent maintenance actions in the longer term.
- They can be combined into re-usable blocks, which can easily be built upon, even outside of the initial supervision scope.

THE REACTIVE STREAMS PARADIGM

"Reactive Streams is an initiative to provide a standard for asynchronous stream processing with non-blocking back pressure." [1]

Asynchronous streams

The stream concept matches well our base use-case: unbounded flows of data, acquired asynchronously, which must then be processed and delivered to client layers. This abstraction is powerful, as it makes very little assumption: any kind and amount of data can be transmitted, at any rate, any process can be applied to it, it can come from any source, etc. It only matters that we can consider data as originating from a source and emitted in sequence. Streams can then be used to model everything in between the acquisition layer and the delivery and fit accordingly.

Further, streams are defined with simple yet expressive semantics. This basic language allows to accurately describe what processing is applied to the data, and how the different streams relate to one another. A very useful tool to visualize streams and their semantics is the marble diagrams [2]. Figure 1 shows an advanced example of marble diagrams, modeling the combination of two streams in order to analyze together the data from both sources, on specific events.

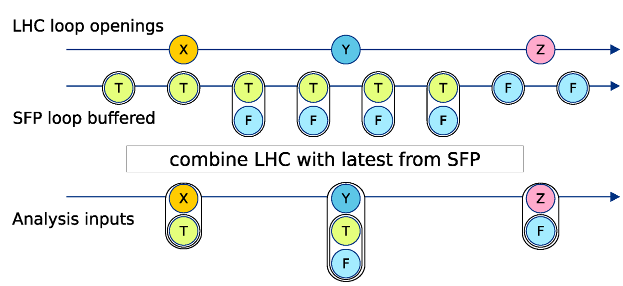

Figure 1: Complex case, modeled visually.

When implementing complex use cases, involving timing considerations or multiple streams, this kind of representation became essential. It served first as a design tool to frame the problems, then as a visual documentation.

Staying Reactive

Backpressure is what happens when the consumer of a stream is slower than the data sources. Unhandled backpressure can have various and likely harmful consequences, depending on the actual data sources and implementations involved. These range from permanent data loss, to software failure or even to frozen obstructed real-time controls devices.

Reactive streams as a concept only make the backpressure explicit to handle and do not magically solve it, but prevent ignoring. Thankfully, reactive streams libraries are provided with built-in strategies to deal with backpressure, and high-level ways to selectively apply these strategies.

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REAL-TIME JAVA TO SUPPORT THE DEVICE PROPERTY MODEL

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Abstract

Today's front-end controllers, which are widely used in CERNs controls environment, feature CPUs with high clock frequencies and extensive memory storage. Their specifications are comparable to low-end servers, or even smartphones. The Java Virtual Machine (JVM) has been running on similar configurations for years now and it seems natural to evaluate the behaviour of JVMs on this environment to characterize if Firm or Soft real-time constraints can be addressed efficiently. Using Java at this low-level offers the opportunity to refactor CERNs current implementation of the device/property model and to evolve from a monolithic architecture to a promising and scalable separation of the area of concerns, where the front-end may publish raw data that other layers would decode and re-publish. This paper presents first the evaluation of Machine Protection control system requirements in terms of real-time constraints and a comparison of the respective performance of different JVMs. In a second part, we will detail the efforts towards a first prototype of a minimal RT Java supervision layer to provide access to the hardware layer.

INTRODUCTION

The device property model has been used at CERN since the exploitation of the Proton Synchrotron (PS) in the early 1960s and the subsequent Super Proton Synchrotron (SPS). In this model, users are aware about devices. A device is uniquely named, and represents a physical device such as a Beam Interlock System, or a software service such as an abstraction layer to a group of systems. Each device belongs to a Class. The Class defines the Properties that can be used to access the device. A property can support 3 types of operations: get, set, subscribe.

A set operation allows the user to send a value to the property. The device will then handle the values in the appropriate way, typically in case of a hardware device, writing it into a register. A get operation allows the user to read a value from the property. Typically in case of a hardware device, this actions reads a value from a register. A subscribe operation allows the user to receive notifications from the property. Typically reading the value from a register following the refresh frequency of the hardware device.

The device property model is supported at CERN by the Controls Middleware (CMW [1]) for the communication. The control software for any equipment consists basically in a software server exposing the devices along with their properties using CMW.

The Machine Protection interlock systems, like the Beam Interlock System (BIS [2]), are designed in a highly dependable way: The entire critical functionality is implemented in a hardware layer, while the software layer brings only monitoring and control features. If the software is unavailable, the system safety is not compromised and it will continue to be able to perform the most critical safety functions and put the machine into a fail-safe state, if required. However, controlling and e.g. re-arming the system will not be possible anymore without a fully operational software layer, hence the availability of the accelerator could be reduced.

The software layer for the interlock system is therefore not safety critical. Simply put, it provides monitoring and control operations to:

- get all the board registers
- get the history buffer
- set a register value

The clients of this API are multifold. Operation crews and interlock experts are using Graphical User Interfaces (GUIs) to control the interlock systems, to perform operations on them and to know their state. As interlock systems are a crucial component of accelerators handling large amounts of stored energies, they are also used by automated sequences [3], and by online and offline analysis tools.

The interlock software layer also handles some repetitive procedures. They send values to users that subscribed to properties or verify some states in the hardware. In addition, the software layer reacts upon asynchronous events such as a Post Mortem [4] dump request in order to send its internal states and history buffer to the Post Mortem service for diagnostic. The handling of repetitive procedures and asynchronous events as well as synchronizing the accesses to the hardware buses are the most relevant use cases for the required real-time behavior.

The Machine Protection use cases for the interlock controls supervision software is to acquire data from the hardware registers and rolling buffers at a frequency of 1 Hz. Only a few routines are executed periodically. Measurements have shown that the longest execution time was 130 ms. This leaves a large portion of the one second period to handle asynchronous requests from users and other tasks.

The Machine Protection software layers also involve a few virtual devices backed by Java servers, in order to provide a better level of abstractions to its clients, and to perform more advanced functionalities, e.g. to decode on the fly all boolean signals published by the interlock devices.

The Front-End Controllers (FEC) on which the supervision layer is executed are becoming more powerful. The current architecture has 2 cores and 1 GB of RAM, while the minimum setup of the next generation osf FEC is 4 cores and 4 GB of RAM. These ressources are more than enough to run a Java Virtual Machine. The FEC runs Real Time Linux.

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EXPERIMENT CONTROL WITH EPICS7 AND SYMMETRIC MULTIPROCESSING ON RTEMS

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Abstract

We are in the process of setting up a high-speed scanning tunneling microscope (STM) to study the dynamics of the crystal-glass transition. While so far Experimental Physics and Industrial Control System (EPICS)v3 [1] had been sufficient for our conventional experimental STM studies, a new project to study dynamics needs considerably higher data throughput than possible using EPICSv3. For this reason, we control the high-speed-STM with the new EPICS7, using the protocol pvAccess. The development version 3.16 of EPICSv3 and bundleCPP of the EPICSv4-suite are in use. Both of them will be the base components of the new EPICS7 framework. We expect a data rate of 4 Gbit/s for up to 5 hours in order to address dynamic processes in oxide networks structures in real space over a wide range of temperatures.

SCIENTIFIC MOTIVATION

In this project we focus on crystalline and vitreous silica films and their interconversion. Silica is the prototype glass network former and the basis of many glasses. As it is one of the most abundant materials on earth, it is relevant in various branches of modern technologies. While the atomic structure of crystalline materials in general is well understood due to the application of diffraction techniques, the structure of amorphous or vitreous materials such as silica glass is still an open field in research [2]. In fact, diffraction techniques have only been able to deliver pair correlation functions, which reveal the density of a material around a given atom, but do not allow a detailed reconstruction of the atomic structure as in the case of crystalline materials. For the first time, a real space image of a silica glass with atomic resolution was recorded with scanning probe microscopy (SPM) techniques applied to a thin silica film grown atomically flat on a metal substrate [3]. This film has verified the early predictions from 1932 by Zachariasen [4]. Density Functional Theory (DFT) calculations have been performed to look into the energetical differences between crystalline and the simplest model of a vitreous film by exchanging four 6-membered rings into two 5- and two 7-membered rings. The spatial transition from the crystalline to the vitreous phase has already been studied in our group [5]. Under the impact of a probing electron beam structural changes in the the silica film have been observed during transmission electron microscope (TEM) measurements [6]. By monitoring the temperature induced phase transition in real space, we want to shed some light on the dynamics in glasses - especially on the processes occurring during the conversion via a liquid phase during the glass-crystal transition. For this purpose, an SPM is developed that allows the study of the atomic structure over a wide range of temperatures including the two extremes: cryogenic temperatures and the dewetting temperature of the silica film [7]. This instrument may also be used to address a number of other scientific problems in the field of surface science. The achievable scan rate with our SPM seems to be the most critical point in this project.

TIME RESOLUTION

Inspired by pump-probe techniques [8], time resolution ranging from nanoseconds to subpicoseconds has been achieved in STM experiments by incorporating voltage [9], laser [10] or terahertz pulses [11, 12] into the tunneling junction. Such experiments have allowed to study the dynamics of spins, charge carriers and quasiparticles upon excitation in nanostructures. However, these concepts do not allow for imaging in real space at such time scales.

In order to directly resolve dynamic processes of atom diffusion [13, 14], film growth [15, 16] and chemical reaction [17, 18], a lot of effort has been made to construct an STM that can scan following such processes at time scales ranging from a few seconds down to milliseconds [19, 20].
Here, one bottleneck for fast scanning is the bandwidth of the mechanical loop of the scanner unit. In order to minimize the noise originating from the piezo movement, it is crucial to use piezo elements with a resonance frequency higher than the waveform frequency driving the fast scan of the piezo. Another challenge is the high speed electronics for hardware controlling and data acquisition. Feedback electronics with a bandwidth of 1 MHz and preamplifier with a bandwidth of 600 kHz were developed by Frenken et al. [19], which allow frame rates up to 200 images/s with 256×32 pixels per image scanning with hybrid mode between the constant-height and constant-current modes. Our aim is to build an STM with comparable or even higher frame rates. For this purpose, we designed a hybrid scanner including a large scanner and a small scanner as the STM head (Fig. 1). Both of them are made from segmented tube piezos. The large scanner is controlled by the Nanonis SPM Control System from Specs GmbH [21] and used for large area and slow scan in constant current mode. After a good place is observed in the slow scan, we can start the fast scan in a small area by using the small scanner. The small scanner has a resonance frequency above 1 MHz and is controlled by the FHI High Speed Controller. The fast scan is performed in constant height mode and the tunneling current is measured by a preamplifier with a bandwidth up to 200 MHz from FEMTO Messtechnik GmbH [22], so that no feedback loop is needed

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PLC INTEGRATION IN EPICS ENVIRONMENT: COMPARISON BETWEEN OPC SERVER AND DIRECT DRIVER SOLUTIONS

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Abstract

In the IFMIF EVEDA project [1], INFN-LNL Laboratory has been involved in the design and construction of a normal conducting Radio Frequency Quadrupole (RFQ) used to bunch and accelerate a 125 mA steady beam to 5 MeV. The EPICS based control system [2] has been entirely developed in house using different hardware solutions: PLC for tasks where security is the most critical feature, VME system where the acquisition speed rate is crucial, common hardware when only integration is required without any particular feature in terms of security. Integration of PLCs into EPICS environment was originally accomplished through OPC DA server [3, 4] hosted in a Windows embedded industrial PC. Due to the issues analyzed in injector LCS, LNL proposed to migrate to the usage of EPICS Direct Driver solution based on s7plc [5]. The driver itself is suitable for direct communication between EPICS and PLCs, but it doesn't take care of data update and synchronization in case of communication failure. As consequence LNL team designed a dedicated method based on state machine language to manage and verify data integrity between the two environments, also in case of connection lost or failure.

INTRODUCTION

The main objective for IFMIF (International Fusion Materials Irradiation Facility) is the construction of a linear accelerator for neutron irradiation effects on materials that will be used to realize future fusion reactors.

The IFMIF facility will provide an accelerator-based neutron source that produces, using deuterium-lithium nuclear reactions, a large neutron flux with a spectrum similar to that expected at the first wall of a fusion reactor (Fig.1). The main components of the apparatus for the neutron beam production are therefore the following:

- the generation system of deuterons, consisting of two linear accelerators in parallel each producing a current of 125mA beam and made up of an ion source (INJ), a low energy beam transport (LEBT), a radio frequency quadrupole (RFQ), a medium energy beam transport (MEBT), superconducting cavities and high energy beam transport (HEBT);
- the lithium target and the associated circuit for the evacuation of the produced power;
- test cell where are arranged the samples of the materials to be tested.

Because of the complexity of the project, its implementation requires a preliminary step related to the validation of the prototypes. For this reason, IFMIF-EVEDA (Engineering Validation Engineering Design Activities) involves the construction of prototypes of each of the components mentioned above. Prototype of the accelerator facility named LIPAc (Linear IFMIF Prototype Accelerator) is currently being commissioned at QST site, Rokkasho, Japan [6]. In this scenario the Italian contribution is related to the construction of the RFQ system in charge of INFN-LNL.

During 2016 and the first half of 2017 the RFQ and its ancillaries, including Local Control System (LCS), were assembled at the Rokkasho site in Japan, currently the hole apparatus are in use for the RF conditioning [7].

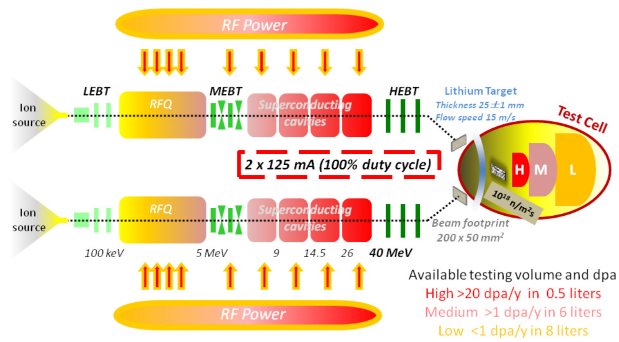

Figure 1: Schematics of IFMIF facility [1]

IFMIF EVEDA RFQ LCS

The RFQ Local Control System (LCS) architecture is designed to optimize the reliability, robustness, availability, safety and performance minimizing the costs related to its purchase and maintenance. Following this philosophy and the IFMIF-EVEDA guidelines, the control system network is composed by two different kinds of hosts:

- physical hosts for critical control system tasks;
- virtual hosts where no particular functional tasks or hardware is required.

The architecture realizes the 3-layer structure and each layer defines a proper hosts group (equipment directly connected to the apparatus, control devices, Human-Machine Interface) while the EPICS framework provides the interface between them (Fig. 2). In the final stage LCS is integrated in the LIPAc Central Control System (CCS). The upper software layer of the CCS realizes the common layer where all the different LCS will communicate and share information without any additional effort [8].

The RFQ system is a complex apparatus composed by many kinds of subsystems (radio frequency, vacuum, water cooling, etc.) developed using different hardware solutions. As a consequence, every part of this structure must be properly integrated to obtain the desired degree of control. Following these criteria, the system was designed and realized using these assumptions:

- PLC hardware is chosen in tasks where security is the most critical feature;
- VME system is used where the acquisition speed rate is crucial;

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IFMIF EVEDA RFQ LOCAL CONTROL SYSTEM INTEGRATION INTO MAIN CONTROL SYSTEM

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Abstract

The RFQ apparatus Local Control System built for IFMIF EVEDA Project[1] has been designed and realized for being both a standalone architecture and part of a more complex control system composed by different sub-systems. This approach lets RFQ's engineers and scientists have a degree of freedom during power tests in Legnaro and during the RFQ integration in IFMIF-EVEDA facility in Rokkasho. In this paper we will describe the different aspects observed when the LCS was converted from the standalone configuration to the final integrated one.

INTRODUCTION

The required acceleration in continuous wave (CW) of 125 mA of deuterons up to 5 MeV poses IFMIF RFQ at the forefront frontier of high intensity injectors[2].

This RFQ is indeed meant to be the injector of a 5 MW deuteron linac (40 MeV final energy) for fusion material irradiation tests. The International Fusion Materials Irradiation Facility project aims at producing an intense (about $10^{17}s^{-1}$) neutron source facility, with spectrum up to about 14 MeV, in order to test the materials to be employed in the future fusion reactors.

The IFMIF-EVEDA project was funded at the time of the approval of ITER construction (2007); the task is to validate the IFMIF design by the realization of a number of prototypes, including a high-intensity CW deuteron accelerator (called LIPAc, Linear IFMIF Prototype Accelerator) for a beam power exceeding 1 MW. LIPAc is being installed at the QST site in Rokkasho (Japan). Accelerating structures of the prototype linac, operating at 175 MHz, are the RFQ and the first Half Wave Resonator cryomodule. LIPAc realization is a strict collaboration between Japan and Europe.

Technically the RFQ cavity is divided into three structures, named super-modules. Each super-module is divided into 6 modules for a total of 18modules for the overall structure. Before the construction of the entire RFQ prototype, the final three modules had to be tested at high power to verify and validate the most critical RF components of RFQ cavity and, on the other hand, to test performances of the main ancillaries that will be used for the IFMIF-EVEDA project (vacuum manifold system, tuning system and control system). The choice of the last three modules is due to the fact that they will operate in the most demanding conditions in terms of power density (100 kW/m) and surface electric field(1.8*Ekp). After the power test performed at Legnaro National Laboratories [3] and using the results obtained from it, the RFQ design (including the control system) has been finalized and prepared for the final installation in Japan.

GENERAL ASSUMPTION FOR THE CONTROL SYSTEM DESIGN

The RFQ Local Control System (LCS) Architecture approved by the IFMIF-EVEDA Collaboration is designed to optimize reliability, robustness, availability, safety and performance minimizing all the costs related to it (purchase and maintenance). Following this philosophy and the IFMIF-EVEDA Guidelines, it has been realized a control system network composed by two different kinds of hosts:

- Physical machines for critical control system tasks.
- Virtual hosts in machines where no particular functional task or hardware is required.

The architecture realizes the 3-layer structure described in the Guidelines and each layer defines a proper hosts group: equipment directly connected to the apparatus, control devices, Human-Machine Interface.

The Experimental Physics and Industrial Control System (EPICS) environment [4] has been chosen as framework standard for realizing the distributed control system required in facilities such as the one in construction in IFMIF-EVEDA project: the framework will be used to monitor and supervise any equipment composed the low level layer in the control system architecture, implement the algorithmic and provide to the higher layer (client services and operator interfaces) the information required to operate with the apparatus.

Because of the different conditions required by the power test and the final installation, the RFQ control system architecture has been designed to work as standalone environment and as part of the LIPAc control system environment. In addition, because of the RFQ power test executed in Italy was also a test bench for the entire control system, different solutions and changes in the architecture have been realized based on the results obtained.

Technical Assumption during Design Stage

The RFQ system is complex apparatus composed by several subsystems (radio frequency, vacuum, water cooling, etc.) developed using different hardware solutions. As consequence, every part of this structure must be properly integrated to obtain the desired degree of control.

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FIRST STEP TO MANAGE MIGRATION TO SIEMENS S7-15XX PLCS USING TANGO FRAMEWORK

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Abstract

Over the past years, SOLEIL [1] uses SIEMENS PLC as a standard for signal monitoring and security. SOLEIL is today thinking about a major upgrade of the facilities, and has to adapt its organization to face efficient operation and R&D. In this context, automation experts are now merged in a single group. In a middle term, migration from the existing 3XX series PLCs to the new 15XX series will be necessary. As the new 15XX series PLCs do not support Fetch/Write protocol anymore, a first step is the upgrade of TANGO [2] PLCServer. This software device ensures data exchange with supervisory applications using TANGO infrastructure. It opens multiple TCP/IP connections to the PLC hardware, manages asynchronous communication to read/write PLC Data blocks (DB) and acts as a server for other clients. The upgrade of PLCServer is based on Snap7 [3] open source Ethernet communication suite for interfacing with Siemens PLCs using the *S7* native protocol. This paper details the evolutions, performances and limitations of this new version of the PLCServer.

INTRODUCTION

When it was created in 2003, the SOLEIL synchrotron chose the TANGO software bus as the only intermediate layer between the devices intended to be read or remotely controlled and the supervision applications. In TANGO, the concept of Device Server (DS) is paramount.

Within the support groups, the use of a DS PLCServer has been standardized, as well as the SIEMENS PLC models. However, the program architectures and the structure of the DBs evolved differently according to the people in charge of programming PLCs in each groups. In 2017, following SOLEIL reorganization, automation experts were grouped in the accelerator and engineering division to offer homogeneous practices and tools to all support groups for their automation-based control systems. Approximately 250 configurations are concerned for Machine Protection System, vacuum control, Personal Safety Systems, Radio frequency, beam diagnostics and magnet power supplies.

In order to push the performance limits of the current PLCServer, but also to make it compatible with the new generations of SIEMENS PLC, it was decided to publish a new version of this DS.

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CURRENT SITUATION

TANGO Device Server Concept

The TANGO system works around the concept of "Device Server ". A device server is a program that deals specifically with permanent dialogue ("server") with the apparatus ("device"). The PLCServer is a DS (written in C++) based on a PLC device.

Use of Client/Server Model

The PLCServer is the core of the data exchange mechanism between the SIEMENS 3XX series PLCs and the TANGO software bus. This DS is responsible for performing readings and writes from/to PLC data blocks via a dedicated protocol over TCP/IP and for distributing this data to its clients (see Fig 1).

Clients are higher-level DS. They represent physical equipment such as valves, pumps, gauges, etc. They communicate with the PLCServer via TANGO's internal protocol.

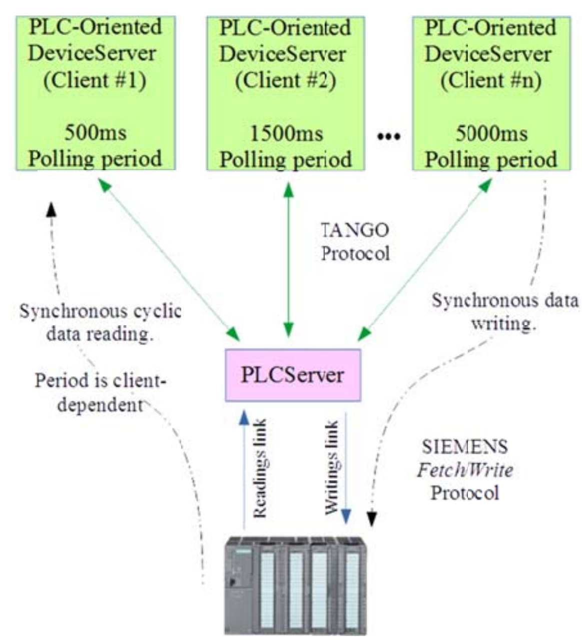

Figure 1: Communication model between Tango devices and PLC using PLCServer.

After registering with a PLCServer, clients cyclically address the PLCServer via a polling mechanism to retrieve a data area present in a DB of the target PLC.

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WHAT IS SPECIAL ABOUT PLC SOFTWARE MODEL CHECKING?

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Abstract

Model checking is a formal verification technique to check given properties of models, designs or programs with mathematical precision. Due to its high knowledge and resource demand, the use of model checking is restricted mainly to core parts of highly critical systems. However, we and many other authors have argued that automated model checking of PLC programs is feasible and beneficial in practice. In this paper we aim to explain why model checking is applicable to PLC programs even though its use for software in general is too difficult. We present an overview of the particularities of PLC programs which influence the feasibility and complexity of their model checking. Furthermore, we list the main challenges in this domain and the solutions proposed in previous works.

INTRODUCTION AND MOTIVATION

The promise of model checking is to provide precise, mathematically sound means to check the satisfaction of given requirements on models, representing for example software. Although some tools are available (e.g. CBMC[1] [1], BLAST[2], Bandera[3] [2], DIVINE[4] [3]), it is still difficult to use model checking on real-sized software in practice. One of the bottlenecks is the verification performance, the excessive need of resources for the successful verification.

Besides checking software written in general-purpose programming languages (e.g. C, C++, Java), active research can be observed focusing on PLC (Programmable Logic Controller) programs specifically. It has been studied by dozens of research groups over the last 20 years [4]. However, model checking is still far away from being easy-to-use or part of the state of the practice of PLC program development.

The reader may ask the question: what is the reason for targeting PLC model checking specifically? What makes this domain special and why there is a need for specific tools? What makes PLC model checking different from verifying general-purpose programs? This paper is dedicated to the specificities of PLC programs, which facilitate their verification, or contrarily, make the model checking more difficult. Our aim is to summarise our experience with PLC software model checking that we have acquired during the development of PLCverif [5], and to help formal verification researchers to specialise in this field, or to make their model checker tools applicable to the PLC program verification domain too.

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[1] http://www.cprover.org/cbmc/
[2] http://cseweb.ucsd.edu/~rjhala/blast.html
[3] http://bandera.projects.cs.ksu.edu/
[4] http://divine.fi.muni.cz/

The paper first overviews the difficulties and advantages arising from the domain specificities. Then the syntactic and semantic particularities of PLC programs are discussed. Finally, the need for environment modelling is mentioned.

An extended version [6] of this paper is also available which contains more details and example programs.

DOMAIN SPECIFICITIES

Many of the differences between the general-purpose and PLC programming languages, but also between the available verification methods originate from the differences in the respective domains. Therefore, we start by overviewing the most important properties and specificities of the PLC domain which influence the formal verification of PLC programs.

Medium Criticality

Except for trivial programs, it is difficult to imagine and prove absolute correctness or safety, just as absolute security. Instead of pursuing those ideals, a more pragmatic approach is needed: the verification costs and the risks of failure should be in balance. Formal verification is already often used where the cost of failure is exceptionally high: in case of highly critical systems (e.g. nuclear, railway or avionics systems) or systems produced in high quantities (e.g. microprocessors). Even the methods requiring special knowledge and lots of resources may be affordable in those cases. Contrarily, in case of systems with low criticality, deep analysis may not be required.

PLC systems are in the middle of this criticality scale: their criticality is often not high enough to afford an independent, specially skilled verification team. However, a potential failure or outage may cause significant economic losses, motivating a sound and detailed verification approach.

Consequence PLC model checking approaches should be easily accessible, specifically targeting the PLC domain, without requiring unaffordable resources or having an excessive cost compared to the level of criticality.

Advantage: Simple Operations and Data Structure

In general, the functionality of PLC programs is simpler than most programs written in C or Java. PLC programs do not deal with graphical interfaces, large data structures; they do not create files, do not perform complex operations. All these features may complicate the software model checking.

Consequence The simplicity of the programs makes model checking more feasible computationally. This makes the PLC domain a good target for formal verification.

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EXPERIENCE WITH STATIC PLC CODE ANALYSIS AT CERN

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Abstract

The large number of industrial control systems based on PLCs (Programmable Logic Controllers) available at CERN implies a huge number of programs and lines of code. The software quality assurance becomes a key point to ensure the reliability of the control systems. Static code analysis is a relatively easy-to-use, simple way to find potential faults or error-prone parts in the source code. While static code analysis is widely used for general purpose programming languages (e.g. Java, C), this is not the case for PLC program languages. We have analysed the possibilities and the gains to be expected from applying static analysis to the PLC code used at CERN, based on the UNICOS framework. This paper reports on our experience with the method and the available tools and sketches an outline for future work to make this analysis method practically applicable.

INTRODUCTION

Programmable Logic Controllers (PLCs) are the most popular control devices for industrial control systems due mainly to their robustness and the simplicity of building control systems with them. In terms of software, one of the main obstacles that automation engineers have to face in order to improve the quality of PLC programs is the lack of proper testing or verification tools. This problem does not exist in other programming languages, which have a significant number of tools to apply unit testing, static analysis and even software model checking. However in the industrial domain, the use of these techniques with PLCs is still far from being a common practice

At CERN, PLC programs are developed using the UNICOS framework [1]. These programs are tested during the development phase and the commissioning on the real installation. In addition to the traditional testing methods, a methodology to apply model checking to PLC programs was designed at CERN. A tool was created based on this methodology: the PLCverif tool [2]. This technique is not extensively used at CERN yet but it has been successfully applied to several PLC programs at CERN [3], [4] and [5]. The goal of these techniques is to minimize the number of bugs in the control logic of the PLC programs and the discrepancies between the code and the specifications. Static analysis of PLC programs is certainly a good complement to these techniques and it has never been applied before to CERN UNICOS PLC programs.

Static Analysis

The basic idea of static code analysis is to examine a program without actually executing it [6]. It is performed by automated tools and is similar to code review or program comprehension. The main benefit of this method is the early detection of potential bugs in the development process. Another benefit is the future maintenance of the code as it can impose the code guidelines of the organization. While it can often be difficult to analyze whole programs due to the size of software projects, static analysis tools can be used to examine the on-going projects for violations as they are being created [7].

Some of the problems that static analysis can detect are: naming conventions violations, bad code smells (e.g. dead or duplicated code), overcomplicated expressions, multitasking problems, etc. There are several methods for static analysis depending on the kind of violations they are meant to detect. Some of the most popular ones are rule-based AST (Abstract Syntax Tree) analysis, control-flow analysis and Data-flow analysis.

The availability and use of static analysis tools for PLC programs is still limited, however researchers and companies are advancing on this field to bring static analysis techniques to the PLC domain [8].

Motivation

Our goal is to explore the potential of static analysis for the UNICOS PLC programs and complement our testing and verification techniques in order to improve the quality of our programs. This paper presents an analysis of the characteristics of these programs and a basic review of some relevant static analysis tools for PLC programs.

The existing CERN methodology to perform model checking of PLC programs has the necessary modularity and flexibility to be extended in order to apply static analysis. Reusing some of the modules would allow us to integrate rule-based AST analysis techniques with a relatively small effort. This paper also presents a first attempt to develop basic static analysis rules in the PLCverif environment.

UNICOS PLC PROGRAMS

This section describes the characteristics of the UNICOS PLC programs in order to identify the potential violations that static analysis can detect in the source code. The UNICOS framework [1] is based on a well-defined set of standard device types or objects, which represent physical control equipment (i.e. sensors and actuators) and functional units of the whole process (e.g. refrigerator unit in a cryogenics plant) as stated in the ISA-88 standard. UNICOS control systems are built by connecting the instances of these objects and adding the specific control logic to maintain the process at the desired setpoints.

Automation engineers can develop UNICOS control systems using Siemens or Schneider PLCs. UNICOS supports several IEC 61131-3 languages but SCL from Siemens and ST from Schneider are the most common ones. In addition,

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APPLYING MODEL CHECKING TO CRITICAL PLC APPLICATIONS: AN ITER CASE STUDY

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Abstract

The development of critical systems requires the application of verification techniques in order to guarantee that the requirements are met in the system. Standards like IEC 61508 provide guidelines and recommend the use of formal methods for that purpose. The ITER Interlock Control System has been designed to protect the tokamak and its auxiliary systems from failures of the components or incorrect machine operation. ITER has developed a method to assure that some critical operator commands have been correctly received and executed in the PLC (Programmable Logic Controller). The implementation of the method in a PLC program is a critical part of the interlock system. A methodology designed at CERN has been applied to verify this PLC program. The methodology is the result of 5 years of research in the applicability of model checking to PLC programs. A proof-of-concept tool called PLCverif implements this methodology. This paper presents the challenges and results of the ongoing collaboration between CERN and ITER on formal verification of critical PLC programs.

INTRODUCTION

ITER aims to be the first fusion device that produces net energy. To achieve this goal, thousands of engineers work on building the world's largest tokamak to prove the feasibility and pave the path to commercial production of fusion-based electricity. This unique installation has many associated safety risks and the Interlock Control System is in charge of the supervision and control of all the ITER components involved in the instrumented protection of the tokamak and its auxiliary systems. This system implements the interlock functions to protect ITER from incorrect operation and other hazards. The architecture of the Interlock Control System is based on Programmable Logic Controllers (PLCs) on the control layer and WinCC OA SCADA (Supervisory Control and Data Acquisition) on the supervision layer..

Under certain exceptional situations, like commissioning or maintenance, the interlock functions have to be disabled or some interlock signals shall be masked or forced in the interlock control system. This has to be performed remotely, via the SCADA system. The SCADA system also ensures that the operator will always be aware of the presence of any active masked interlock function. The ITER developers have designed and implemented the HIOC (High Integrity Operator Commands) protocol to ensure that these critical commands sent from SCADA are properly received by the PLCs.

The PLC code that implements the HIOC mechanism is a critical part of the system. For this reason, in addition to the traditional testing techniques, model checking has been applied to verify the behaviour of the program according to the given specifications. Model checking is a formal verification method that takes the model of a system and a formalised requirement, and checks whether the requirement is satisfied by the modelled system with mathematical precision.

Motivation

The ultimate goal of the presented work is to verify the PLC program implementing the HIOC protocol, to prove that it satisfies its specification. The verification project is still in progress, however, we can already report on our experience about how formal verification can reveal implementation faults, flaws in the protocol, or to help understanding the precise requirements.

The goal of this CERN-ITER collaboration is to apply the novel verification technologies developed at CERN to improve the reliability of the HIOC protocol's PLC implementation to be used by ITER.

Related Work

The IEC 61508 standard on functional safety provides guidance for developing an application and communication between the components. The protocols available in WinCC OA for communication with the PLCs do not provide the required level of integrity. The standards, such as IEC 61784, discuss the use of "black channels" for critical applications, i.e. providing a safe communication channel by adding various countermeasures without depending on the reliability of the underlying (non-safe) channel. The HIOC protocol follows this philosophy.

Formal verification of PLC programs is not part of the industrial state-of-the-practice yet. However, more and more projects aim to support and improve the development of industrial control software by complementing the traditional methods with formal verification [1,2]. CERN is committed to push the affordable formal verification of PLC programs forward, which lead already to successful verification case

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MONITORING OF CERN'S DATA INTERCHANGE PROTOCOL (DIP) SYSTEM

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Abstract

CERN's Data Interchange Protocol (DIP) [1] is a publish-subscribe middleware infrastructure developed at CERN to allow lightweight communications between distinct industrial control systems (such as detector control systems or gas control systems).

DIP is a rudimentary data exchange protocol with a very flat and short learning curve and a stable specification. It also lacks support for access control, smoothing or data archiving.

This paper presents a mechanism which has been implemented to keep track of every single publisher or subscriber node active in the DIP infrastructure, along with the DIP name servers supporting it. Since DIP supports more than 55,000 publications, regrouping hundreds of industrial control processes, keeping track of the system activity requires advanced visualization mechanisms (e.g. connectivity maps, live historical charts) and a scalable web-based interface to render this information is essential.

DATA INTERCHANGE PROTOCOL (DIP)

DIP [1] is a communication system which allows relatively small amounts of soft real-time data to be exchanged between very loosely coupled heterogeneous systems. These systems do not need very low latency. The data is assumed to be mostly summarised data rather than low-level parameters from the individual systems, i.e. cooling plant status rather than the opening level of a particular valve.

DIP publications contain :

- a key-value map supporting standard basic data types (such as string, integer *etc.*.) or their array-based variants (string array, integer array *etc.*.),
- a publication timestamp indicating when the publication data was issued,
- a quality flag indicating over two logical bits the confidence the data publisher places in the issued publication update
- an optional quality string, giving further details about the reason for a lack of confidence in the issued publication update (*e.g.* sensor out of range).

DIP is a peer-based data exchange protocol : peers (publisher and subscriber) locate each other via a naming directory (hereby referred to as a DIP Name Server, or DIPNS), then establish a direct TCP communication based on the DIM protocol [2].

DIP publisher and subscriber processes locate each other on the network via a so-called DIP Name Server (DIPNS), which acts as a directory and prevents publication naming collisions. Among many usages, DIP is employed for essential, non-critical communication such as the Large Hadron Collider (LHC) Handshake sequence that allows the LHC machine and LHC experiments (via the JCOP framework) to initiate data acquisition sequences.

This paper presents the last two web-based DIP services recently introduced at CERN: the DIP Contract Monitoring System and the DIP Web Tools.

DIP CONTRACT MONITORING SYSTEM

DIP is an open and permissive data exchange protocol: it does not provide any access control on data, allows data to be pushed at any supported rate without support for smoothing or filtering, and does not provide any history of its participants' activity. Such a permissive approach to data exchanges requires however a good understanding of the current state of the entire system: DIP data providers must be able to know which other computers and processes are currently consuming their data; DIP data consumers must be able to understand simply why the data they are relying on might be missing from the infrastructure, and for how long it has gone missing; all DIP users must be able to see the level of availability of the DIP name servers.

The DIP Contract Monitoring (DIPCM) is an application that fulfils two main objectives:

- to provide a widely accessible interface to DIP publications,
- and to help specify and enforce quality constraints on DIP publications for monitoring purposes.

Quality constraints placed on DIP publications are gathered into a **DIP contract.**

In order to implement these objectives, it was decided to adopt the CERN Monitoring Data Entry System for Technical Infrastructure (MoDESTI) [3] as the system to gather the quality constraint specifications from end-users, and run said specifications through an approval and signature workflow, thereby ensuring that all involved parties are in agreement over the contract.

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A MODEL-DRIVEN GENERATOR TO AUTOMATE THE CREATION OF HMIS FOR THE CERN GAS CONTROL SYSTEMS

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Abstract

A total of 33 gas control applications are currently in production in the LHC Experiments and the CERN accelerator complex. Each application contains around fifty synoptic views and hundreds of plots. In this paper, the entirely model-driven approach followed to generate all these HMIs is presented. The procedure implemented simplifies the creation of these graphical interfaces; allowing the propagation of changes to all visualizations at once in a coherent manner, thus reducing the long-term maintenance effort. The generation tool enables the creation of files of similar content based on templates, specific logic (rules) and variables written in simple user-defined XML files. This paper also presents the software design and the major evolution challenges currently faced, how the functions performed by the tool, as well as the technologies used in its implementation, have evolved while ensuring compatibility with the existing models.

INTRODUCTION

The gas systems are essential for the LHC Experiments and accelerator complex, as they have to provide their corresponding chambers with the appropriate proportion and correct gas mixture, hence a software control layer is mandatory for their monitoring and control. Since 2005 the requests for new gas systems and upgrades of existing ones are increasing.

Thanks to the model driven approach [1] and common standards adopted in 2005, the development, support and maintenance of the software control layers can be achieved with minimal manpower and costs.

These gas control systems are independent application instances, which consist of a supervision layer based on a SCADA System (SIEMENS WinCC Open Architecture (OA) [2]), a process control layer (based on Schneider and SIEMENS PLCs) and standard middleware protocols. Although both layers are built following the same approach, only the supervision layer is addressed in this paper. The supervision layer provides the gas expert central team and Experiment end-users with a homogeneous look & feel and standard control for the monitoring and operation of their gas systems. Each of these supervision instances are based on the UNICOS [3] and JCOP [4] frameworks and are composed of several user interfaces, means for navigation between views and trending plots, which are all generated automatically.

The next sections describe the methodology behind the adopted model driven approach, the limitations that the current generation tool reached with time and the challenges of the design of a new tool to achieve the same functionalities and beyond.

HOW THE MODEL DRIVEN APPROACH WORKS

All layers of the gas control systems were designed with a modelling approach and use standard and homogenous building blocks. The architecture of the LHC's gas systems is modular. Every element that can be inserted into the gas control system is previously modelled. Models, templates and generation tools are created to build the systems.

A gas control system is hierarchically organized, as shown in Figure 1. A plant is always made of gas systems (i.e. sub-detector of an Experiment) which are in turn made of gas modules like Mixers, Pumps, Purifiers, etc. .

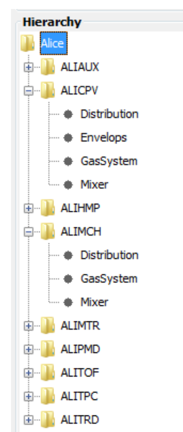

Figure 1 ALICE gas systems hierarchy.

A gas module is composed, in turn, of graphical objects or devices, which may or may not be present in the gas system. All gas control applications are organized following this model. The specificity (such as the required gas modules, and the optional elements) of each gas control system is then captured in so-called variable files, as shown in Figures 2 and 3, and described in the next section.

The gas systems are described with system templates. These templates specify the architecture of the plants, the modules used, the building blocks used and their configuration. The templates can refer to variables and use their values to configure the resulting generated gas system, as will be described in the next sections.

Specifying the Diversity, the Variables

This paragraph will introduce the concept of variables, and how these variables can define the architecture of the systems and the modules used.

All gas systems (sub-detectors) have a variable file, which specifies all the modules a plant is composed of. The

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AUTOMATED SOFTWARE TESTING FOR CONTROL AND MONITORING A RADIO TELESCOPE

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Abstract

The 64-dish MeerKAT radio telescope, under construction in South Africa, will become the largest and most sensitive radio telescope in the Southern Hemisphere until integrated with the Square Kilometre Array (SKA). Software testing is an integral part of software development that is aimed at evaluating software quality; verifying and validating that the given requirements are met. This poster will present the approach, techniques and tools used to automate the testing of the software that controls and monitors the telescope. Jenkins continuous integration system is the server used to run the automated tests together with Git and Docker as the supporting tools to the process. In addition to the aforementioned tools we also use an Automated Qualification Framework (AQF) which is an in-house developed software that automates as much as possible of the functional testing of the Control and Monitoring (CAM) software. The AQF is invoked from Jenkins by launching a fully simulated CAM system and executing the Integrated CAM Tests against this simulated system as CAM Regression Testing. The advantages and limitations of the automated testing will be elaborated in the paper in detail.

INTRODUCTION

Nowadays any software functionality is required to be delivered faster and with minimum cost while maintaining the quality expected. This applies to any software and also to process automation applications. These critical applications need to be extensively tested to validate the requirements and ensure a smooth operation of the targetted instrument. It is generally accepted to divide tests according to their level of specificity into: unit testing, where a specific section of code is tested separately, and integration testing, where all individual units are put together to be checked globally. The paper describes the software environment where testing procedures, techniques and the test methods employed focusing basically in automated tests mechanisms as they are applied within the CAM team. Among the tools and techniques used in CAM for automated testing include Jenkins, Github, slack, vitech core, *Automated Qualification Testing Framework and Docker. Finally the paper summarises the results and analysis of the positives and drawbacks of applying these automated testing techniques as compared to manual testing.

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CAM DEVELOPMENT PLAN

MeerKAT CAM software is developed through agile iterative implementation cycles with simple basic solutions being put in place first, which are then enhanced during subsequent development cycles, with close input from the system engineers and commissioners as the understanding of requirements matures [1]. This is managed through the MeerKAT CAM project plan.

Various integration levels will allow verification against a sequence of progressively more complete system element configurations, including Unit testing, Component testing, Integrated CAM testing, CAM Qualification Testing, Lab Integration Testing and CAM Acceptance Testing.

The CAM qualification stage for each cycle/timescale will include unit testing, Component testing, a continuous build server for Regression testing, Integrated CAM Testing against CAM verification requirements producing an automated Qualification Test Plan (QTP) and Qualification Test Report (QTR).

Qualification testing is performed to functionally prove the CAM design and implementation against the CAM requirements. Qualification testing of CAM software is performed on representative CAM hardware in the lab in Cape Town with all external subsystem/devices simulated. To ensure timely integration, the suppliers of subsystems that the CAM interfaces to provide Karoo Array Telescope Communication Protocol (KATCP) [2] simulators that represent their subsystem's external CAM interface. In cases where the suppliers do not provide a KATCP simulator for the subsystem, the CAM team will develop such a subsystem simulator. The CAM application software is released for deployment to site after successful CAM qualification testing.

Acceptance testing is performed to accept the deployed CAM subsystem on site. It will reuse a predefined set of the CAM qualification tests that are non-intrusive and benign and can therefore be executed on the real hardware and on site. Figure 1 show the integrations, qualification and acceptance testing in the cycle forms.

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CONTROL SYSTEM INTEGRATION OF A MicroTCA.4 BASED DIGITAL LLRF USING THE CHIMERATK OPC UA ADAPTER

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Abstract

The superconducting linear electron accelerator ELBE at Helmholtz-Zentrum Dresden-Rossendorf is a versatile light source. It operates in continuous wave (CW) mode to provide a high average beam current. In order to meet the requirements for future high resolution experiments the analogue low level radio frequency control (LLRF) is currently replaced by a digital MicroTCA.4 [1] LLRF system based on a development at DESY, Hamburg.

Operation and parametrization is realized by a server application implemented by DESY using the ChimeraTK software framework. To interface the WinCC 7.3 based ELBE control system an OPC UA adapter for ChimeraTK has been developed in cooperation of DESY, Technische Universität Dresden (TUD) and HZDR. The contribution gives an overview of the collaborating parties, the variable mapping scheme used to represent LLRF data in the OPC UA server address space and integration experiences with different industrial OPC UA Clients like WinCC 7.3 and LabVIEW.

INTRODUCTION

The ELBE accelerator has been operated with an analogue LLRF system since more than 15 years. To meet increasing demands on beam quality (jitter and energy stability) it has been decided to migrate to a digital FPGA based LLRF system developed by DESY for the European XFEL. Thus allowing for the implementation of advanced control methods and beam based feedback loops.

The adaption of the MicroTCA.4 LLRF system required:

- hard- and software revision the for CW operation
- interfacing the ELBE control system

The latter topic is in the main scope of this paper.

SYSTEM DESCRIPTON

Digital LLRF

The MicroTCA.4 based LLRF is a multi-layer system: the FPGA-Firmware is parametrized, diagnosed and operated by a server application running on a controller board inside the MicroTCA.4 chassis. This controller is a full featured single board computer running Ubuntu server 16.04.3 LTS. It is connected via PCI express bus (PCIe) to all LLRF FPGA cards (Fig 1).

A single LLRF server application provides access to about 500 process variables (PV) over Ethernet. The variables are mainly scalars and 16384 element arrays of 32 bit integer and double data types. Dependent on the accelerator operation mode they are updated at a rate of around 10 Hz.

ELBE accelerator

The ELBE LLRF controls phase and amplitude for seven cavities in total. Two of them are normal conducting buncher cavities the other are super conducting TESLA-type cavities.

At ELBE industrial control hard- and software is used, namely Siemens S7-300/400 programmable automation controllers (PLCs) on the field level and WinCC 7.3 SCADA on the human-machine interface (HMI) level. WinCC is not especially suitable to process and display large data arrays with decent update rates. For such tasks usually LabVIEW is used at ELBE.

In summary integrating the digital LLRF into the ELBE control system requires suppling data to 3 types of clients (see Fig. 1):

- an expert GUI for system commissioning, configuration and diagnosis;
- WinCC 7.3 HMI for general operation;
- ELBE S7 PLCs for exchanging status and control data.

INTEGRATION SCHEME

The LLRF server application is developed at DESY, Hamburg using ChimeraTK [2]. A major feature of this tool kit is the abstraction of device server development from middle layer control system communication by defining an adapter mechanism [3]. A device server for a specific control system is generated by compiling it with the respective control system adapter.

A middle layer (Ethernet) protocol had to be selected, that is supported by all commercial products used at the ELBE accelerator (Siemens PLCs, WinCC SCADA, LabVIEW). At the same time an open source stack of the protocol had to be available to be license compatible with ChimeraTK. OPC UA as an open, cross-platform communication standard has been identified as the most appropriate interface solution. The chair of distributed control engineering of Technical University Dresden supported the LLRF integration by development of an according adapter using the open source OPC UA stack Open62541 [4].

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EPICS DATA STREAMING AND HDF FILE WRITING FOR ESS BENCHMARKED USING THE VIRTUAL AMOR INSTRUMENT *

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Abstract

As a contribution to the European Spallation Source as part of BrightnESS, the Paul Scherrer Institut is involved in the streaming of EPICS data and the writing of NeXus compliant HDF5 files. We combine this development with the transition of the AMOR instrument at the Paul Scherrer Institut to EPICS and a streaming based data architecture. To guide our development before ESS has operational equipment, we use a detailed simulation of the instrument AMOR at SINQ to test and integrate our data streaming components. We convert EPICS data sources to Google FlatBuffers as our message format and distribute them using Apache Kafka. On the file writing side, we combine the messages from EPICS data sources as well as from neutron events to write HDF5 files at rates up to 4.8 GiB/s using Parallel HDF. This platform will also be used for testing the experiment control software on top of EPICS.

INTRODUCTION

The European Spallation Source (ESS) [1] will offer higher brightness and higher data rates than previous neutron sources. This demands a capable infrastructure to handle the produced data. As part of the BrightnESS [2] project, the Paul Scherrer Institut (PSI) [3] contributes to the development of the data streaming layer and to the writing of NeXus-compliant [4] HDF [5] files.

Instruments at ESS use among others the Experimental Physics and Industrial Control System (EPICS) [6] for control, to expose status information and to publish measured values. We incorporate EPICS data sources into the data streaming layer by converting EPICS data to a common serialization format and streaming them to a unified messaging layer.

Experimental data is also made available to the users in the form of NeXus-compliant HDF files. We present the ongoing development of the HDF File Writer which reads the selected data streams from the common messaging layer and creates the HDF file as configured by the user. The architecture is modular and extensible. General purpose writer modules are available which can handle the common types of data streams, while specialized writer modules can be easily added. This allows handling of new types of data streams or exploiting possible invariants of a data stream for more aggressive optimizations.

During development, we also use a simulation of the AMOR [7–9] instrument at PSI which contains a range of virtual devices modelled after the real instrument, and in addition some extensions specific to ESS.

In this conference note, we present the current status of the streaming of EPICS data to the messaging layer and the writing of HDF files.

STREAMING EPICS DATA SOURCES

Data Sources

EPICS is used at many scientific facilities around the world as a control system, including at particle accelerators and telescopes. At ESS, data coming from EPICS sources typically includes the sample environment, choppers and motion control.

Motion control and choppers contribute to the overall data acquisition with a rather low data rate, even though at ESS, the chopper top-dead-centre (TDC) events will be recorded and made available via the EPICS interface. Even though TDC events contribute a slightly higher rate, the events will be gathered in batches already at the EPICS interface so that the EPICS update rate is much lower than the actual TDC event rate. Furthermore, the EPICS update rate can be kept independent of the TDC event rate.

The sample environment provides information such as temperature, positioning and electromagnetic fields. While data rates from temperature sensors are very low, fast changing electromagnetic fields can produce a moderate data rate. Similar to the chopper TDC events, measured field values can be batched at the EPICS interface.

Messaging Layer

All generated data at ESS is represented uniformly as messages which get pushed into a queue of the intermediate messaging layer. The usage of a separate messaging layer improves decoupling between the individual components of the system by enforcing well defined common interfaces. It simplifies the overall design because components do not need separate interfaces to each other (n:m), but only to the common messaging layer (n:1). This allows for easier addition and replacement of individual components of the ESS data streaming architecture in the future. This also facilitates the scaling of the data distribution layer.

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BUILDING S.C.A.D.A. SYSTEMS IN SCIENTIFIC INSTALLATIONS WITH SARDANA AND TAURUS*

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Abstract

Sardana and Taurus form a Python software suite for Supervision, Control and Data Acquisition (SCADA) conceived for scientific installations. Sardana and Taurus are open source and deliver a substantial reduction in both time and cost associated to the design, development and support of control and data acquisition systems. The project was initially developed at ALBA and later evolved to an international collaboration driven by a community of users and developers from ALBA, DESY, MAXIV and SOLARIS as well as other institutes and private companies. The advantages of Sardana for its adoption by other institutes are: free and open source code, comprehensive workflow for enhancement proposals, a powerful environment for building and executing macros, optimized access to the hardware and a generic Graphical User Interface (Taurus) that can be customized for every application. Sardana and Taurus are currently based on the TANGO Control System framework but also capable to inter-operate to some extend with other control systems like EPICS. The software suite scales from small laboratories to large scientific institutions, allowing users to use only some parts or employ it as a whole.

INTRODUCTION

ALBA is a third generation synchrotron located near Barcelona in Spain. The Beamlines started the operation in 2012. The ALBA installation relies on Ethernet as the standard fieldbus. This makes the installation homogeneous, easy to maintain and guarantees a good longevity of the components. About 1200 Ethernet connections, 5000 identified instruments, and 10000 variables stored in the permanent database form the infrastructure of the control system of the particle accelerator. Each Beamline comprises about 40 Ethernet connections, 200 instruments and 300 process variables stored in the permanent database. In addition, Beamlines have dedicated detectors, producing a throughput of 300 MB/s increasing every year with newer technologies [1]. Beamlines of the same institute or across different installations share the basic requirements, although depending on their particular purpose they may have specific requirements; detectors, sample environments, synchronization, etc.

One of the first decisions on the control system design was TANGO[2] [3] as a framework. TANGO was chosen among the three options considered. The other two were EPICS [4], and a commercial SCADA. At that time, the commercial SCADAs were not adapted to the requirements, and although they presented some interesting features off-the-shelf, like the archiving, trending or the alarm handling, many applications needed to be developed "ad-hoc" and a significant effort was required to integrate motion, synchronization, the sequencer, and the scientific data formats. In other words, they were not a solution *per se*, but to be combined with EPICS, TANGO or other toolkits. This is the usual case, found for example at CERN, where PVSS (nowadays integrated in WinCC) is combined with other frameworks such as JCOP and UNICOS [5].

In several installations, like synchrotrons, we find a large control system for the particle accelerators with different subsystems such as vacuum, radio frequency, power supplies, diagnostics, motion, timing and protection systems. Besides, many "smaller" control systems, one per experimental station, coexist, interact and in some aspects share information and resources with the central system. They usually have significantly different requirements. We needed a flexible graphical interface, allowing multiple clients, with a number of specific capabilities such as the control of diffractometers, and above all a powerful sequencer. Many of these characteristics are found in SPEC [6]. SPEC is a complete and powerful software tool, which for many years has been and still is, the *"de-facto"* standard control system for X-ray and neutron experimental stations. Still, SPEC has few limitations, when aiming for multiple graphical interfaces and in general managing multi-clients or using operating systems other than Unix. Therefore at that point ALBA decided to start a development of a SCADA for scientific institutions: It was named Sardana [7] [8].

Sardana was early presented to the TANGO community, where in particular DESY and the ESRF showed interest and contributions. Later it became a

* On behalf of the Sardana community.

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USAGE AND DEVELOPMENT OF WEB SERVICES AT MAX IV

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Abstract

The web continues to grow as an application platform, with accessibility and platform independence as major benefits. It also makes it possible to tie services together in new ways through simple APIs.

At MAX IV we are using web services for various purposes related to the control system. For example, monitoring servers and services, accessing alarm history, viewing control system status, managing system and users logs and running recurring jobs. Furthermore, all user management is also accessed via web applications, and even data analysis and experiment control can now be performed via web based interfaces.

We make an effort to use existing tools whenever possible (e.g. Kibana, Prometheus), and otherwise develop systems in-house, based on current well established libraries and standards, such as JavaScript, Python, Apache, etc.

This paper presents an overview of our activities in the field and describes different architectural decisions taken.

MONITORING AND STATUS

In a large and complex control system environment it is often very useful to collect information about many different elements into a single place, to quickly look at some specific aspect of them. We have investigated and implemented several ways of accomplishing this for various purposes, and this section presents the resulting applications.

State Grid

In a TANGO [1] control system, the State attribute of any device gives a high level summary of its current mode of operation and health. For example, if a device can be either "on" or "off", this is reflected by TANGO states ON/OFF, and if something is preventing it from normal operation, it should enter the FAULT state.

To make better use of this information, we have developed an application called the "state grid", see Fig. 1. It's a hierarchical 2D grid of devices, where each grid cell represents either the state of a single device, or the "worst" state of another state grid. This way, we can show a top level grid that represents the collective states of an entire system, for example a storage ring. Bad states will "bubble" up from the lower levels. The user can drill down to get further detail by clicking grid cells, in order to identify any problematic device(s). It's also possible to open control panels for individual devices from the grid, in order to further diagnose problems or directly interact with devices. The main usage of this application is to get a "bird's eye" view of the current operation and health of the entire control system.

The state grid is mainly implemented as a HTML5 application using JavaScript. It is backed by a specifically developed TANGO device that collects the current state from a configured set of devices via event subscriptions and makes this information available as an attribute.

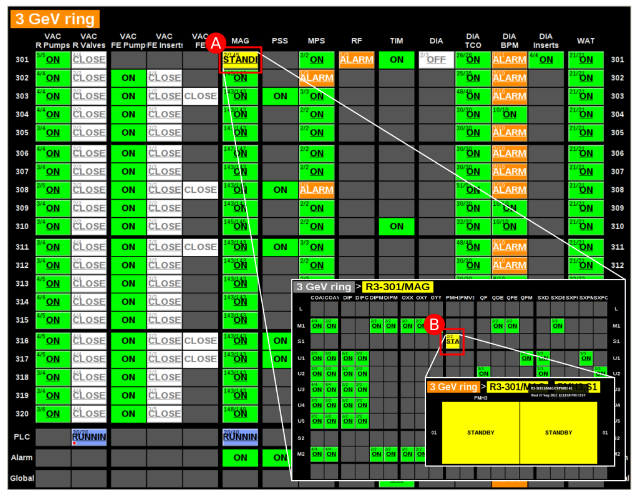

Figure 1: State grid for the large storage ring at MAX IV, showing different subsystems (columns) in each achromat (rows). Clicking the cell marked as "A" changes the grid to displaying the "subgrid" for that part of the machine (in this case the magnet subsystem for achromat 1). The subgrid in turn shows different types of magnet systems (columns) in the parts of the achromat (vertical). Clicking cell "B" here finally reveals individual TANGO devices. Note that the STANDBY state of these devices "bubbles" up to the top level grid since it's considered more important than the ON state.

Monitoring and Alerting

The "state grid" described above gives operators an immediate grasp of the current situation, but it's also very simplified and provides little help when trying to find out what previous events were the root causes of a problem. Conversely, a logging system is usually only configured to store logs for devices that are either new, or suspected to have some issue, since logging usually also means some performance overhead. It also only stores information that the developer has deemed to be of interest. Part of the missing piece is what's usually called an archiving system, but that in turn usually focuses on end user relevant information such as equipment readings.

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CONTROL SYSTEM SOFTWARE DEVELOPMENT ENVIRONMENT IN ELI BEAMLINES

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Abstract

The ELI Beamlines facility is a Petawatt laser facility in the final construction and commissioning phase in Prague, Czech Republic. End 2017, a first experiment will be performed. In the end, four lasers will be used to control beamlines in six experimental halls. The central control system connects and controls more than 40 complex subsystems (lasers, beam transport, beamlines, experiments, facility systems, safety systems), with high demands on network, synchronisation, data acquisition, and data processing. It relies on a network based on more than 15.000 fibres, which is used for standard technology control (PowerLink over fibre and standard Ethernet), timing (WhiteRabbit) and dedicated high-throughput data acquisition. Technology control is implemented on standard industrial platforms (B&R) in combination with uTCA for more demanding applications. Approach to software development is very important in such a facility. Component based generic approach described is efficient for both, software development and also software deployment.

INTRODUCTION

ELI Beamlines [1] is an emerging high-energy, high-repetition rate laser facility located in Prague, Czech Republic. Four laser beamlines (ranging from the inhouse developed L1 with <20fs pulses exceeding 100mJ at 1kHz based on DPSS technology to the 10PW-L4, developed by National Energetics) will supply six experimental halls which provide various secondary sources to users. Facility commissioning, and installation work of lasers and experiments is progressing, and first user experiments are expected in 2018.

The central control system connects, supervises and controls all technical installations used for the operation of this facility, which are more than 40 complex subsystems (lasers, beam transport, beamlines, experiments, plant systems (HVAC, vacuum), safety systems) with high demands on network, synchronisation, data acquisition, processing, and storage.

This paper describes the control system software development environment in ELI Beamlines.

APPROACH

There are three factors that make the development of the ELIs' control system challenging:

First, ELI has been designed to be multifunctional, and to provide a highly diverse selection of lasers and secondary sources to researchers. In practise this means that we have to integrate a **multitude of very diverse subsystems** developed by internal and external suppliers; leading to an initially very inhomogeneous technical landscape, and complex system interfaces.

At the same time, ELI is **building ground breaking technology** and its demands on synchronisation and data acquisition are pushing the boundaries on what is possible with current technology. Demands are especially high on safe operation, synchronization, and data acquisition.

Third, in ELI **commissioning and operational phases overlap**. While one part of the facility is still under development, others are being installed, and again others will be already serving early users (whose experiments need to be supported technically, and for whom laser and beam transport operation, safety, timing and data acquisition services must be provided).

We are using following approaches in our software development environment and architecture:

- **Use already available frameworks** for software development. In our case we chose TANGO framework which is available for free and is widely used in many facilities around the world [2].
- **Use only few programming languages** in our case we are using one compiled language which is the C++ and one scripting language which gives opportunity for the users to create their own scripts for experiments, here we chose Python which naturally support object orinted development. Both languages are of course supported by TANGO framework. Also standard user tools like Matlab, LabVIEW and others are supported by providing bindings for software components.
- **Using standard development process** based on modelling language which is UML and SysML in our case. The software development process is based on Iterative Unified Process
- **Use model based development focusing components and well defined API.** Here we use Enterprise architect [3].
- **Use automatic software generators** where possible. Communication with instrumentations

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PREVENTING RUN-TIME BUGS AT COMPILE-TIME USING C++*

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Abstract

In order for a system to be reliable, its software needs to be carefully designed. Despite our best efforts, however, errors occur and we end up having to debug them. Unfortunately, debugging an embedded system changes its dynamics, making it difficult to find and fix concurrency issues. This paper describes techniques, using C++, making it impossible to write code susceptible to certain run-time bugs. A concurrency library, developed at Fermilab, is used in the examples illustrating these techniques.

INTRODUCTION

The C++ Standard Template Library (STL) is an impressive body of work, giving programmers a high-level library while still being performant. Although C++ templates started as a way to generalize containers across any type, the STL authors have discovered techniques which allow complex decisions to be made at compile time. We would like to use this feature to enforce constraints on how our code can be written.

When a template is used, its parameters are specified and they, in turn, get substituted in the body creating a specialization of the template. More interesting, if the library defines a version of the template where the types have been picked, the compiler will use that template instead of specializing the default one[1]. This is not inheritance; each specialized version of a template could have a different API, if it was useful.

Template parameters can also take values, which then get used by the template body as constant values. This may seem similar to using `#define`, but it's not; each instantiation of a template is a new, unique type. An `Array<10>` has no relation to an `Array<20>`, as far as the compiler is concerned (unless the template derives them from the same base class.) We can use this uniqueness to our advantage.

Over the past several years, we've developed a library of C++ templates for our VxWork-based systems. These templates make writing our embedded software easier and more reliable. Writing our drivers is easier because the templates generate the mundane, boilerplate code and let us focus on the core of the driver. Our reliability improves because our concurrency library makes most concurrency bugs impossible.

VERIFYING REQUESTS

When a driver in our embedded system receives a request from the network, part of the request consists of a length value, an offset value, and a buffer of data (for readings, the buffer is to be filled and returned; for settings, the buffer contains data.) Since our controls system supports array devices, the offset could be non-zero. Every driver needs to validate the request before continuing which means both the length and offset values need to be a multiple of the base data size of the device. Plus, combined, they cannot exceed the total size the driver expects. Although this isn't rocket science, it is a tedious part of writing drivers. A further complication resides in the data buffer. ACNET has VAX-centric byte-ordering which is different from our PowerPC systems, so developers were responsible for byte-swapping to and from the network. All these details adds one more layer of debugging when developing, so we felt we needed to fix it.

Proxy objects are used in our library to both verify the request parameters and properly exchange data with the buffer associated with the network. If the request parameters are invalid, the proxy's constructor throws an exception and the remote client gets the appropriate bad length or bad offset error status. Otherwise, the proxy object is created and is used to access the raw buffers, returning the data in a native format.

For instance, if a driver expects an unsigned, 16-bit integer as a setting, it would start its handler with

```
SettingProxy<uint16_t> setting(req);
```

This template expands to two tests (`req` is a pointer to the request structure); the offset must be zero and the length must be 2. It also declares a `uint16_t` typecast operator so that using `setting` in an expression returns a properly byte-swapped, 16-bit integer. The template doesn't define an assignment operator, so the compiler generates an error if the programmer tries to write to the setting (which is always incorrect.)

This template works for all simple data types.

But what if we have an array device? We use template specialization to tell the compiler what to do if it sees an array type. If our driver accepted up to four, 32-bit integers, for instance, it would use this

```
SettingProxy<int32_t[4]> setting(req);
```

Now the test makes sure the length and offset are multiples of 4 bytes and they don't exceed the limits of a four element array of integers. In addition, rather than define a typecast operator, this object defines the subscript operator which returns an `int32_t`.

For completeness, specializations were also defined for pointer and reference types. Since it doesn't make sense to pass pointers or references across the network, these specialized template define an empty class so trying to use them results in compile-time errors.

In the case that a driver returns data to a request, a ReadingProxy is used. This proxy template has the same validation tests as the setting and it, too, recognizes array types. But instead of defining operators that access the

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STREAMING POOL - MANAGING LONG-LIVING REACTIVE STREAMS FOR JAVA

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Abstract

A common use case in accelerator control systems is subscribing to many properties and multiple devices and combine data from this. A new technology which got standardized during recent years in software industry are so-called reactive streams. Libraries implementing this standard provide a rich set of operators to manipulate, combine and subscribe to streams of data. However, the usual focus of such streaming libraries are applications in which those streams complete within a limited amount of time or collapse due to errors. On the other hand, in the case of a control systems we want to have those streams live for a very long time (ideally infinitely) and handle errors gracefully. In this paper we describe an approach which allows two reactive stream styles: ephemeral and long-living. This allows the developers to profit from both, the extensive features of reactive stream libraries and keeping the streams alive continuously. Further plans and ideas are also discussed.

INTRODUCTION

In practically any application within the operational environment of CERN accelerators, a common pattern is repeated:

- Subscribe to N properties of different devices,
- extract values and/or transform and/or combine them with values coming from other devices
- and buffer the incoming values to have a history of a certain length.

For the first part (subscription), a common mechanism exists through *JAPC* (Java API for Parameter Control). However, already this part is not ideally solved as it implies coupling down to the device layer of each application. For the two other steps, no common approach exists at all. The *Streaming Pool* project aims to close this gap by providing coherent means to implement processing- and abstraction layers. The code was kept general (not bound to any CERN specific library) and was open sourced under Apache License 2.0 [1].

Streaming Pool was designed with the following objectives in mind:

- Decoupling of Layers (e.g. When subscribing to the stream delivering the tune of a machine, the application does not have to know which device delivers this),
- rich set of operators for transformations,
- sensible defaults for error treatment
- and testability built in from the beginning.

Since this framework was never developed as a dedicated product, but always as a side product of operational applications under development, its feature set evolved according to the requirements from these applications. Therefore, some goals are only partly achieved in the current version (E.g. the decoupling of layers is possible, but in some applications not fully implemented). However, most of them (the last three in the above list) are fully available: Error treatment and testability are enabled by the internal design, while the rich set of operations are provided by the chosen technology (reactive streams), as described in the following sections.

REACTIVE STREAMS

A stream of data is a specialization of the Observer design pattern that is especially useful in contexts where the business logic of the application can be expressed as a series of transformations over a flow of data. In a stream there are typically three components:

- Publisher: is the source (or start) of the stream, it pushes the data through the stream.
- Processor: is an operation applied to a data item currently flowing through the stream.
- Subscriber: it consumes the data of the stream.

According to the items described above, a stream of data has a certain Publisher, zero or more Processors that act on the data (transforming them according to the business logic) and one or more Subscribers that consume the data.

Reactive streams are an initiative for creating truly asynchronous data streams that handle back pressure in a non-blocking way [2]. Being asynchronous, a reactive stream can switch context (thread of execution) at any time between Processors. In this scenario, boundaries between threads need special care. Avoiding the undesirable situation of unbounded buffers, reactive streams introduced the concept of back pressure. Data in a reactive stream flow on request, e.g. a Subscriber requests 10 items from the stream. In this way the Publisher does not flood the Subscriber with data that it is not able to process. A back pressure strategy is then needed in order to define the behavior when the aforementioned rule cannot be applied. For example, lets assume subscribing to a hardware device publication which delivers updates on a rate of 100 items per second. If the processing pipeline can only accept 90 per seconds there are typically three options (although more sophisticated techniques are possible):

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TENSORICS - A JAVA LIBRARY FOR MANIPULATING MULTI-DIMENSIONAL DATA

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Abstract

Accelerator control software often has to handle multi-dimensional data of physical quantities when aggregating readings from multiple devices (e.g. the reading of an orbit in the LHC). When storing such data as nested hashtables or lists, the ability to do structural operations or calculations along an arbitrary dimensions is hampered. Tensorics is a Java library that provides a solution to these problems. A Tensor is an n-dimensional data structure, and both structural (e.g. extraction) and mathematical operations are possible along any dimension. Any Java class or interface can serve as a dimension, with coordinates being instances of a dimension class. This contribution will elaborate on the design and the functionality of the Tensorics library and highlight existing use cases in operational LHC control software, e.g. the LHC luminosity server or the LHC chromaticity correction application.

INTRODUCTION

A common need in applications that manipulate numerical data is to organize them in data structures which allow easy transformations and calculations. This paper describes the *tensorics* [1] library for the Java programming language which provides several, complementary concepts to ease such tasks. Despite the libraries name is derived from "tensor", it contains several additional concepts which complement each other. The features are designed to work smoothly together, but each of them can of course also be used standalone. In the following sections, we give a short overview on the different concepts, together with some explanatory code examples.

TENSORS

The name “Tensorics” is derived from “Tensor”. Loosely speaking, a tensor in mathematics is a multidimensional data structure, whose dimensionality is given by the number of indices. A tensor of dimensionality N contains a value for each N-tuple of index values. Tensors in mathematics are usually denoted by noting their elements with a full set of indices. E.g. an element of a 3-dimensional tensor **A** would be denoted as a_{ijk}. Each index (i, j, k) can potentially have its own range (e.g. $1 <= i <= M_i$, $1 <= j <= M_j$, $1 <= k <= M_k$).

Another way to see this is that a tensor has a value for each point in an N-dimensional integer space. In the above notation a dimension is identified by the position of the respective index, and the coordinate in that dimension is given by the value of the index. These mathematical concepts are extremely useful, especially when it comes to operations on such tensors (as we see in later sections). Therefore, tensorics borrows many concepts from mathematics. At the same time it translates them into the programming language in a way that is aimed to form a powerful data structures which encourages readable code as much as possible and helps avoiding confusion and mistakes. For this reason, we use the word “Tensor” in an even sloppier manner.

The main particularity of a tensorics *tensor* is that a dimension is not identified by the position of the index, but by a java type (class). Instances of the respective type we denote as *coordinates*. A point within the N-dimensional coordinate space is then defined by a set of objects (instances of coordinate classes), of which each type must be exactly once. This key concept allows easier and less error-prone usage (because the order of the coordinates/indices is not relevant) and still leads to readable code.

A tensorics tensor has one type parameter, the type of the values it contains, usually denoted as `<V>`. Therefore, the tensor data structure can be used as container for any Java type. However, some operations on the tensors will be only possible for certain value types (e.g. mathematical operations).

An Example

Since tensorics concepts and syntax are best explained in a practical walk-through, we will use the following example throughout the subsequent sections:

Consider weather analysis: A data set consists of weather data from different cities and times. The class City and Time are defined and some constants are instantiated. Temperature values are stored in a tensor of doubles, for example:

Listing 1: Constants for examples.

```
City SF = City.ofName("San Francisco");
City LA = City.ofName("Los Angeles");

Time T1 = Time.of("2017-01-01 15:00");
Time T2 = Time.of("2017-01-02 15:00");

Tensor<Double> degrees;
/* creation omitted */
```

Accessing Values Assuming the above constants, we can then simply get temperature values from the tensor:

Listing 2: Accessing Tensor Values.

```
Double t = degrees.get(T1, SF);
```

As visible here, this looks very similar to getting values from a map, with the following important differences:

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A FRAMEWORK FOR ONLINE ANALYSIS BASED ON TENSORICS EXPRESSIONS AND STREAMING POOL

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Abstract

Among other functionalities, the Tensorics library provides a framework to declaratively describe expressions of arbitrary values and resolve these expressions in different contexts. The Streamingpool framework provides a comfortable way to transform arbitrary signals from devices into long-living reactive streams. The combination of these two concepts provides a powerful tool to describe modules for online analysis. In this paper we describe this approach, elaborate on the general concepts and give an overview of actual and potential use cases as well as ideas and plans for future evolution.

MOTIVATION

Devices of accelerators deliver their measurement data through asynchronous channels to which higher level applications can subscribe. This data can be seen as streams of data items. Recent technology evolution provides concepts on top of which a framework for management of such streams - Streamingpool - was created and is used in operational applications, as described in [1]. Most of the time, subscribing to a single stream is not sufficient, but multiple streams have to be combined and some decision based on a certain logic has to be taken. To base such logic completely on asynchronous operators, as provided by RxJava (the technology used and provided by Streamingpool), turns out to be overly complicated and difficult to read and debug. Additionally, experience from previous application developments at CERN (e.g. the Software Interlock System [2]) showed that it was favorable to base such analysis on immutable snapshots.

When work was started by the BE-OP-LHC software team on a new system for LHC (Large Hadron Collider) injection diagnostics, exactly these challenges arose. The goal was to be able to formulate conditions in a way which could be read and understood by non-programmers and at the same time provide the necessary comfort (e.g. IDE support and code completion) for people who have to formulate such conditions. Further, as good results were already achieved with a similar approach for powering test analysis in the LHC [3,4], it was decided to aim for a Java internal Domain Specific Language (DSL).

This finally led to the analysis framework described in this contribution. It is built in a modular way and consists of the following components, which can be used alone or together, depending on the usecase:

- **Streamingpool** [1] provides an abstraction to streams of data coming from accelerator devices and, in the context of the analysis framework, is used for all kind of asynchronous processing which is required to build the snapshot which then is passed on to the real analysis logic (e.g. triggering, buffering and mapping of streams).
- The **Analysis DSL** is based on (and an extension to) the DSL provided by the Tensorics library [3]. It describes the logic to apply to the data and can e.g.be used standalone, for example to analyze static data (e.g. by pulling from the LHC logging service).

In the following sections these components are described in further detail.

STREAMING POOL

Streamingpool is an open-source framework [1, 5] that abstracts the way long-living reactive streams are discovered, created and managed.

In the Streamingpool, each stream is uniquely identified by a `StreamId`. A `StreamId` provides an abstraction over what the developer wants to get as stream (e.g. a stream of data from an hardware device). Given a `StreamId`, one can discover the associated stream (returned as a `Publisher<T>`) using a `DiscoveryService`. This service queries the Streamingpool for the stream that is identified by the provided `StreamId`. If the stream was already discovered before the Streamingpool then returns the same `Publisher<T>`, otherwise triggers its lazy creation and then caches it for subsequent requests.

ANALYSIS DSL

The logic for an online analysis is described by extending the `AnalysisModule`. The `AnalysisModule` provides a custom Java-based DSL for expressing the analysis logic. This feature gives the possibility to the developer to implement complex logic while having the full flexibility of the Java programming language. It also makes the analysis type-checked as it is possible to check for errors at compilation time and it gives full auto-completion capabilities during the development.

Assertions

The basic building blocks for an analysis are assertions. They are used for specifying conditions to check during the analysis. As an example, consider a user wants to assert that “protons are **produced**”, but this condition should only be taken into account when “protons are **requested**” (because only then the condition makes sense).

This could be formulated through the analysis DSL as shown in Listing 1.

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VISUALISATION OF REAL-TIME FRONT-END SOFTWARE ARCHITECTURE (FESA) DEVELOPMENTS AT CERN

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Abstract

The Front-End Software Architecture (FESA) framework is the basis for most real-time software development for accelerator control at CERN. FESA designs are defined in an XML document which is validated against a schema to enforce framework constraints, and are used to automatically generate C++ boilerplate code in which the developer can then implement specific code. Design files can rapidly grow in complexity making the overview of the resulting system almost impossible to understand. One way to overcome this is to benefit from a graph-based representation of the design, with XML fragments summarized into logical blocks and association between the blocks depicted by arrows. As the intricacy of the graph is analogous to a potential complex design, it is also essential to provide an interactive Graphical User Interface (GUI) for parameterising and editing the graph generation in order to fine-tune a simpler and cleaner illustration of a FESA design. This paper describes such a GUI (FESA Graph Editor) and outlines how it benefits the design and documentation process of the FESA-design-document.

INTRODUCTION

The control system of the accelerator complex at CERN can be divided in three physical layers and can therefore be described as having a 3-tier architecture. The top tier consists of dedicated computers for running operational and expert high-level client applications, while the middle tier consists of servers that implement business and supervision logic. The lower tier is composed of embedded front-end computers (FECs) running real-time software, to control and monitor the accelerator equipment [1].

Software in the lower tier is developed using the FESA framework in order to standardise, speed-up and simplify the software development process [2]. FESA is a complete environment where developers model their software according to the framework's standards, which results in generated C++ boilerplate code. This generated code includes the necessary real-time scheduling classes and sophisticated mechanisms to ensure data consistency in multi-threaded environments [3]. Thus, not only do they benefit from ready-made solutions accelerating the development time, but also from a common structure that facilitates its long-term support and maintenance.

Figure 1 shows how structures can be divided into three major segments that developers need to define. The *Server* part comprises the software's Application Programmable Interface (API), organized in so called *Properties* accessible to the control system. Each *Property* can contain a group of readable and/or writable value-items. The *Real Time* part is organized in C++ classes called *Actions* and is where the low-level access to the hardware typically takes place. The configuration which triggers such *Actions* (i.e. events the software must react on) also belongs to this part. Finally, the *Data Store* is a set of fields and custom structures creating the internal data model, which is shared by the aforementioned parts.

The definition of all these parts is stored in an XML document called a FESA-design, which is validated against a schema to impose the framework's constraints [2]. While the XML format is convenient for its validation and code generation, it becomes cumbersome to edit or visualise, especially as the complexity of the software grows.

The FESA framework currently complements the documentation of a FESA-design with a graph generated by a python script with the help of the graphviz library [4]. Although this proof-of-concept is very inspiring, the structure and the static nature of the graph often makes the result unusable.

This paper describes a new graphical representation of the FESA design as an alternative to the XML text. In addition, it describes a GUI that facilitates editing to make the resulting graph cleaner and more user-friendly, addressing the issues with the existing graphical visualisation.

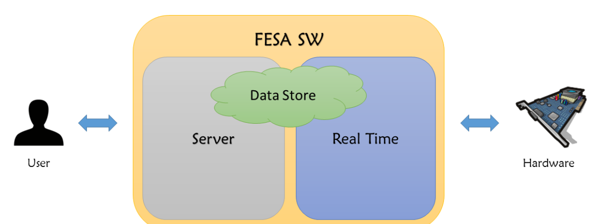

Figure 1: FESA software structure.

PROBLEMS

The current version of the framework (FESA 3) is integrated in the development environment as an Eclipse [5] plug-in. It provides two ways of viewing and editing a design document: a FESA design view, which is a prettified XML editor, and the eclipse's text editor to access the source document directly [1].

In a FESA-design, there exist numerous elements which can refer to other elements often located far from each other in the document. Consequently, both ways of viewing in Eclipse lack the ability to give a good overview of the software described, making its maintenance troublesome. This

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WEB BASED VISUALIZATION TOOLS FOR EPICS EMBEDDED SYSTEMS: AN APPLICATION TO BELLE2

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Abstract

Common EPICS visualization tools include standalone Graphical User Interface or archiving applications that are not suitable to create custom web dashboards from IOC published PVs. The solution proposed in this work is a data publishing architecture based on three open-source components: Collectd: a very popular data collection daemon with a specialized plugin developed to fetch EPICS PVs, InfluxDB: a Time Series DataBase (TSDB) that provides an high performance datastore written specifically for time series data, Grafana: a web application for time series analytics and visualization able to query data from different datasources. A description of this architecture will be provided showing flexibility and user friendliness of such developed solution. As a case study, we show the environment developed and deployed in the Belle2 experiment at KEK Laboratory (Tsukuba, Japan) to monitor data from the endcap calorimeter during the installation phase.

INTRODUCTION

EPICS process variables (PVs) represent a named set of data associated with an Input Output Controller (IOC) that publish status or measurements of a given instrument.

Users are interested to display PVs using user-friendly Graphical User Interfaces (GUI) in order to highlight critical trends and to handle alarm status.

Control System Studio (CSS) [1] is a very useful tool for EPICS PVs visualization. CSS allow users to easy design their own Operator Interface (OPI) using "widgets" that allow display of a single PV in different graphics format (text, gauge, bar, plot, ...).

A similar approach to EPICS PVs visualization is performed by Qt-based GUI systems [2] where users can choose to design an OPI using C++ classes or in "code-free" fashion by drag-and-drop a set of controls on a panel.

Another approach is to extend commercial scientific applications with EPICS Channel Access API in order to visualize and process PVs data. Matlab is widely used for this kind of tasks. With Matlab Channel Access plugin (MCA) [3] it is possible to retrieve, visualize and process EPICS PVs on a Matlab user designed GUI [4].

Although these solutions for EPICS PVs visualization represent a viable compromise between software coding and "drag-and-drop" GUI design, they don't provide a solution to display a PVs dashboard using Internet protocols but rely on a desktop application. It is desirable for some use cases to apply the same vision of Internet of Things (IoT) to EPICS PVs in order to access to dashboard and control panels by a simple web browser on a desktop PC as well as on a smartphone or tablet device.

ARCHITECTURE

The proposed data publishing architecture is based on a common pattern of data collection. Each produced data fragment (PV) is collected by any EPICS node and sent by network to a central server that gathers all data and store them in a database. A web application runs on the central server and displays collected data.

In order to overcome either network policies enforced on incoming traffic of each scientific institution and the frequently adoption of Network Address Translation (NAT) of local IP addresses, we have selected HTTP as transport protocol and organized the data flow to "push" data from inside a LAN to outside on a central server. With this option, the PVs published by an EPICS IOC running on a machine with a private IP network and Internet connectivity can be collected and displayed on an arbitrary platform, without any issue.

Data Collection

The data collection task is performed by Collectd [5] an open-source software. Collectd is a daemon which collects system and application performance metrics periodically and provides mechanism to store the values in a variety of ways.

Collectd community provides plugins to monitor system resources availability, performance and offers a wide set of interface to the most used database services (MySQL, Postgresql, RRD).

Plugins are classified as "input plugins" if they send values in Collectd logic or "output plugins" if they send values outside Collectd [Fig. 1].

A specialized input plugin [6] for Collectd has been developed in order to read EPICS PVs. This plugin uses Python API of Collectd and PCASpy [7] library for EPICS Channel Access.

The "write_http" output plugin of Collectd is used to push read EPICS PV towards a Python Tornado [8]

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COMMON STANDARDS FOR JavaFX GUI DEVELOPMENT AND ITS APPLICATION TO THE RENOVATION OF THE CERN BEAM INSTRUMENTATION SOFTWARE PORTAL AND DELIVERY MECHANISM

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Abstract

Until recently, Java GUI development in the CERN Beam Instrumentation Group has followed an ad-hoc approach despite several attempts to provide frameworks and coding standards. Triggered by the deprecation of Java's Swing toolkit, the JavaFX toolkit has been adopted for the creation of new GUIs, and is foreseen for future migration of Swing-based GUIs. To increase homogeneity and encourage modular coding of JavaFX GUIs, libraries have been developed to standardise accelerator context selection, provide inter-component GUI communication and optimise data streaming between the control system and modules that make up an expert GUI. This paper describes how this has allowed the use of model-view-controller techniques and naming conventions via Maven archetypes. It also details the modernisation of the software delivery process and subsequent renovation of the software portal. Finally, the paper outlines a vision to extend the principles applied to this Java GUI development for future Python-based developments.

INTRODUCTION

The CERN Beam Instrumentation Group (BI) is responsible for studying, designing, building and maintaining all the instruments that allow the observation of the particle beams and their related parameters in the CERN accelerator complex [1]. The BI Software Section provides software necessary to develop, test, diagnose and maintain such instruments including expert graphical interfaces (GUI) implemented in Java. The main GUI clients are hardware specialists responsible for the instruments, along with a few operators and accelerator physicists who require additional status and control beyond that provided by operational applications. Such clients benefit from signal visualisation, parameter setting, error diagnostics, calibration, data post processing, etc. [2]

Over the past few years, there has been an increase in demand to have platform independent applications that would be able to operate on both the Unix and Windows operating system. Java fulfils this requirement and hence was standardised at CERN for GUI development in the accelerator sector.

Initially, development of such applications was more adhoc and based upon the Java Swing toolkit. However, as the complexity and number of applications grew, so did the necessity of standardising the development process through the use of conventions and libraries [3].

ADDRESSING THE PROBLEM

There are many factors that determine the need for new expert GUIs, such as the type of instrument, the acquisition electronics, as well as the type of diagnostics to be performed. Specifications for a new system are therefore often particular to that system and cannot be fulfilled with static GUIs and a fixed list of options.

Functionality reviews on current expert GUIs show that a common, generic and modular JavaFX design is an effective means of making reusable and maintainable GUI components. This standardises and facilitates the development process of a Java project. As a result, despite the different software requirements, the similarity in their overall structure allows the applications to be built based on common JavaFX standards. Additionally, the use of common conventions, graphical components and libraries increase software quality, as well as speeding up the development process.

COMMON STANDARDS

The main goal of the adoption of common standards is to facilitate GUI development and maintenance as well as to increase its homogeneity. In addition, it encourages the use of a modular architecture, with specialised libraries that perform common tasks. Typical examples of such tasks are the: inter-component GUI communication, optimised data streaming between the control system and GUI modules, accelerator context selection (the categorisation of the beams of particles in the accelerators).

Maven Archetypes

In order to help the developers use the new common standards, JavaFX template applications can be created. These provide a clear structure, documentation and demo examples of the aforementioned libraries. Such skeleton applications are generated based on Maven archetypes and aim to establish a common modular architecture for all GUIs being developed.

In short, an Archetype is a Maven project templating toolkit. It is defined as an original pattern or model from which all other things of the same kind are made. Archetypes help authors create Maven project templates for users, and provide users with the means to generate parameterised versions of those project templates [4].

The use of such a powerful templating mechanism facilitates the enforcement of the standards while accelerating GUI development with working, entry-point projects.

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STRUCTURE AND DEVELOPMENT OF SESAME'S CONTROL SYSTEM CLIENT

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Abstract

SESAME is a third-generation 2.5 GeV synchrotron-light source based in Allan, Jordan. The Pre-injector (Microtron) and Injector (Booster Ring) have been commissioned while the commission of the storage ring began in January 2017 and we expect machine operation in late 2017. The current components of the control systems software side are IOCs developed using EPICS software tools, Operator Interfaces (OPI) designed using Control System Studio (CSS) software tools, process variables archiving using CSS BEAUTY toolkit, alarm handling using CSS BEAST toolkit and tools to help in automation and reporting. This paper will present the current design of the client system which includes what was needed for the active commissioning period as well as upgrades that are under research including EPICS Qt framework as a client replacement for CSS and the pros and cons of this replacement and upgrading the archiver engine to a scalable and higher performance engine.

INTRODUCTION

SESAME consists of a 22 MeV Microtron, an 800 MeV Booster Synchrotron and a 2.5 GeV Storage Ring. Control System Implementation uses (EPICS) base R3.14.12. Servers are implemented as EPICS Input/ output Controllers (IOCs). Clients are implemented using a custom build of Control System Studio (CSS) based on V.3.16. CSS version 4.5 is under testing. Siemens S7 PLC controllers are used for the machine interlocks. An Allen Bradley PLC controller is used for the Personal Safety System (PSS). VME hardware is used for the timing system. Development and administration platforms use Scientific Linux 7.3 while maintaining version 6.4 for legacy support. A Git version control is used to track development. All clients, servers, and controllers are connected to an isolated machine network. There are twelve virtual servers are reserved to run the IOCs, archive system, alarm system and Git repositories.

The control systems have been implemented for the entire machine from Microtron all the way to the Storage Ring. Both the Booster and Storage Ring's control system is divided into seven subsystems: vacuum, power, RF, diagnostics, cooling, timing and Personal Safety System (PSS). Each control subsystem consists of one or more clients, servers, and controllers [1].

CLIENT SYSTEM STRUCTURE

The control system client at SESAME is divided based on the machine stages as a first level, then each stage is divided based on the stage's subsystems. Examples of the subsystem's divisions are

1. Power supplies.
2. Vacuum.
3. Diagnostics.
4. Radio-Frequency.

Figure 1 shows the main interface OPI of the control systems.

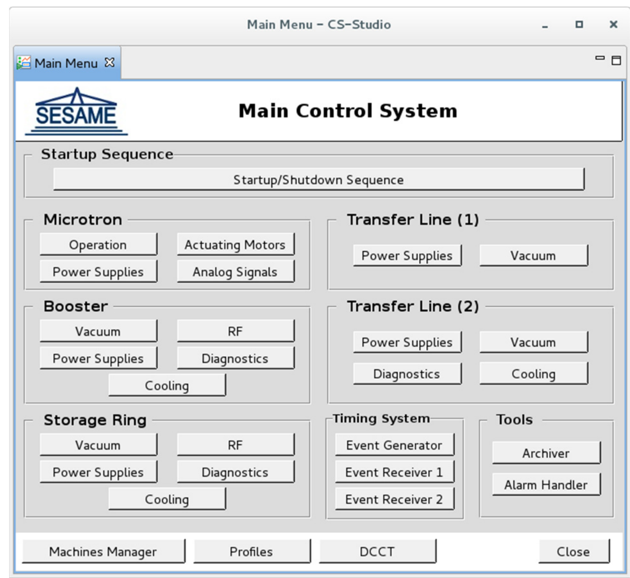

Figure 1: Main interface for the control system client.

Storage-Ring DC Power Supplies

The Storage-ring power supplies system consists of the following:

1. One power supply for bending magnet.
2. 64 power supplies for quadrupole magnets.
3. 4 power supplies for sextupoles magnets.
4. 64 power supplies for corrector magnets.
5. 8 power supplies for skew quad magnets.

With a total of 141 power supplies making it the largest GUI in the client system. Figure 2 shows the main OPI of the power supplies system.

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MALCOLMJS: A BROWSER-BASED GRAPHICAL USER INTERFACE

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Abstract

A browser-based graphical user interface has been developed at Diamond. It is known as MalcolmJS as it communicates using Diamond's Malcolm Middleware protocol. The original goal was to communicate, via Websockets with a PandABox [1] in order to allow a user to examine and set attributes of numerous functional blocks within the instrument. With the continuing maturity of the Javascript language, in particular the release of ES6, along with the availability of off-the-shelf reactive open-source Javascript libraries, such as Facebook's React and Node.js, a rich set of tools and frameworks have entered the arena of user interface development suitable for control systems. This paper describes the design decisions based on these tools, experiences and lessons learned during and after the development process and the possibilities for future development as a generic, adaptable framework for instrument and control system user interfaces.

INTRODUCTION

In 2016/17, Diamond (in collaboration with SOLEIL) developed a digital signal level converter and position capture unit, named PandABox. PandABox consists of a number of static functional blocks defining functionality such as pulse stretching or position compare that can we wired together by an end user at run-time. An ASCII based TCP protocol allows control system access to the device, but a graphical interface was desired to allow end users to easily visualize the wiring of these functional blocks. It was also deemed necessary for an end user to be able to configure a PandABox without having to install any software on their computer. Having developed a tightly specified middle layer service named "Malcolm" [2], which allows high level configure/run control of control system components, the next stage was the design of a companion browser based user interface that has been named MalcolmJS.

REQUIREMENTS

Malcolm objects form a network of parent child relationships with duplicated nodes. For example, the same motor controller is likely to be used in many scans. A typical tree of objects might look like that shown in Fig. 1.

The bold items correspond to blocks, everything else is an attribute. The Palette items are generated by the User Interface(UI) giving a list of blocks from which the user can drag and drop (Fig. 2).

Outline UI Requirements

The external devices have diverse functionality; MalcolmJS must, therefore interrogate the attached device(s) for

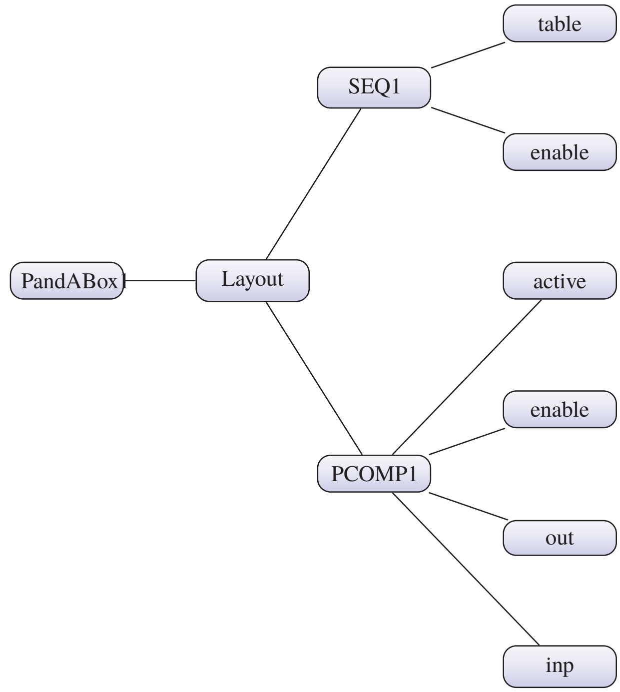

Figure 1: Example block and attributes tree structure.

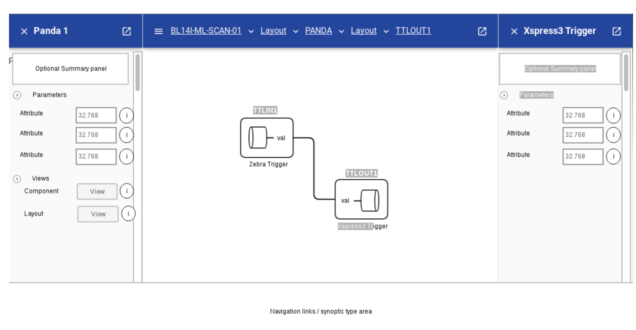

Figure 2: Proposed GUI.

information on all the available function blocks, attributes and associated meta-data. The collection of internal resources then being listed in a "palette" in the right-hand side-pane of the UI. A user will then have the option of selecting a block from the side-bar, dragging and dropping it onto the central canvas panel. A number of ports will be shown along the boundaries of each block; the ports have a type attributed to them and ports of compatible types can be connected together by selecting one port and dragging a connector "wire" to another port. When this is completed, the same connection information is transmitted to the device, where physical connections are made. This might, for example, be the "out" port of a Look Up Table(LUT),

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RADAR 2.0, A DRAG AND DROP, CROSS PLATFORM CONTROL SYSTEM DESIGN SOFTWARE

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Abstract

In the ever-growing control system at CERN, there is a need for having an easy to use, yet fast and flexible tool that interfaces with all the different middleware and communication interfaces in the accelerator, experiments and technical infrastructures. With RADAR 2.0 we wanted to address this issue, making a LabVIEW based, drag and drop visual tool that hides much of the system complexity from the user and within seconds gives the operator a ready to use, fully functional control system GUI. RADAR 2.0 interfaces with the CERN Middleware (CMW), the CERN Accelerator and Logging system (CALS), OPC-UA and DIM. With its class based implementation it can easily be extended to other data sources (Files, Databases, middleware) on demand. This paper reports how the implementation was done, the architecture, underlying technology and an outlook to other possible applications.

MOTIVATION

Getting the knowledge needed to properly analyse or interact with the Large Hadron Collider (LHC) control system can be a lengthy process which in many cases requires years of experience. The information on where to connect and how to interact with devices is often domain specific knowledge, spread across many different equipment experts and teams. In addition, many of the temporary users and operators at CERN are professors, students and collaborating partners that only stay for a short time, which can make interacting with the infrastructure quite an undertaking [1][2].

Many initiatives have been done to consolidate and reduce the diversity of the control system, which has reduced the complexity and eased access over the years, but it is still not straight forward to retrieve information regarding device configuration, calibration, response and behaviour, especially in cases where equipment have either direct or indirect correlations [1][3][4][5]. RADAR 2.0 tries to address these issues by combining all the accelerators devices and data sources in one interface and automatically detect, and adapt to the specific interface of the equipment. In addition, the components created with RADAR 2.0 can be saved, customize and shared across projects and users. This, over time, aims to ease the effort of mapping equipment specificities, allowing the operators to focus on commissioning and running the machine.

BACKGROUND

The application core of the RADAR 2.0 Drag and Drop toolkit was derived from two other applications called UNICOS in LabVIEW (UiL) [1][6] and RADAR 1.0 [7].

UNICOS in LabVIEW

UiL was introduced as a lighter, less expensive alternative to UNICOS [1]. For some specific projects (small or initial prototypes not connected to accelerator operation or located outside CERN) a more customisable supervision application using LabVIEW was an attractive alternative. UiL provides a set of customisable re-usable components, devices and utilities [1].

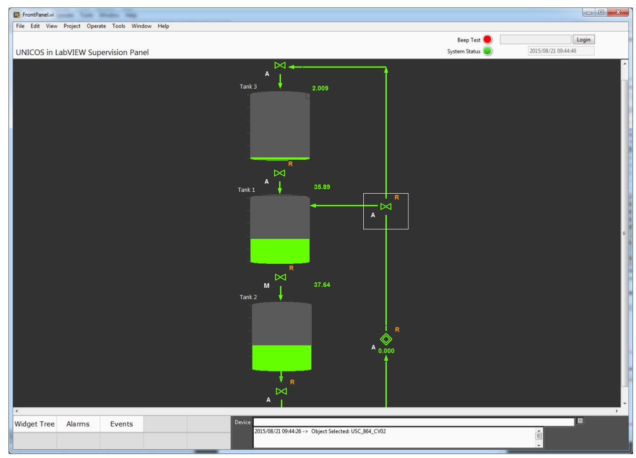

Figure 1 : UiL Example Application.

RADAR 1.0

RADAR was initially developed as an extension to the CERN Open Analog Signals Information System (OASIS) which is a highly configurable virtual oscilloscope that makes it possible to configure acquisition hardware with wide analogue bandwidth and flexible distributed triggering schemes across the CERN accelerators [2].

RADAR later evolved beyond interfacing only with OASIS, and became a connectivity tool that interfaced with all CERN devices using the CERN Middleware (CMW) [2][8].

RADAR 2.0

RADAR 2.0 consists of several stand-alone modules which intercommunicate. The main parts are described in the architecture section below. There are two modes to the application: Development and run. In development mode, the user interfaces with a dedicated infrastructure which can be deployed on any server. In run mode, the application acts as a stand-alone executable which either interfaces with the CERN and RADAR infrastructure or directly with the dedicated devices.

Workflow and Development

The users' starting point when developing with RADAR 2.0 is the project generator pane. The user is presented with a login screen (See Figure 2) where he or she

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PARALLEL EXECUTION OF SEQUENTIAL DATA ANALYSIS

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Abstract

The Parallel Execution of Sequential Data Analysis (ParSeq) software has been developed to work on large data sets of thousands spectra of a thousand points each. The main goal of this tool is to perform spectroscopy analysis without delays on the large amount of data that will be generated on Balder beamline at Max IV [1]. ParSeq was developed using Python and PyQt and can be operated via scripts or graphical user interface (GUI). The pipeline is consisted of nodes and transforms. Each node generally has a common group of components: data manager (also serves as legend), data combiner, metadata viewer, transform dialog, help panel and a plot window (from silx library [2]) as main element. The transforms connect nodes, applying the respective parameters in the active data. It is also possible to create cross-data linear combinations (e.g. averaging, RMS or PCA) and propagate them downstream. Calculations will be done with parallel execution on GPU. The GUI is very flexible and user-friendly, containing splitters, dock widgets, colormaps and undo/redo options. The features mentioned are missing in other analysis platforms, which justifies the creation of ParSeq.

INTRODUCTION

ParSeq has been projected to perform data analysis on a large amount of spectroscopy data through a downstream pipeline. This paper aims to present the tool and the status of the project, as well as describe the features implemented and what software technologies were used.

MAIN WINDOW

ParSeq has a main window composed of transformation nodes. Each node has a separated tab and defines which stage of the pipeline the user is working on. The nodes have a common group of components that will be detailed in next section. Figure 1 shows an overview of the main window.

ParSeq can be operated both via GUI or via scripts, where the user can define programmatically what is the data processing pipeline wanted and what are the parameters for each transform and for each spectrum. Processing pipelines are Python modules imported by GUI or scripts and are predefined for any analysis technique and therefore are (a) ready to use and (b) extensible if required. The currently implemented pipeline is only one: for X-ray Absorption Spectroscopy.

All graphical elements were implemented using Python and PyQt4 and the main plot window is from the silx library. The initial layout was designed with Qt4 Designer program, as shown in Fig. 2.

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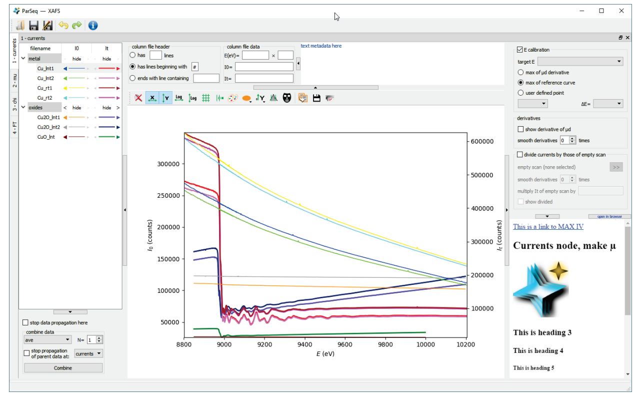

Figure 1: ParSeq Main Window.

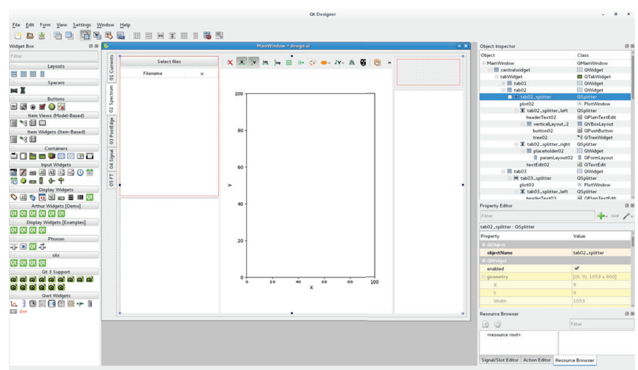

Figure 2: Qt4 Designer layout of ParSeq.

Dockable Widgets

The node widgets are dockable and can be placed wherever the user prefers, giving the flexibility to the user to decide where to position the windows or to have them grouped in tabs. ParSeq saves the current perspective of the widgets in order to be able to restore it next time the program is opened again.

Undo Redo Actions

ParSeq has implemented undo and redo options related to the transform operations. These options allow the user to revert one transform that was occasionally done with wrong parameters, or even that the result was not the expected. If one action is reverted (undo) it will then be available to be reapplied (redo).

Splitters

Corner widgets of ParSeq are divided by splitter bars (qtSplitter widget) that can be resized by the user. Furthermore, the splitters have a button to collapse/expand the corner wid-

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THE SKA DISH LOCAL MONITORING AND CONTROL SYSTEM USER INTERFACE

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Abstract

The Square Kilometre Array (SKA) project is responsible for developing the SKA Observatory, the world's largest radiotelescope ever built: eventually two arrays of radio antennas - SKA1-Mid and SKA1-Low - will be installed in the South Africa's Karoo region and Western Australia's Murchison Shire, each covering a different range of radio frequencies. In particular SKA1-Mid array will comprise 133 15m diameter dish antennas observing in the 350 MHz-14 GHz range, each locally managed by a Local Monitoring and Control (LMC) system and remotely orchestrated by the SKA Telescope Manager (TM) system.

Dish LMC will provide a Graphical User Interface (GUI) to be used for monitoring and Dish control in standalone mode for testing, TM simulation, integration, commissioning and maintenance.

This paper gives a status update of the LMC GUI design involving users and tasks analysis, system prototyping, interface evaluation, provides details on the GUI prototypes being developed and technological choices and discuss key challenges in the LMC UI architecture, as well as our approaches to addressing them.

SKA DISH

SKA-MID1 Dish array is composed of 15-m Gregorian offset antennas with a feed-down configuration equipped with wide-band single pixel feeds (SPFs) for the bands 1 (0.35-1.05 GHz), 2 (0.95-1.76 GHz) and 5 (4.6-13.8 GHz) of SKA frequency. The array will consist of 133 dishes plus the 64 MeerKAT dishes, arranged in a dense core with quasi-random distribution, and spiral arms going out to create the long baselines that go up to 200km.

Four sub-elements can be identified in the SKA-Mid1 dish element: the Dish Structure (DS), the Single Pixel Feed (SPF), the Receiver (Rx) and the Local Monitoring and Control (see Figure 1).

The Dish structure features the following components: an offset Gregorian reflector system with a feed-down configuration to optimise system noise performance, a fan-type feed indexer at the focal position which allows for changing between the 5 frequency bands by moving the appropriate feed into position, a pedestal providing a RFI shielded cabinet for housing digital electronics and computing equipment hosting other sub-elements' controllers, hardware for antenna movement control and monitoring (Antenna Control Unit or ACU), power distribution to all sub-elements, networking equipment, lightning protection and earthing, cooling ventilation for all the equipment mounted in the RFI shielded compartment itself.

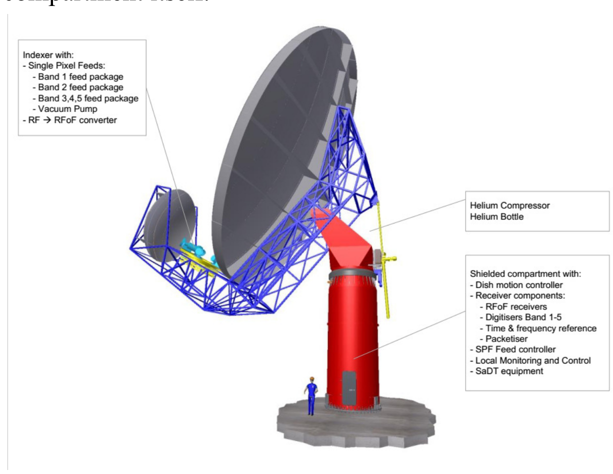

Figure 1: SKA DISH overview.

Single Pixel Feed (SPF) receivers include feed packages for the bands 1 (0.35-1.05 GHz), 2 (0.95-1.76 GHz) and 5 (4.6-13.8 GHz) of SKA frequency, three cryostat assemblies (respectively for band 1, band 2 and band 3,4,5) housing each a Gifford McMahon (GM) cryogenic cooler to cool the LNAs at a set point of approximately 20K, a second amplification stage and a calibration noise source, both temperature stabilised inside the vacuum, a common shared Helium System, a Vacuum System and a SPF controller, i.e. a single controller located in the pedestal which controls and monitors all three feed packages, helium system and vacuum system, and interfaces with the Dish LMC for external control and monitoring.

The Receiver (Rx) includes the following components: RF over fibre transport to the antenna pedestal where the digitisers are located, Digitizers performing some RF conditioning (filtering and level control), digitisation, packetizing and transmission to SKA Central Signal

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LCLS MACHINE PROTECTION SYSTEM HIGH LEVEL INTERFACE IMPROVEMENTS

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Abstract

The Linac Coherent Light Source (LCLS) is a free electron laser (FEL) facility operating at the SLAC National Accelerator Laboratory (SLAC). The LCLS Machine Protection System (MPS) contains thousands of inputs and hundreds of protection interlocks. Control room operators use a high-level Graphical User Interface (MPSGUI) to view and manage faults [1].

MPSGUI contains a wealth of useful information, from hardware input details to high-level logic flow, but in its first version it was difficult for accelerator operators to take full advantage of this. A recent project has greatly improved the workflow and usability of MPSGUI.

INTRODUCTION

The purpose of the MPS is to prevent damage to beamline components due to beam. The MPS monitors the states of devices throughout the accelerator. If it detects a condition that may lead to damage, it turns off the beam.

MPSGUI, a Java application, is the primary operator interface to the MPS. Operators use it to identify, diagnose, and manage faults. This paper will describe the enhancement provided by this project on MPSGUI.

MPSGUI

The MPS defines its static input and logic configuration in SQLite database files. Real-time state information is hosted by EPICS signals. The MPSGUI uses this combination of static and dynamic data to provide detailed fault and diagnostic information to operators.

The information is distributed in the MPSGUI tabs, accessible at the interface's bottom (Figure 1) [2].

- Summary: displays current rates, current faults, and bypasses
- Faults: details of MPS inputs;
- Logic: details of MPS logic, how inputs translate to rate limits
- Ignore logic: condition under which logic can be ignored
- History: full history of MPS input state changes;
- Recent Faults: last 1000 MPS faults that affected beam (faults that clear quickly, except sub second may not appear here)

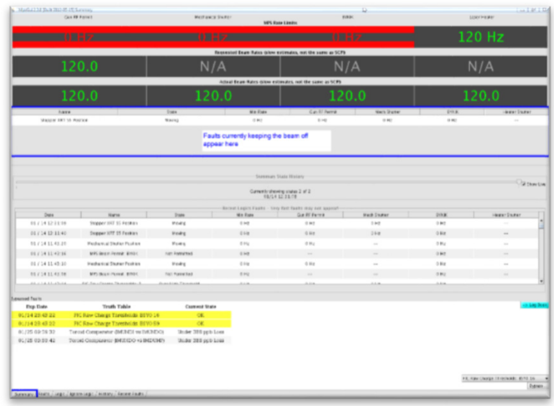

Figure 1: MPSGUI summary tab.

ENHANCEMENTS

MPSGUI contains a lot of information available to describe the MPS details but not fully utilized by Operations. In fact, the navigation from High Level GUI down to the logic fault description, hardware level bits related to this fault requires cross-reference and the use of several screens.

The complete requirements list was defined during a series of meetings with control room operators. A task list was made based on MPSGUI's maintenance tickets, user feedback and feasibility balanced with the limited resources of time and budget.

The intent of this project was to solve the following main MPSGUI's issues:

- Hard to find inputs associated with a given piece of logic.
- Missing information in displays.
- Challenging to identify faults that clear quickly.
- Difficult to associate a fault to the related logic details.
- Resolve issues that were discouraging operators from using the GUI.

Faults History Server

The most important of Operation's requests was the desire to identify fast non-latching recurring faults. This category of faults would appear repeatedly and clear at a very fast rate. Originally, MPSGUI was providing information about "current faults", operated by a separate JAVA thread. The thread was running on the user launched interface process, increasing the CPU load on the user side. The "current faults" information was not available when launching a new interface, instead was

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IMPLEMENTING CS-STUDIO AT ReA3*

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Abstract

ReA3 is the 3 MeV/u rare isotope beam (RIB) reaccelerator at Michigan State University's National Superconducting Cyclotron Laboratory (NSCL) [1]. ReA3 is unique in that it reaccelerates RIBs produced in-flight by projectile fragmentation. These beams are currently provided by the Coupled Cyclotron Facility (CCF) and will be provided in the future by the Facility for Rare Isotope Beams (FRIB), which is currently under construction and early commissioning.

A transition to Control System Studio (CS-Studio) [2] as the graphical user interface tool is underway to align ReA3 Human-Machine Interfaces (HMIs) with the FRIB style, providing operators with a consistent, integrated environment. This contribution will describe the challenges and strategies for implementing new HMIs at an operating facility.

STATUS

Over the past few years, many of ReA3's control interfaces have been transitioned to CS-Studio. This includes operator interface pages (OPIs) and tuning pages (OpsTuners), live and archived data browsing, alarm handling, and save/restore functionality. The previous interfaces include a set of local tools written in QT, Tcl/TK and Perl.

CHALLENGES AND STRATEGIES

There are two general types of challenges in implementing new HMIs at any facility: changing the tools themselves, and changing people's behavior. Difficult at any time, this process is made more challenging due to the need to maintain the operational program with a high level of availability.

There are several strategies for encouraging adoption of new interfaces while minimizing the disruption of learning to use new tools. People generally hesitate to learn new ways of doing their current work. They are busy, and new tools are often a source of new quirks and conventions to learn. Often, they will acknowledge that their current tools are not perfect but they have learned to use them well enough to be effective. The following strategies attempt to ease the transition period by providing a familiar workflow for basic tasks and focusing new development on high-level overviews and tailored control pages. Using online mock-up tools and realistic simulated prototypes for preliminary design, user testing and training can reduce disruptions to the operational system.

Provide New and Exciting Tools

Providing content that was not available previously is one of the easiest ways to encourage people to use a new HMI tool. At ReA3, the addition of two 50-inch, 4K display TVs provided an opportunity to develop a new set of status pages. Figure 1 shows the contents of these new screens, displaying three key pages: accelerator equipment status, safety information and alarms. This layout provided enough extra space to allow for a history plot of device temperatures.

Figure 1: New large screen status displays for the ReA3 control room.

Creating tailored control pages is another way to encourage the transition. Figure 2 show a page for an ion source which combines controls across various subsystems and displays the status in an easy to understand schematic. Figure 3 shows a page for the task of starting up the electron beam ion trap (EBIT). This style of page can be used to turn a procedural document into a guided walkthrough that gathers all relevant information and controls into one place. This provides an opportunity to capture the knowledge of experts, reduces operational

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THE USE OF A 90 METRE THERMOSIPHON COOLING PLANT AND ASSOCIATED CUSTOM ULTRASONIC INSTRUMENTATION IN THE COOLING OF THE ATLAS INNER DETECTOR

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ABSTRACT

A new 60kW thermosiphon fluorocarbon cooling plant has been commissioned to cool the silicon tracker of the ATLAS experiment at the CERN LHC. The thermosiphon operates over a height of 90 metres and is integrated into the CERN UNICOS system and the ATLAS detector control system. The cooling system uses custom ultrasonic instrumentation to measure very high coolant vapour flow (up to 1.2 kg/second), to analyse binary gas mixtures and detect leaks. In these instruments ultrasound pulses are transmitted in opposite directions in flowing gas streams. Pulse transit time measurements are used to calculate the flow rate and the sound velocity, which – at a given temperature and pressure – is a function of the molar concentration of the two gases. Gas composition is computed from comparisons of real-time sound velocity measurements with a database of predictions, using algorithms running in the Siemens SIMATIC WinCC SCADA environment. A highly-distributed network of five instruments is currently integrated into the ATLAS DCS. Details of the thermosiphon, its recent operation and the performance of the key ultrasonic instrumentation will be presented.

INTRODUCTION

The inner tracker of the ATLAS experiment contains silicon microstrip and pixel detectors, evaporatively cooled with C_3F_8 (octafluoro-butane: R 218) and CO_2.

The present compressor-driven C_3F_8 recirculator [1] is being replaced with a new 60kW thermosiphon [2] (Fig. 1) exploiting the 92 metre depth of the ATLAS cavern to generate sufficient liquid hydrostatic pressure (16 bar) to circulate C_3F_8 through the tracker, without any moving parts in the primary coolant loop. Vapour returns by pressure differential to the above-ground condenser; the lowest pressure part of the system.

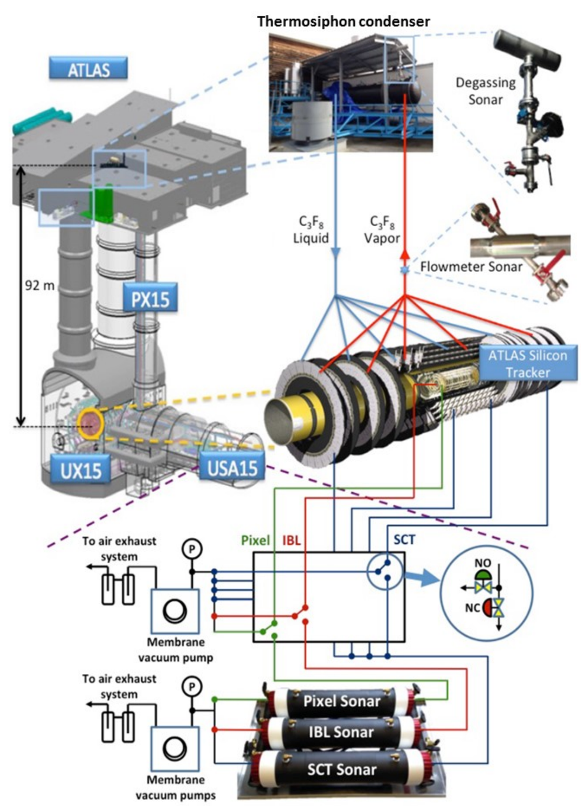

Figure 1: The ATLAS thermosiphon recirculator for the C_3F_8 evaporative cooling of the inner silicon tracker, showing the linked ultrasonic instruments.

The thermosiphon has a cooling capacity of 60 kW and circulates C_3F_8 at a high mass flow of up to 1.2 kg/second.

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STATE MACHINE DESIGN FOR CSNS EXPERIMENT CONTROL SYSTEM

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Abstract

This paper directs attention to the state machine design of the neutron scattering experiment control system in CSNS. The task of the software system is to complete the experiment on spectrometer, the purpose of the state machine design is to work with each other among the subsystems. Spectrometer experiment in CSNS spectrometer by internal control, data acquisition and analysis software, electronics, detector, sample environment and many other subsystems combined，this paper focuses on the introduction of the design details of state machine.

Keyword: CSNS, Neutron Scattering, Experiment Control, software design, EPICS.

INTRODUCTION

CSNS (China Spallation Neutron Source) includes a powerful linear proton accelerator, a rapid circling synchrotron, a target station and three neutron instruments. CSNS Experiment Control System works as an overall controller of all kinds of devices, as well as a manager in charge of running the procedure of experiment correctly and stably [1]. Generally, a neutron experiment at CSNS comprises several interacting modules like control system, detectors, data acquisition(DAQ), and physics analysis. Then control system will gather all the parameters user submitted and compose scan scripts for automation. During the automated execution of scan scripts, control system doesn't only interact with other modules by signaling start/stop to DAQ and Physics Analysis, but also gathers and assembles configuration data and process value, integrates them into a summary file for users tracing back the process of the experiment. Besides, errors are also required to be handled properly in the whole course of experiment process. Moreover, the procedure of each module is changeable on different type of spectrum. On this account, there must be a simple extensible and efficient interacting mechanism that reduces complexity and enhance extensibility when requirement varies in the future, which leads to a stable and maintainable control system. In such design, control system provides GUI for users submitting experiment proposal and making up the controlling procedure of an experiment task. The framework of the CSNS control system is based on EPICS. In a view of data, serving as a data transmission medium, EPICS is a reliable and convenient technique to guarantee stable sending and receiving process value(PV) [2]. PV is designed to be the necessary and sufficient data layer that other modules need to pay attention to. In a view of process, it is also required that specifically stating the interactions between modules to ensure the system handling all kinds of actions under different operating conditions. In this paper, the finite state machine mechanism will be mainly explained how to decompose and process the multiple modules interactive experiment task through the state machine and EPICS service. It provides a more standardized and effective method for task decomposition and processing.

Table 1: Data Flow of a Normal Experiment

Phase	Action	Datafile
Generation	Fetch Configuration information into file.	Spectrum configured Nexus file.
Static data collecting	Collect experimental parameters on OPI.	Experimental proposal Nexus file.
Dynamic data gathering	Gather process values.	Experiment report
Output	Adding the locations of DAQ file.	Experiment summary

DATAFLOW OF EXPERIMENT CONTROL

From a data flow perspective, an experiment summary file, which is generally the product a control system

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THE CERN n_TOF FACILITY DATA ACQUISITION SYSTEM

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Abstract

n_TOF is a pulsed neutron facility at CERN which studies neutron interactions as function of the energy. Neutrons are produced by a pulsed proton beam from the PS directed to a lead target. In a typical experiment, a sample is placed in the neutron beam and the reaction products are recorded. The typical output signals from the n_TOF detectors are characterized by a train of pulses, each one corresponding to a different neutron energy interacting with the sample. The Data Acquisition System (DAQ) has been upgraded in 2014 and is characterized by challenging requirements as more than hundreds of 12 or 14-bit channels at a sampling frequency of 1 GS/s and 1.8 GS/s acquired simultaneously every 1.2 s for up to 100 ms. The amount of data to be managed can reach a peak of several GB/s. This paper describes the hardware's solutions as well as the software's architecture developed to ensure the proper synchronization between all the DAQ machines, the data's integrity, retrieval and analysis. The software modules and tools developed for the monitoring and control of the n_TOF experimental areas and the DAQ operation are also detailed.

INTRODUCTION

The CERN neutron time-of-flight facility n_TOF [1] features a white neutron source produced by spallation through 20 GeV/c protons produced by the PS and impinging on a lead target. The facility, aiming primarily at the measurement of neutron-induced reaction cross sections, was operating at CERN between 2001 and 2004, and then underwent a major upgrade in 2008 with the so called Experimental ARea (EAR) 1. During the CERN long shutdown 2013-14, n_TOF constructed a new experimental area (EAR2) above the spallation source, 10 times closer than EAR1 to the lead target. This allowed increasing the neutron flux by about 40 times. A whole renovation of the DAQ was also done, focused both on the software and the hardware, by increasing the number of readout electronic channels to cover EAR2 and the new physics challenges.

THE N_TOF DAQ REQUIREMENTS

The typical n_TOF DAQ measurement application consists in the digital acquisition of the detectors output signals to perform time domain analysis. The signal shape is a pulse train where each pulse amplitude is proportional to the energy of the neutron interaction products, the rise/falling time to the detector type and the integral to the neutrons flux. The acquisition time window for each PS pulse corresponds to the whole neutron energy range, i.e. from a gamma flash detected when the proton beam impinges on the target until approximatively 100 ms for thermal neutrons (the slowest ones) which travel a 185 m path to the EAR1. This also corresponds to the longest time window since the travel path to the EAR2 is only of 20 m, which gives an acquisition time window of about 10 ms. The acquisition is triggered by the PS timing signal and the data samples should be transferred to the memory of the host controller before the next acquisition starts again 1.2 s later. Data are stored permanently on the CERN Advanced Storage (CASTOR) [2]. The architecture is conceived to be modular with different ADC multichannel cards, distributed on several chassis equipped with a host controller running Linux CentOS 7 (DAQ units).

The key parameters of the digitizers are:

- The **ADC front-end** to match all the possible signals from the different detectors (bandwidth and amplitude). A variable input gain and a bias adjustment is preferable to use the entire ADC dynamic range.
- **ADC resolution and sampling frequency**: the detector signal noise floor gives an indication of the ADC resolution needed whilst the signal shape, rise time and duration, specify the minimum sampling frequency needed.
- **On board memory size**: there should be enough local memory on the digitizer to store the entire acquisition time window per channel at the maximum sampling frequency.
- **Card Data interface**: the digitizer data interfacing has to transfer on time all the channels' samples related to the maximum time window to the host controller memory, before the next PS cycle (1.2 s).

THE N_TOF DAQ COMPONENTS

The global DAQ hardware architecture for each experimental area is depicted in Figure 1.

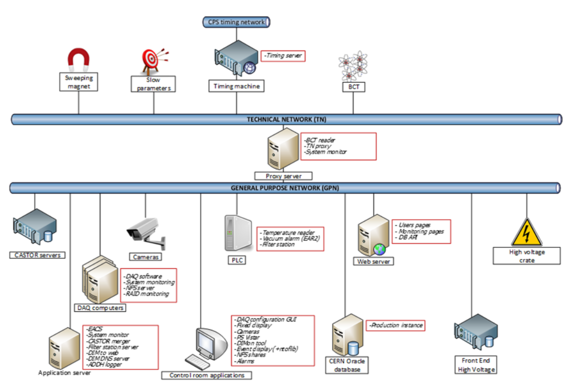

Figure 1: n_TOF DAQ hardware architecture.

The DAQ Units

Each DAQ unit hosts several high sampling Data Acquisition Cards (DAC) as well as the high writing speed local storage able to sustain the raw data bandwidth related to a maximum acquisition window of 100 ms. It guarantees a data buffer for 3 days of acquisition in nominal operation

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AUTOMATIZED OPTIMIZATION OF BEAM LINES USING EVOLUTIONARY ALGORITHMS

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Abstract

Due to the massive parallel operation modes at the GSI accelerators, a lot of accelerator setup and re-adjustment has to be made during a beam time. This is typically done manually and is very time-consuming. With the FAIR project the complexity of the facility increases furthermore and for efficiency reasons it is recommended to establish a high level of automation. Modern Accelerator Control Systems allow a fast access to both, accelerator settings and beam diagnostics data. This provides the opportunity together with the fast-switching magnets in GSI-beamlines to implement evolutionary algorithms for automated adjustment. A lightweight python interface to CERN Front-End Software Architecture (FESA) gave the opportunity to try this novel idea, fast and easy at the CRYRING@ESR injector. Furthermore, the python interface facilitates the work flow significantly as the evolutionary algorithms python package DEAP could be used. DEAP has been applied already in external optimization studies with particle tracking codes [1]. The first results and gained experience of an automatized optimization at the CRYRING@ESR injector are presented here.

INTRODUCTION

FAIR – the Facility for Antiproton and Ion Research – will constitute an international center of heavy ion accelerators that will drive forefront heavy ion and antimatter research. The goal of the FAIR facility is to provide antiproton and ion beams of unprecedented intensities as well as qualities. As a special feature, the facility will provide a broad range of high-intensity ion, antiproton and rare-isotope beams parallel to multiple experiments.

The High Energy Beam Transport System of FAIR, with a total length of more than 2350 meters, forms a complex system connecting seven accelerator- and storage rings, the experiment caves, beam dumps, stripping stations, the antiproton target and the Super Fragment Separator. The variety of beams to be transported is considerable, ranging from slow extracted beams with long spills of up to 100 s to short intense bunches with lengths of a few nanoseconds and momentum spreads of up to ±1%. The range of beam intensity covers more than six orders of magnitude [2]. The complexity of the FAIR facility demands a high level of automation for future operation, because otherwise the anticipated manpower requirements for operators would be

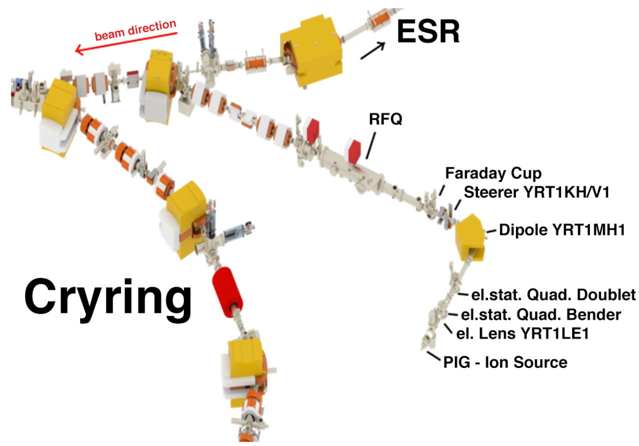

Figure 1: The settings of the steerers and electrostatic quadrupoles between ion source and Farady Cup after the dipol of CRYRING@ESR injector at GSI have been automatized optimized with evolutionary algorithm to maximize the beam transmission.

excessive, as shown in [3]. Modern accelerator control systems allow a fast access to both, accelerator settings and beam diagnostics data. This provides the opportunity to implement algorithms for an automated adjustment. Therefore, the Parameter Evolution Project (PEP) has been launched for automatized online parameter optimization in beam lines. An automatized machine based optimization using genetic algorithms for a storage ring has been already successfully demonstrated experimentally [4].

In the frame of the Swedish in-kind contribution to the FAIR project the storage ring CRYRING@ESR is planned to be used for experiments with low-energy ions and antiprotons. The ring is already installed in the existing GSI target hall and commissioning has started in 2015 [5, 6]. Since CRYRING@ESR has its own local injector it can be used stand-alone for testing novel technical developments like automatized configuration of beam line devices. Figure 1 shows the part of the CRYRING@ESR injector (from ion source to Faraday Cup), which has been used for testing automatized online evolutionary algorithm optimization. A semi-automatized optimization has been already preformed at the CRYRING in Sweden [7].

PYTHON INTERFACE TO FESA AND LSA

Currently, most of the GSI facility is undergoing heavy construction work or large up-grade measure and is therefore not available for beam time until 2018. An exception is the

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A SUB-PIXEL AUTOMATED FEATURE-BASED ALIGNMENT FOR TOMOGRAPHY EXPERIMENTS *

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Abstract

Three-dimensional image reconstruction in X-ray computed tomography (XRCT) is a mathematical process that entirely depends on the alignment of the object of study. Small variations in pitch and roll angles and translational shift between center of rotation and center of detector can cause large deviations in the captured sinogram, resulting in a degraded 3D image. Most of the popular reconstruction algorithms are based on previous adjustments of the sinogram ray offset before the reconstruction process. This work presents an automatic method for shift and angle adjust of the center of rotation (COR) before the beginning of the experiment removing the need of setting geometrical parameters to achieve a reliable reconstruction. This method correlates different projections using Scale Invariant Feature Transform algorithm (SIFT) to align the experimental setup with sub-pixel precision and fast convergence.

INTRODUCTION

Synchrotron computed tomography (CT) has made significant progress concerning the spatial resolution achieving nanometric precision using conventional transmission CT. Nevertheless, determination of geometrical parameters with subpixel precision is becoming extremely challenging. Ideally, the projection of the center of rotation has to be collinear to the center of detector, which is a hard condition to be satisfied in a real experimental setup [1].

The two main factors to ensure the accuracy of the image reconstruction is the position and the perpendicularity of projected COR. Some authors showed that a deviation on COR bigger than 1 or even 0.4 pixels can cause artifacts in the reconstructed image [4, 6]. Figure 1 illustrates a typical fan-beam CT. The main objective of this work is to create an alignment method to minimize τ_0 in each horizontal line of the detector to eliminate the existence of artifacts in the reconstruction process. For achieve this is necessary the correct positioning of the COR and also ensure its orthogonality.

Robust algorithms have already been created by several authors to find COR position before reconstruction [2, 5], however it differs from this work because our process is performed before the beginning of the experiment. Due to possible small sample movements during the experiment it is still interesting to perform the COR search before the reconstruction but this align method can drastically reduce the computational effort of this step.

* Work supported by Brazilian Center for Research in Energy and Materials (CNPEM)

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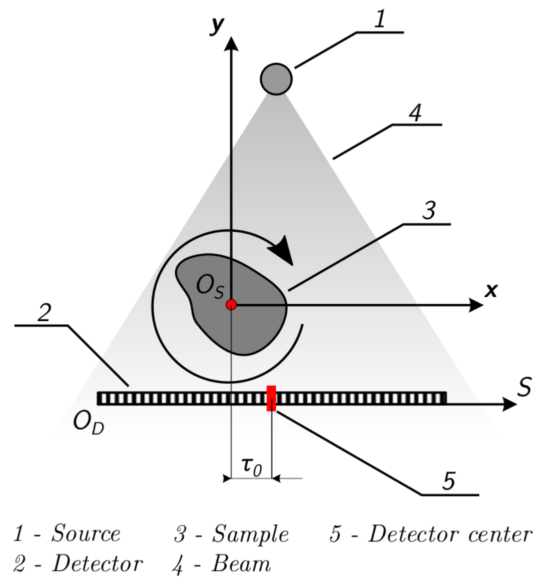

Figure 1: Illustration of a cone-beam tomography experiment.

The alignment process is performed in two steps. The first one is related to the variation of pitch and roll angles and the second one is related to the linear position of the sample in relation to the detector. Ideally pitch and roll should be aligned only when sample or detector stages are translated and the sample should be aligned always before any experiment.

Pitch and Roll Alignment

For perfect alignment of the pitch and roll angles the COR projection must be exactly parallel to the detector plane. Thus, when a rotation is performed the heights of the sample features are not affected. Figure 2 illustrates sample projections at positions 0 and 180 degrees with a fully aligned COR and with sample within the field of view. The light gray ellipse represents a projection of the sample at zero degrees position and the dark gray ellipse represents a projection of the sample at 180 degree. Colored circles represent sample features. The red axis represents the center of field of view, ie the center of detector. The yellow axis represents the center of sample and blue is COR.

The objective function to be minimized in this case is the average of the absolute variation of the feature heights, given by equation 1. Where n is the number of true matches.

$$\overline{\Delta Y} = \frac{\sum_{k=1}^{k=n} \Delta Y_k}{n} \quad (1)$$

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DEVELOPMENT OF MQTT-CHANNEL ACCESS BRIDGE

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Abstract

The integration of the Data Acquisition, Offline Processing and Hardware Controls using MQTT has been proposed for the STAR Experiment at Brookhaven National Laboratory. Since the majority of the Control System for the STAR Experiment uses EPICS, this created the need to develop a way to bridge MQTT and Channel Access bidirectionally. Using CAFE C++ Channel Access library from PSI/SLS, we were able to develop such a MQTT-Channel Access bridge fairly easily. The prototype development for MQTT-Channel Access bridge is discussed here.

INTRODUCTION

Most of the STAR (Solenoidal Tracker At RHIC) Experiment Control System has been based upon the EPICS (Experimental Physics and Industrial Control System) from the beginning. Currently roughly 60,000 parameters are controlled and monitored with EPICS. Recently, MQTT [1] has been chosen to integrate the STAR DAQ, Offline, and Control Systems. As there was no MQTT-Channel Access bridge available, we needed to develop one.

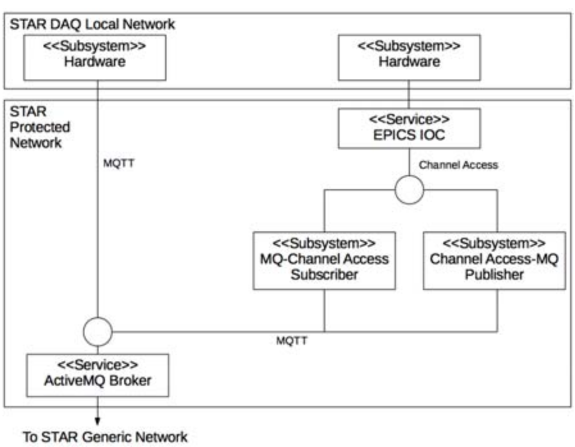

Figure 1: Schematics of the STAR Control Integration plan.

Figure 1 shows the schematic diagram of the STAR Integration plan. [2] The MQTT Broker further publishes the data to the STAR Generic network and the data will be accessible via WebSocket such that it can be viewed via a web browser.

At the moment, the existing EPICS infrastructure will remain as it is. In the STAR Control Room, we use various EPICS tools such as Alarm Handler [3], MEDM [4], and Control System Studio [5] during the commissioning and the data-taking period of the experiments as we have been doing for the past 17 years. EPICS to MQTT is a first stage transition but new detector sub-systems seem to be going the native MQTT way.

MESSAGE QUEUE TELEMETRY TRANSPORT: MQTT

MQTT was initially developed by IBM and Eurotech in 1999. Originally, it was intended for an oil pipeline to satellite communication link. It was internally used and maintained by IBM until 2010. In 2010, the version 3.1 was released royalty free. In 2013, International Standards Organization OASIS begin officially advocating MQTT as a lightweight, open source solution for device to device communications. In 2016, ISO officially approved MQTT version 3.1.1 as an ISO standard (ISO/IED 20922). MQTT has been very popular choice among Internet of Things (IoT) as the communication protocol.

MQTT protocol typically runs on top of TCP/IP as well as UDP and Zigbee. It is relatively simple and easy to implement. It is lightweight and bandwidth efficient. It is based upon a publish and subscribe architecture and the Quality of Service (QoS) is built-in to the protocol. Unlike Channel Access, it requires a Message Broker that functions as a communication hub on the network. In MQTT, the data are called as messages. The message is in ASCII based format. MQTT also use topic as filter and categorize the messages in the broker. The topic could be used by the clients to get only the information they need. Figure 2 is the MQTT schematic diagram illustrating the overall MQTT concept.

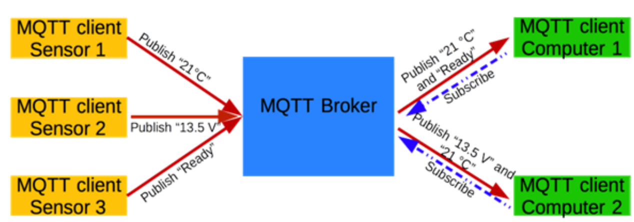

Figure 2: MQTT concept diagram.

MQTT-CHANNEL ACCESS BRIDGE

The prototype MQTT-CA bridge was written using standard Channel Access C library. While it is possible to accomplish the same in Python or Java, C was chosen, as that provided more powerful sets of libraries as well as the request from one of the STAR experts from a different system. Since we needed an MQTT library, we chose the Paho [6] library, which supports C/C++ as well as Python, Java and many others. For EPICS Channel Access, we used the standard EPICS portable Channel Access C library that comes with EPICS Base 3.14.

The message broker needed for the MQTT had already been chosen by the time the Control Group was involved for the project; the STAR Experiment has adopted Apache ActiveMQ Apollo [7] for the message broker.

The first prototype was written in about two weeks, including the time to setup the broker and understand the

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BART: DEVELOPMENT OF A SAMPLE EXCHANGE SYSTEM FOR MX BEAMLINES

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Abstract

Automation plays a key role in the macromolecular crystallography (MX) beamlines at Diamond Light Source (DLS). This is particularly evident with sample exchange; where fast, reliable, and accurate handling is required to ensure high quality and high throughput data collection. This paper looks at the design, build, and integration of an in-house robot control system. The system was designed to improve reliability and exchange times, provide high sample storage capacity, and accommodate easy upgrade paths, whilst gaining and maintaining in-house robotics knowledge. The paper also highlights how peripheral components were brought under the control of a Programmable Logic Controller (PLC) based integration unit, including a vision system.

INTRODUCTION

Data collection on Diamond's [1] Macromolecular Crystallography beamlines [2] involves working through hundreds of crystallised macromolecules mounted on small sample holders and stored in liquid nitrogen. Each sample needs to be mounted on a rotatable stage before being exposed to the X-ray beam. The data collected are the diffraction patterns created by the beam passing through the mounted crystal. [3]

Robotic arms are ideal for the mundane process of exchanging samples: moving them from inside a storage dewar of liquid nitrogen to the mounting point and back again. Their motions are precise and repeatable even at high speeds, they can operate in the controlled radiation area of the experiment hutch and the gripper tools can be engineered to operate with liquid nitrogen. They also offer great flexibility; very useful on beamlines where equipment and configurations can change and develop frequently.

The DLS MX beamlines have been using robots for sample exchange since 2007, employing either Rigaku ACTOR robotic systems [4] or IRELEC CATS robotic systems [5]. Diamond's data acquisition software (GDA) [6] communicated with the Rigaku or IRELEC control software directly to trigger robot actions. Three beamlines used Rigaku ACTOR robots which used a Mitsubishi RV-6S robot arm and two beamlines used the CATS robots, which utilised a Staubli TX60 arm.

These systems worked well but over time, as beamline technology developed and data collections became quicker, both systems required significant upgrades to increase sample capacity and reduce sample exchange times.

A project was created with the goals of fully integrating a robot system into the beamline control system, to upgrade and optimise peripheral devices to improve performance and reliability and, through this process, to gain and maintain in-house automation knowledge allowing for better local support including faster problem resolution. The decision was made to develop a single robotic system, based around a Mitsubishi RV-6SL arm that could be installed on all of the MX beamlines with only minor customisation required.

This would be achieved by moving software device support to EPICS [7], creating our own integration unit built around a PLC, and the redesign of supporting components and peripherals to maximise performance and cater for future upgrade paths. (See Fig. 1)

INTEGRATION UNIT

The complete system consists of many components, each requiring a software interface and their own control requirements. The role of the integration unit is to connect all these separate peripherals to a common interface with which the software can communicate, whilst also providing low level logic and feedback control. The decision was made to build the unit around an Omron CJ2M CPU33 Ethernet PLC [8]. This model is used extensively at DLS for all the machine protection systems and so was already familiar to our engineers, with proven performance, reliability and versatility, and with established EPICS software support. It can also be supported by stock parts, removing the cost and overhead of maintaining an independent spares set.

The unit controls the robot's gripper, drier, beacon, computer vision system, liquid nitrogen fill control, and dewar heaters. In addition, by passing all of the robot's input and output channels through the integration unit, it allows these signals to be overridden by the PLC, either pulled high or pulled low. This is incredibly useful for testing and debugging, or simulating an input from a failed or missing component on the beamline.

DEWAR AND LIQUID NITROGEN SYSTEM

Sample storage dewars for MX beamlines need to have high capacity, reliable autofill systems and should be designed to minimise ice build-up in or around the dewar. The dewar used in the BART system is based on a design developed by the P11 beamline at PETRA [9] and manufactured by CryoTherm [10]. Up to 592 samples can be accommodated within the dewar.

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CUSTOMIZATION OF MXCuBE 2 (Qt4) USING EPICS FOR A BRAZILIAN SYNCHROTRON BEAMLINE

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Abstract

After studying some alternatives for macromolecular crystallography beamlines experiment control and had considered the effort to create an in-house made solution, LNLS decided to adopt MXCuBE [1]. Such decision was made considering main technologies used to develop it, based on Python, which is being largely used in our laboratory, its basic support to EPICS (Experimental Physics and Industrial Control System), the control system adopted for the LNLS beamlines, and because of its stability. Then, existing MXCuBE implementation has been adapted to cover LNLS requirements, considering that previously it was mainly ready to control systems other than EPICS. Using basic MXCuBE engines, new classes were created on devices abstraction layer, which communicates to EPICS IOCs (Input/Output Controllers), like AreaDetectors, MotorRecords among others. Py4Syn [2] was employed at this abstraction layer, as well. New GUI components were developed and some enhancements were implemented. Now, MXCuBE has been used on LNLS MX2 beamline since the end of 2016 with positive feedback from researchers. The adoption of MXCube proved to be right, given its flexibility, performance and the obtained results.

MOTIVATION

LNLS macromolecular crystallography beamline, MX2, has been reformed to be the base for its correspondent on Sirius, new Brazilian Synchrotron Light Source. During it, software control systems were also revised. EPICS was kept as the basic control system for devices operation, and using that we looked for a better GUI to offer a good experience for researches when performing experiments on MX2. In the past, some GUI solutions were tested on such beamline, like Blu-Ice [3] and an in-house development based on CS-Studio [4], but they were not totally well-succeeded.

Because MX2 coordinator, Ana C. M. Zeri[‡], had experienced the usage of MXCuBE on ESRF, she asked software support group of LNLS to take a look at it as an alternative, and then we started to customize it for our environment.

ARCHITECTURE OVERVIEW

Main organization of MXCuBE Qt4 was kept untouched; the basic support for EPICS was used but modified in some parts to allow the usage of Py4Syn. As other laboratories that contribute to MXCuBE development do, we created new folders named LNLS on layers that abstract hardware objects and their configuration. This way, we could develop our own Python classes with procedures performing operations according to our equipment and necessities.

An overview of MXCuBE architecture we customized to offer full experiment operations control for researchers of MX2 beamline at LNLS is presented on Figure 1.

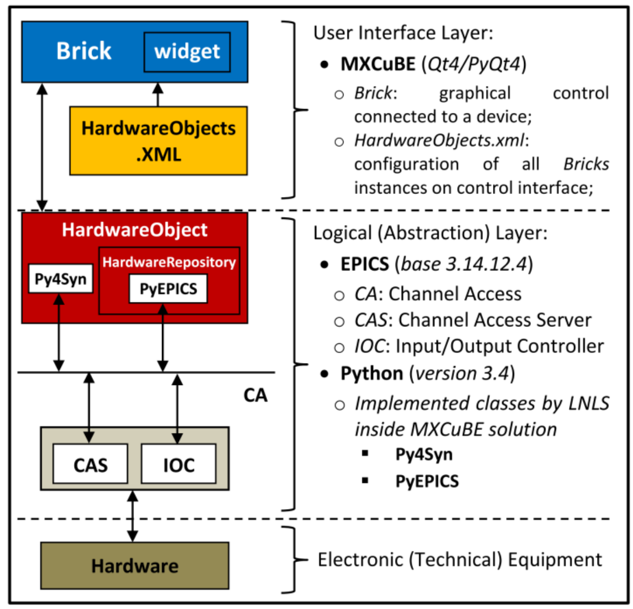

Figure 1: Overview of MXCuBE for LNLS Solution Architecture

Electronic (Technical) Equipment

At lower level of control system are the typical technical devices present in synchrotron beamlines. In fact, they have their own controllers which receive instructions, via serial (RS232/RS248) or Ethernet connection, for example, and then command the equipment. Some devices present in MX2 beamline of LNLS are:

- Galil DMC-4183: motor controller
- Parker OEM750: motor controller
- Kollmorgen S300: motor controller (air bearing)
- Heidenhain MT 2501: optical encoder
- Keithley 6485: picoammeter
- Cryojet: temperature controller of cryogenic cooling system
- Stanford SR570: low noise current preamplifier
- Dectris Pilatus 2M: CCD camera
- IDS GigE uEye: industrial camera (view sample)
- Stäubli CS8: robot controller (sample changer)

Logical (Abstraction) Layer

Over the devices controllers is the first abstraction of them, build in EPICS, with correspondent IOCs

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CLARA VIRTUAL ACCELERATOR

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Abstract

STFC Daresbury Laboratory is developing a novel Free Electron Laser (FEL) test facility focussed on the generation of ultra-short photon pulses of coherent light with high levels of stability and synchronisation. The main motivation for CLARA[1] is to test new FEL schemes that can later be implemented on existing and future short wavelength FELs. Particular focus will be on ultra-short pulse generation, pulse stability, and synchronisation with external sources. Knowledge gained from the development and operation of CLARA will inform the aims and design of a future UK-XFEL. To aid in the development of high level physics software, EPICS, a distributed controls framework, and ASTRA, a particle tracking code have been combined to simulate the facility as a virtual accelerator.

This paper will discuss how a EPICS [2], a distributed controls framework, and ASTRA [3], a particle tracking code, are used to simulate electron bunches in a virtual accelerator. The simulation is currently used by the accelerator physics group as a rapid application development framework for high level physics software. It is also being used by the controls group to test high level interfaces to CLARA. The simulation contains magnets; diagnostic screens; BPMs and camera beam positions; and low level RF. The next stage is to develop a more detailed simulation for the cameras and BPMs. Another objective is to distribute the transport code to external servers to increase the number of simulated particles.

INTRODUCTION

The Compact Linear Accelerator for Research and Applications, CLARA [1] is being developed using Daresbury's existing expertise and experimental experience of electron accelerators and FELs. Of note are VELA, the Versatile Electron Linear Accelerator, which will share a common front-end with CLARA. Daresbury has also worked with an IR FEL on the superconducting accelerator ALICE [4, 5].

CLARA consists of several major subsystems that themselves contain many individual devices. The FEL will requires tight tolerances on all these devices to operate. A suite of high level physics software and automation will be needed to control the FEL. The controls and accelerator physics groups wanted the ability to test and develop concepts in simulation before they are deployed. These requirements drove the development of the virtual accelerator.

CLARA consists of timing, magnets, beam position monitors (BPM), beam shaping, vacuum control, RF systems, electron gun, environmental controls and lasers. The operation of all these devices is handled by EPICS, a distributed control framework. EPICS provides tools to develop custom device drivers and the control logic for connected devices under time critical constraints. EPICS also provides a uniform interface to manage operations over a dedicated controls network using process variables (PVs). Using PVs over the dedicated CLARA control network allows operator applications, data-logging, high level software or even other EPICS controlled devices to communicate and interact across the machine seamlessly.

The core of EPICS is a server called the IOC, see Figure 1. The IOC will signal its presence over a control networks to other EPICS compatible clients and manage PV requests. CLARA will have many tens of IOCs and thousands of PVs running simultaneously when the machine is in operation. This is itself a major challenge that the virtual accelerator is helping to address.

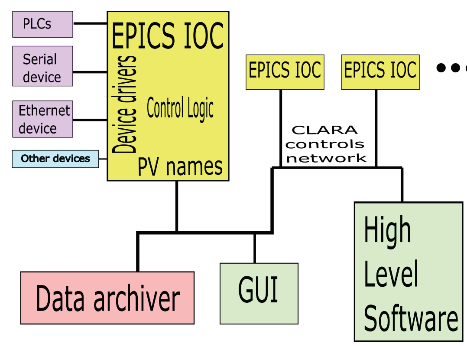

Figure 1: EPICS IOC and PVs.

PREVIOUS VIRTUAL ACCELERATORS: EMMA

Simulations of accelerators have been employed at KEKB [6], the SNS linac [7], Diamond [8], J-PARC [9], TPS, Taiwan [10].

Two main functions of a simulation tool were described by Yamamoto:

- For rapid application development (RAD)

"Tightly integrated modelling code in a control system, or a virtual accelerator, is also useful as a RAD tool in the construction of an accelerator control system. Application programmer and/or an accelerator physicist can develop a code without waiting for the completion of hardware installation. Realistic response using the VA will help the development of high level applications in the control system."

- A simulation as a "Flight Simulator"

"Trainee of the accelerator operation can learn the response of the system even in a situation which should not occur in the real machine. 'Flight simulator' allows accelerator physicist to examine his/her algorithm without disturbing the operation."

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COMMUNICATION ARCHITECTURE OF THE DETECTOR CONTROL SYSTEM FOR THE INNER TRACKING SYSTEM

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Abstract

This paper presents the proposed communication architecture of the Detector Control System (DCS) for the Inner Tracking System (ITS). The purpose of the DCS is to acquire and control the states of the ITS. Since the ITS is not yet fully implemented, an emulator of the communication architecture is being developed. The proposed architecture comprises five levels. At the bottom, the detector is emulated by sensors connected to microcontrollers. Each microcontroller is then connected to a Raspberry Pi which represents the ALICE low-level front- end (ALF) electronics at the second level of communication architecture. The third level is represented by Front-End Device (FRED), a Linux server where more than one ALF device can be connected. FRED is then connected to the fourth level, implemented by the SCADA interface – WinCC OA. Above all these levels is an archiving and configuration database setup. Configuration bypasses the SCADA interface and is managed directly through FRED. The purpose of the emulator is to verify the proposed architecture in terms of data throughput and cooperation of the mentioned modules.

INTRODUCTION

Since 2012, the Technical University of Košice, represented by the Center of Modern Control Techniques and Industrial Informatics at the Department of Cybernetics and Artificial Intelligence, Faculty of Electrical Engineering and Informatics has been the member of the ALICE project and since 2015, the full member of the ALICE Collaboration in CERN. During this time, its members have worked on several assigned tasks. One of the tasks carried out by our team is the development of a new communication mechanism dedicated to the front-end electronics control and monitoring to be used in the ALICE experiment at CERN. A new architecture called ALFRED (Alice Low-level Front-end Device) is now being tested using various electronics prototypes. The final version of the software will be deployed for the new inner tracker system (the ITS) currently developed by the ALICE collaboration [1], [2].

The new data acquisition architecture for ALICE [3] requires a complete redesign of the front-end access mechanism. A modular, scalable and reliable architecture is required to controls the front-end modules installed in the experiment. This paper focuses on the developments serving as verification of the concept and base for the final implementation. After the proposal of the communication architecture, tests to obtain throughput of this architecture were performed.

DETECTOR CONTROL SYSTEM AND INNER TRACKING SYSTEM

The present inner tracker of the experiment has been designed to cope with the requirements of the LHC operation until 2018. During its operation its performance fulfilled the expectations. However, the architecture of the ITS is not compatible with the new requirements after the planned LHC upgrade. The ALICE experiment operation at high luminosities triggers a need for faster detector readout and improved tracking capabilities. The new ITS composed of pixel detectors replaces the present tracker, combining silicon pixel, strip and drift detector technologies.

Detector Control System

Detector Control System (DCS) continuously ensures secure and stable operation of all sub-detectors as well as the entire ALICE detector. DCS provides remote control and monitoring of all systems. DCS uses various industrial as well as custom devices such as low and high voltage power supplies, PLC computers, custom made data acquisition boards or front-end electronics. They are hierarchically interconnected within a distributed control system. The majority of these devices communicate via Ethernet, controlled either by industrial standards such as OPC or the DIM protocol [4] developed at CERN. Other devices use other industry standard buses such as CANbus, Profibus or RS232.

Supervision of individual devices is provided by SCADA/HMI software WinCC OA from Siemens using the JCOP framework. WinCC interface enables a single operator to operate the whole ALICE experiment. Within the ALICE experiment, each detector has its own independent distributed control system containing from 2 up to 16 WinCC OA systems. All of these systems are interconnected by a central DCS, comprising together one complex system. Control hierarchy of the entire detector and all its subsystems is made up of finite state machines (FSM) organized into multi-layer tree structure.

Detector Control System for Inner Tracking System

The structure of the new ITS control system follows the new architecture of the detector as seen in Fig. 1. The main changes in the traditional design are mainly in the frontend part, which will be accessed by the GBT link [5], shared with the data acquisition system. The physics data, containing the information about the particle trajectories, is sent to the further levels of processing implemented in the O2 facility [3]. The conditions data supervised by the DCS is processed in the SCADA system and a subset of the

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ADVANCED PROCESS CONTROL TOOL FOR MAGNET MEASUREMENT AT PSI

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Abstract

Magnet measurements at the Paul Scherrer Institute (PSI) are performed with the use of a process control tool (PCT), which is fully integrated into the PSI control system. The tool is implemented as a set of user friendly graphical user interface applications dealing with particular magnet measurement techniques supported at PSI, which include advanced Hall probe, vibrating wire, and moving wire methods. The core of each application is the state machine software developed by magnet measurement and control system experts. Applications act as very efficient assistants to the magnet measurement personnel by monitoring the whole measurement process on-line and helping to react in a timely manner to any possible operational errors. The paper concentrates on the PCT structure and its performance.

INTRODUCTION

Charged particle accelerators and their experimental stations at PSI contain a number of various magnetic field generating components: dipoles, quadrupoles, solenoids, etc. The quality of these components, which are usually referenced as magnets, strongly affects the accelerator and experiment capabilities. To assure that all magnetic field quality specifications are met, such components are systematically measured at the PSI magnet measurement laboratory (MML). The equipment of this laboratory was significantly upgraded few years ago. In parallel with this upgrade, an advanced magnet measurement data acquisition and control system (MMDACS) was created. The system was implemented as a part of the PSI controls environment, which is based on EPICS [1].

Major features of this system were presented at the ICALEPCS'13 conference [2]. Since then, the system was consistently showing its high efficiency and reliability in all magnet measurements at the MML. It was also successfully adapted to an advanced 3D Hall probe setup and a new 64 bit Linux PC platform at PSI. The main activities around MMDACS, though, were concentrated on the development and enhancement of user friendly control applications that can efficiently assist operators in routine magnet measurement procedures. The result of such activities is a magnet measurement process control tool (PCT). The tool consists of a set of applications specialized in particular magnet measurement techniques supported at PSI, which include Hall probe, vibrating wire, and moving wire methods. The core of each application is the state machine software designed by magnet measurement and control system experts.

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HALL PROBE MEASUREMENT COMPONENTS AND PROCESS CONTROL APPLICATION

Magnetic field mapping at the PSI is performed by Hall probes. Measurements are done with the use of a Magnet Measurement Machine (MMM). To provide stable long-term measurement conditions, the machine is located in a temperature controlled (±0.1° C) room. A magnet is positioned on the measurement bench with the use of the extremely accurate portable coordinate measuring system FaroArm Quantum system.

Five MMM stepper-motors can move a Hall probe, which is mounted on a titanium arm, in three translation directions or axes (X, Y, Z) as well as rotate it in the horizontal plane and around the arm. Since rotations are used only for proper probe positioning in space, any particular measured field map at the PSI corresponds to a line, a plane, or a volume in the Cartesian coordinate system (X, Y, Z). The measurements are performed in a "continuous scan on the fly" mode, which means that the MMM doesn't stop to make a particular measurement. This allows one to finish a complex field mapping process for each magnet in a relatively short time period, which is typically one day or less.

The MML possesses a set of classical Hall probes, which are sensitive to only one magnetic field component or one-dimensional (1D) by design. Recently, this set was enhanced by an innovative, in-house developed, high accuracy 3D Hall probe [3]. This probe consists of three pairs of 1D Hall probes forming a sub-millimeter cubic active volume (see Fig. 1) and, therefore, is sensitive to all three magnetic field components.

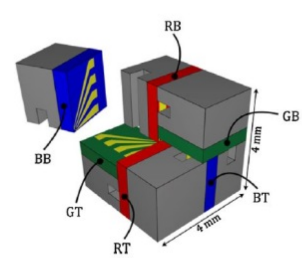

Figure 1: PSI 3D Hall probe structure. For clarity, pairs of 1D Hall probes sensitive to the same direction of the magnetic field are shown in the same color (blue: sensors BB and BT, green: sensors GB and GT, red: sensors RB and RT).

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LISE/M – A MODERNISED AND UNIFIED MODULAR EXPERIMENT CONTROL SYSTEM FOR HZB BEAMLINES

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Abstract

After more than 15 years of stable operation it was time to develop a new standard experiment control and data acquisition system for HZB beamlines. The aim is to create a modular system based on commercial hardware components. Because of the convincing hardware interfacing and good experience with PXI devices we choose this as hardware platform and LabVIEW as software development system.

Starting in late 2015, we developed a framework with modules for configuration, (scan) processing, device communication, logging etc. The user interface is bisected as (i) graphical and (ii) scripting version. Where the 'included' script engine is python.

The system serves both, standard commissioning tools as well as specialised instrument setups. It is integrated into the metadata catalouge system (ICAT) of the HZB in terms of collecting log and meta data and storing those according to the data policy of the institute [1].

We present an overview of the system features in general and a specific instrument view of a rather complex beamline at HZB.

INTRODUCTION

A system of inhouse-developed hardware and software has been the standard measuring equipment used at the HZB storage ring. The components were working reliably but became more and more difficult to maintain. First ideas about an improved replacement based on commercial hardware components with a flexible software architecture lead to a first prototype in 2013. In 2015 this development became a regular project watched by the HZB management.

Influenced by results of projects like 'unified log data management' [2] the project started as MoVE (modernisation and unification of experiment control systems at the storage ring BESSYII) [3]. Putting emphasis on a modular design and based on best experiences with PXI hardware and the LabVIEW software stack, these components were chosen as a development base. In development our focus have been beamlines at the storage ring but the framework should serve as universal experiment control system.

ARCHITECTURE

The architecture of the LabVIEW program is based on a textual message bus (see figure 1). All modules are connected to this bus and send messages by event while receiving data by queues.

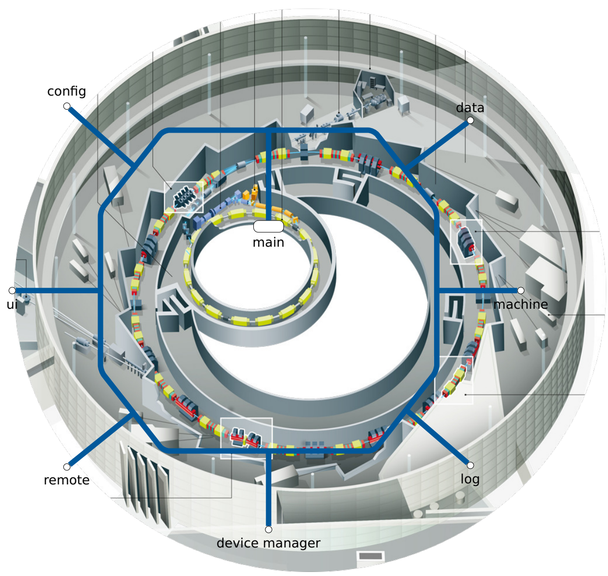

Figure 1: LISE's message bus system.

The message bus uses a common command set with a common command structure (message format):

```
sender|time stamp|instruction|[parameter]
```

Since all modules implement this textual command interface it is a relativly easy task to add new modules to the system.

Internally the bus is a slightly modified queued message handler approach with control queues for each module and an event subscriber bus for the module replies. Modules implement an individual queue for all regarding messages to avoid parsing 'classical' bus messages with an address header. The send direction of messages is handled via events. Each module broadcasts messages and any interested party could subscribe to this event bus to read and evaluate all relevant module answers.

The general system configuration is stored in XML files. An user friendly editor is provided to enable instrument scientists to set up e.g. device parameters and EPICS parameters. Experienced users could even change elements of the graphical user interface (see figure 6).

A special section is provided for user defined stuff as data file columns, additional devices etc. This is meant as the only section of config files for user access.

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RAPID CONTROL PROTOTYPING TOOL FOR THE SIRIUS HIGH-DYNAMIC DCM CONTROL SYSTEM

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Abstract

The monochromator is known to be one of the most critical optical elements of a synchrotron beamline. It directly affects the beam quality with respect to energy and position, demanding high stability performance and fine position control. The new high-dynamic double-crystal monochromator (HD-DCM) [1], prototyped at the Brazilian Synchrotron Light Laboratory (LNLS), was designed for the future X-ray undulator and superbend beamlines of Sirius, the new Brazilian 4th generation synchrotron [2]. At this kind of machine, the demand for stability is even higher and conflicts with factors such as high-power loads, power load variation, and vibration sources. To identify and ensure sufficient control of the dynamic behaviour of all subcomponents in the prototype, an implementation in MATLAB/Simulink Real-Time environment in a Speedgoat Real-Time Performance Machine was developed. This approach enables rapid prototyping, by allowing a shared environment for system modeling and testing. The tool was developed in a modular architecture aiming at practical model iteration and platform migration to standard beamline controllers, which can prove portability and scalability features.

INTRODUCTION

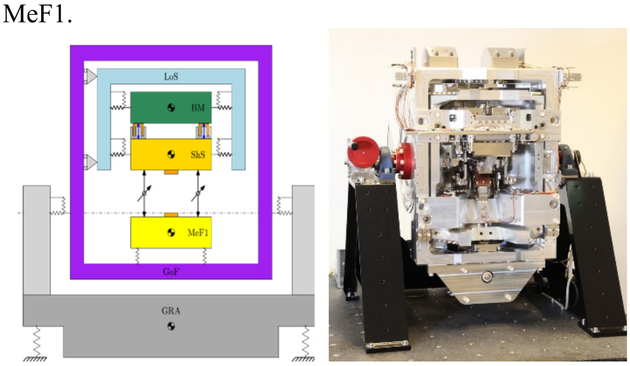
The first beam for Sirius, the new 4th generation synchrotron light source being built in Brazil, is planned for mid-2018. When fully operational, Sirius promises to deliver a beam with very low emittance (250 pm.rad) and high brilliance [3], putting this facility amongst the best in the world for its energy range. This will enable beamlines to perform time-resolved experiments or use nanobeams to increase the flux and resolution at the sample even further, pushing for new performance standards for all kinds of beamline instrumentation and optics [4]. At X-ray beamlines, key factors as photon flux, energy selection, and beam positioning at the sample may be directly affected by instabilities of a Double-Crystal Monochromator (DCM), resulting in a decrease of the beamline experiment performance [5]. This way, not only the mechanical systems and mechatronics concepts had to be reviewed for this new generation DCM, but also the control system had to be quickly adapted to a new demand level. The concept review resulted in the HD-DCM, a system with high noise rejection and trajectory tracking capability. Considering the upcoming tight deadlines for having not only the HD-DCM system, but also other instruments with similar complexity, fully commissioned at Sirius, a Rapid Control Prototyping (RCP) tool became necessary to speed up control design and testing phases.

This paper describes the implementation of such an RCP tool for the new HD-DCM. In the next sections, an introduction to the control system parameters of the HD-DCM is followed by a brief description of the RCP concept and the hardware chosen for this project. Then, a detailed description of the software architecture implemented in MATLAB/Simulink environment and a quick report of the system performance and advanced capabilities are presented.

It is important to say that this implementation is meant for prototyping purposes only and that its architecture and parametrization also focuses on a smooth migration to the standard platform of advanced applications control for Sirius beamlines [6].

HIGH-DYNAMIC DCM

The HD-DCM is a completely reviewed version of the usual DCM systems, designed to bring parallelism stability between crystals to the level of a few nanoradians. As depicted in Fig. 1a and more detailed in [5], [7], the core of the DCM comprises: the main rotating frame (GoF) for the Bragg angle selection, with the horizontal rotation on the optical surface of first crystal; the metrology reference frame (MeF1), which is fixed to the GoF and to which the first crystal is stiffly connected; the long-stroke frame (LoS) with one translational degree of freedom (coarse gap) with respect to the GoF; and the high-dynamic module of the second crystal, with the short-stroke frame (ShS), to which the second crystal is stiffly connected, and the balance mass (BM), both with three degrees of freedom (fine gap, pitch and roll) with respect to the LoS. The high-dynamic performance is achieved by using low-stiffness (voice-coil) actuators between the ShS and the BM, and an embedded interferometry system between the ShS and the MeF1.



(a) (b)

Figure 1: HD-DCM mechanical design schematics (left) and prototype assembly (right).

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A CONTROL ARCHITECTURE PROPOSAL FOR SIRIUS BEAMLINES

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Abstract

With the increased performance provided by 4th generation synchrotron light sources, precise motion control and event synchronization are essential factors to ensure experiment resolution and performance. Many advanced beamline systems, such as a new high-dynamic double crystal monochromator (HD-DCM) [1], are under development for Sirius, the new machine under construction in Brazil. Among the expected performance challenges in such applications, complex coordinated movements during flyscans/continuous scans, hardware synchronization for pump-and-probe experiments and active noise suppression are goals to be met. Two architectures are proposed to cover general-purpose and advanced applications. The HD-DCM controller was implemented in a MATLAB/Simulink environment, which is optimized for RCP [2, 3]. Hence, its software must be adapted to a more cost-effective platform. One candidate controller is the NI cRIO. The portability of both MATLAB and NI PXI, the present standard control platform at LNLS, codes to cRIO is evaluated in this paper. Control resolution, acquisition rates and other factors that might limit the performance of these advanced applications are also discussed.

INTRODUCTION

Sirius is a 4th generation synchrotron light source [4] under construction in the Brazilian Synchrotron Light Laboratory, LNLS. With 3 GeV and low emittance (0.25 nm.rad) [5], it will provide one of the brightest synchrotron light sources in the world.

The LNLS Beamline Software Group is in a strategic moment to review the control system definitions, reevaluate which architecture best fits the new machine needs and define a new standard platform.

In LNLS, two categories of control systems are devised, namely:

- General-purpose control;
- Advanced applications control.

This paper presents an ongoing development whose main goal is to create a robust standard for control systems, minimizing heterogeneousness and enabling fine tuning on controller parameters. For each of these categories, one case is respectively presented:

- cRIO-Linux Project – migration from National Instruments (NI) PXI chassis to NI CompactRIO (cRIO);
- HD-DCM Tool – migration from Speedgoat xPC chassis to cRIO.

cRIO performance tests have been satisfactory and makes it a candidate for both general-purpose and advanced control new standards, offering a large portfolio of I/O modules and some robust software solutions under constant improvement by a large community.

GENERAL-PURPOSE CONTROL

History

In the 90's LNLS created its own hardware for data acquisition and motion control, due to industrial policies and budget constraints [6]. LOCO represented a big technological advance at the time and lasted as the main solution for control systems until 2013.

In a process of upgrade of the beamlines, a new control system standard was defined, which was intended to minimize efforts of maintenance by using solid and widely diffused solutions. This represented a big strategic change. EPICS [7], a world-wide standard, was chosen as middleware, due to its open-source continuous improvements and large collaborative community. The remaining decision to be made was the hardware platform. Although, there was no hardware platform integrated with Linux OS in National Instruments portfolio, NI engineers proved that PXI was a powerful platform and it was decided that starting a collaborative effort to make it compatible with EPICS was worthwhile. Hence, a project named HYPPIE [6] was developed by LNLS Beamline Software Group and NI to allow:

- dual operational system (OS) execution inside NI PXI via NI RT Hypervisor [8] – LabVIEW RT, for accessing PXI hardware, and Linux, for hosting EPICS server;
- DMA (direct memory access) between OSs, to link EPICS to PXI I/O.

Presently, commercial motion controllers (mostly from Galil and Parker) and data acquisition hardware together with HYPPIE compose the current LNLS standard general-purpose control system.

A New Standard Platform

Sirius brightness will be up to 1 billion times more intense than the operating light source (UVX) [9]. This huge increase demands, among other higher performance requirements, more stable instrumentation, meaning that, in terms of control system requirements, faster feedback sampling and more flexible controller configurations shall be common.

At this point, the first HYPPIE limitation arises. The dual OS feature is based on NI RT Hypervisor, whose development was discontinued. Therefore, the effort to support new OSs ended [10], and neither NI LabVIEW RT nor Linux could be upgraded anymore. Another concern is about costs. FPGA would be an appropriate solution for latency reduction, but the FPGA module for PXI

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USING CONTROL SURFACES TO OPERATE CS-STUDIO OPIs

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Abstract

Modern control software has given us virtually unlimited possibilities for monitoring and controlling EPICS [1] systems, but sacrifices the organic feel of faders and knobs at our fingertips. This article will show how to reclaim that experience without losing the power of software through control surfaces commonly used with DAWs (Digital Audio Workstations) to manipulate audio, demonstrating how real motorised touch-sensitive faders, buttons and assignable V-pots will improve and speed up the control experience.

INTRODUCTION

There are interesting similarities between accelerator facilities and audio/video recording studios control rooms. Besides the high costs, from single cables and devices up to the buildings themselves, and the highly specialized technicians required to run the activities, both require a control room to operate their machines.

As can be seen in Fig. 1, physically big knobs, faders, buttons, indicator lamps, and meters were the tools at the operator's disposal to control the facility in the early times.

The computer era brought substantial changes in control rooms (see Fig. 2), substituting meters and indicator lamps with computer monitors, and buttons, knobs and faders with mouse and keyboard. Previous big cabinets plenty of physical controls are now substituted by screens[1] to be operated by means of computer mouse and keyboard (see Fig. 3).

In the audio/video production studios, recording consoles (in the early times, see Fig. 1b) were the command center of the recording studio. It was where all the audio was processed, sent out to dynamics and time-based effects units, headphone cues, the speakers, and final mixes were balanced and summed there as the audio passed from a tracking tape to a mixing tape. All of that now takes place within the computer in the digital audio workstation [11].

The new computer-based DAW's (Digital Audio Workstation) edit window is the old tape machine, and the mix window functions as the old console. While the edit window is great and offers endless improvements in terms of cutting and pasting, fading in/out, overdubs, rearranging, organizing, having playlists, etc., the mix window falls far short of an improvement over mixing with a console. It is incredibly small, relies on the mouse in order to make mixing moves and automation, confines the engineer to change only one control at a time, and forces him/her into a visual-based mixing experience [11]. So, while modern DAW software has given virtually unlimited possibilities for manipulating audio, it sacrifices the organic feel of faders and knobs at our fingertips [12].

This is where the benefits of a DAW *control surface* come to light. The control surface allows the engineer to ascend beyond the limitations of the mix window and get his/her head out of the computer and into the speakers. It relies on sound and touch, rather than numerical values on the fader. When you're limited to moving a little visual representation of a fader with the mouse, it gets between you and the sound. A control surface allows the digital domain of plug-ins, editing, and visual aspects to become secondary to the sound of the mix in itself [11]. Moreover, using a control surface rather than a mouse inevitably means performing a range of different arm movements, rather than the same small movements over and over again, which significantly reduces the risk of acquiring a repetitive strain injury (RSI) or carpal-tunnel syndrome. The potential health benefits alone, therefore, might be reason enough to invest in a control surface and its improved ergonomics [13].

In this paper I'll describe using a control surface to operate the Display Builder tool [14] of Control System Studio (CS-Studio, see [15]), the application widely used to control accelerators based on the EPICS [1] technology. This will add a further bit to the similarities between accelerator facilities and audio/video recording studios control rooms, borrowing something from the latter into the former.

While others already tried to use some control devices to improve the ergonomics of the control room (see, for example, [16]), the approach of directly control the PVs (Process Variables) fails in giving the user a proper feedback, causing him/her to make errors and, at the end, to be unsatisfied of the device and its integration. So, instead of directly operating the PVs, my approach is to control the *widgets* of Display Builder OPIs, leading to a real-time visual feedback much more satisfying for the operators.

MIDI CONTROLLERS

There are a lot of control surfaces nowadays available on the market [13, 17–19], from low-priced ones (see Fig. 4) to middle-priced (see Fig. 5), up to high and very high-priced (see Fig. 6). All of them communicate with the DAW application exchanging MIDI messages [20], and for this reason they are generally referred as MIDI Controllers [21].

Generally speaking, a MIDI controller is any hardware – or software – that generates and transmits Musical Instrument Digital Interface (MIDI, see [22]) data to electronic or digital MIDI-enabled devices, typically to trigger sounds and control parameters of an electronic music performance.

MIDI communication is achieved through multi-byte "messages" consisting of one *Status* byte followed by one

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[1] In the audio recording industry, plug-in interfaces tend to closely mimic the hardware devices whose functionality they are replicating (skeuomorphic graphical user interface [7], see Fig. 3b). This tendency doesn't seem to be followed by the authors of OPI screens in accelerator facilities, where operator's screens are often poorly layed out, cluttered, and not professionally designed (see Fig. 3a, and [8]).

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USING COLOR BLINDNESS SIMULATOR DURING USER INTERFACE DEVELOPMENT FOR ACCELERATOR CONTROL ROOM APPLICATIONS

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Abstract

For normally sighted developers it is hard to imagine how the user interface is going to look to a color blind person. Our purpose is to draw attention to people with color blindness and to consider their color vision. For that, this paper presents the integration of color blindness simulators into the development process of user interfaces. At the end we discuss the main contributing factors.

INTRODUCTION

Developing a user interface contains the usage of visual components in various colors for e.g. to separate areas of interaction, notification or to signal warnings and alarms. Developers with no color blindness or even of the knowledge of it cannot imagine how these people view their applications.

During the designing process of user interfaces we should try to reach as many people as possible who are able to use a desktop rich client or web applications. Our general aim as developer should be to abolish the barriers to operattions applications because people are afflicted with color blindness or in other ways disabled. To produce more effective visualizations, we need to devise techniques which help these people.

In this paper, our purpose is to draw attention to people with color blindness and to consider their color vision. Our approach is to give a short overview of color blindness. Then we investigate simple principles in choosing colors to improve our user interface design, afterwards we involve color blindness simulators into the development process. As a result of this work, we expect to offer improved control room applications for operators affected by color blindness.

COLOR BLINDNESS

Overview

Approximately 8% of all men and 0.5% of all women worldwide are affected by color blindness [1, 2]. That does not mean that they cannot see any colors. They are only unable to differentiate them. For that reason color blindness is also known as color vision deficiency (CVD).

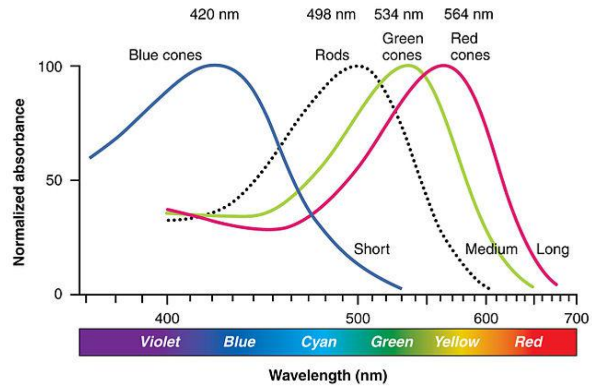

Figure 1: Wavelength of rods and cones [3].

Our human eye contains millions of light-sensitive cells called photoreceptors. Some are shaped like rods and some like cones. Rods are responsible for detecting brightness and are unable to distinguish different wavelengths. Cones on the other hand are sensitive to three certain wavelengths (see Table 1 and Figure 1). The mixture of those three different cone types generates our color vision. If any of these cone types is malfunctioning or missing, causes in color blindness (Figure 2) [4].

Table 1: Human Eye Cones and their Wavelength

wavelength	color	effect: missing/faulty cones
Short	Blue	Tritanopia/ Tritanomaly
Medium	Green	Deuteranopia/ Deuteranomaly
Large	Red	protanopia/ protanomaly

In most cases CVD is the result of defects in the genes. Unfortunately, people with color vision deficiency even do not know that or they are reluctant to admit it. And this has a significant impact on their private and business lives. [5-7]

There are three most common types [8]:

1. Red-Green: The most common types of color blindness - limited function of red or green cone
2. Blue-Yellow: rarer than red-green color blindness
3. Complete color blind: very rare - No cones exist.

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INTEGRATION OF MeeRKAT AND SKA TELESCOPES USING THE KATCP/TANGO TRANSLATORS

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Abstract

The MeerKAT radio telescope control system uses the Karoo Array Telescope Control Protocol (KATCP) protocol and technology stack developed at Square Kilometer Array South Africa (SKA SA). The future SKA project chose the TANGO controls technology stack. However, MeerKAT and phase 1 of the SKA-mid telescope are intimately related: SKA-mid will be co-located with MeerKAT at the SKA SA Karoo site; the first SKA-mid prototype dishes will be tested using the MeerKAT systems; MeerKAT will later be incorporated into SKA-mid. To aid this interoperation, TANGO to KATCP and KATCP to TANGO translators were developed. A translator process connects to a device server of protocol A, inspects it and exposes an equivalent device server of protocol B. Client interactions with the translator are proxied to the real device. The translators are generic, needing no device-specific configuration. While KATCP and TANGO share many concepts, differences in representation fundamentally limits the abilities of a generic translator. Experience integrating TANGO devices into the MeerKAT and of exposing MeerKAT KATCP interfaces to TANGO based tools are presented. The limits of generic translation and strategies for handling complete use cases are discussed.

INTRODUCTION

The Square Kilometer Array (SKA) [1],a large multi radio telescope project is to be built in the co-hosting countries, Australia and South Africa. The telescope will have a total collecting area of approximately one square kilometer. The huge telescope will be made up of a collection of dishes, antennas and aperture arrays.

Currently the project is still in the design phase with construction scheduled to commence in 2019. The project will be developed over two phases - SKA1 and SKA2. SKA1 will be built over 2019 to 2027.

SKA1 will include two telescopes - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies. South Africa will host the mid-frequency telescope, while Australia will be hosting the low-frequency telescope.

The MeerKAT (Karoo Array Telescope) telescope [2] is a interferometric radio telescope. SKA-SA is coordinating its construction in the Karoo, Northern Cape, South Africa. It is regarded as a precursor to the SKA radio telescope. On its completion, it will contain 64 receptors. It will be integrated into the SKA1 MID telescope - more details on the status of project is available [3].

The rest of the paper is will delve into details about the different technology stacks that the two telescope system use, with more focus on the MeerKAT telescope and how it was modified to accomodate these generic translators and the importance of these translators in the SKA project.

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TANGO CONTROLS FRAMEWORK

The TACO Next Generation Objects (TANGO) was chosen as the SKA phase 1 common framework for all the telescope's element LMCs (Local Monitoring and Control). It was considered the most promising framework to meet the SKA requirements after thorough comparative tests between several major control systems such the Experimental Physics and Industrial Control System (EPICS), and the ALMA Common Software (ACS).

TANGO control system [4] is a free open source device oriented controls toolkit for controlling any kind of hardware or software and building SCADA (Supervisory Control and Data Acquisition) systems. It is a distributed system that uses two network protocols - the omniorb implementation of CORBA (Common Object Request Broker Architecture) and ZeroMQ.

TANGO is being developed in collaboration between several research institutions primarily including; ESRF (European Synchrotron Radiation Facility), SOLEIL (Soleil Synchrotron), ELETTRA (Elettra Synchrotron), and ALBA (Alba Synchrotron), with their main goal being to guarantee the successful development of TANGO.

KATCP PROTOCOL

The MeerKAT radio telescope control system uses the Karoo Array Telescope Control Protocol (KATCP). KATCP is a communications protocol based on top of the TCP/IP (Transfer Control Protocol/Internet Protocol) layer [5]. It is a syntax specification for controlling devices over a TCP or RS-232 link. It is the preferred remote command and control interface for open source FPGA (Field-Programmable Gate Array) platforms (e.g. ROACH and SKARAB also used by KAT-7/MeerKAT) developed by the CASPER (Collaboration for Astronomy Signal Processing and Electronics Research) collaboration [6].

KATCP was developed by SKA South Africa in the CASPER collaboration. KATCP is open-sourced and has been adopted by a few projects that use the open source FPGA platforms.

The KATCP protocol is specified as the MeerKAT Control and Monitoring (CAM) interface [7] for all subcontracted and internal hardware devices and subsystems, as well as internal communication between CAM components. In cases where the subcontractor cannot deliver a KATCP interface, a device translator is implemented by the CAM team to trans-

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DESIGN AND IMPLEMENTATION OF THE LLRF SYSTEM FOR LCLS-II*

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ABSTRACT

The SLAC National Accelerator Laboratory is building LCLS-II, a new 4 GeV CW superconducting (SCRF) Linac as a major upgrade of the existing LCLS. The SCRF Linac consists of 35 ILC style cryomodules (eight cavities each) for a total of 280 cavities. Expected cavity gradients are 16 MV/m with a loaded Q_L of $\sim 4 \cdot 10^7$. Each individual RF cavity will be powered by one 3.8 kW solid state amplifier. To ensure optimum field stability a single source single cavity control system has been chosen. It consists of a precision four channel cavity receiver and two RF stations (Forward, Reflected and Drive signals) each controlling two cavities. In order to regulate the resonant frequency variations of the cavities due to He pressure, the tuning of each cavity is controlled by a Piezo actuator and a slow stepper motor. In addition the system (LLRF-amplifier-cavity) was modeled and cavity microphonic testing has started. This paper will describe the main system elements as well as test results on LCLS-II cryomodules.

INTRODUCTION

LCLS-II is an X-ray Free Electron Laser (FEL) under construction at SLAC, driven by a superconducting RF Linac [1]. The electron beam quality will directly translate to the quality of the X-ray beams produced in undulators and used for scientific research in the end stations; hence strict requirements have been placed on the stability of the accelerating cavity fields. An initial stability goal of 0.01° in phase and 0.01% amplitude has been set for the main Linac, composed of 280 nine-cell 1300 MHz superconducting cavities [2].

Plans for the RF controls for the 1.3 GHz cavities have been described elsewhere ([3–6]). It is based on mainstream digital LLRF technology, and incorporates many ideas developed for LBNL's NGLS proposal [7]. The controls use a Single Source Single Cavity (SSSC) architecture, where each cavity has a dedicated amplifier. SSSC has enormous value for simplifying control of narrow-band SRF cavities, It is also a sensible choice for a CW machine, where Solid-State Amplifier technology has approximately matched Klystrons

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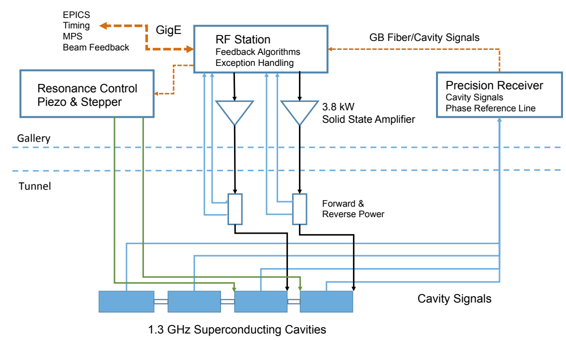

Figure 1: System hardware configuration supporting half of a cryomodule (one of two RF Station chassis shown).

in price, and they are considered easier to operate and maintain.

The LLRF subsystem of LCLS-II is itself a four-laboratory collaboration: LBNL for architecture, FPGA hardware and RF DSP programming, and ADC/DAC hardware development; FNAL for downconverters, upconverters and piezo drivers; JLab for interlocks, stepper controls, and power supplies; and SLAC for LO distribution, MO and PRL, global control system integration, commissioning, transition to operations, and project management.

SYSTEM DESIGN

Each rack (supporting four cavities) includes a separate Precision Receiver Chassis (PRC), linked only by optical fiber to two RF Control Chassis (RFS), as shown in Fig. 1. This density of rack equipment matches the civil layout of the accelerator, where one LLRF rack is cabled to one penetration to the tunnel. The physical separation between PRC and RFS maximizes isolation between the critical stabilized cavity signals and the wildly fluctuating forward and reverse monitoring channels. Preliminary measurements show that this separation has succeeded, in that the measured isolation is at least 125 dB.

The system bypasses some of the usual compromises in choosing an IF by means of an unusual split-LO design, where a low-frequency IF (20 MHz) is used for RF downconversion, and a higher-frequency IF (145 MHz) is used for RF upconversion. Separating transmit and receive signals in

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INTERNET OF THINGS (IoT): WIRELESS DIAGNOSTICS SOLUTIONS

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Abstract

ALBA requires a diagnostic system, where mainly include the temperature acquisition around the facility, such as tunnel, service area, experimental area, laboratories and auxiliary facilities. There is a big area to be covered and the location of the sensors may not be fixed, those measurement spots require a strong correlation to the machine startup configuration. This has an impact on the size whether a traditional wired installation is used, due the huge of measurement points to be covered; in addition, the restricted machine access schedule makes difficult their installation. In this paper we intend to describe one solution based on ESP8266 system-on-a-chip (SoC).

INTRODUCTION

The ALBA Equipment Protection Systems (EPS) is a homogeneous system based on B&R PLCs distributed system independent of from the Tango Control System [1] and became a versatile system that has been adapted for interlock, diagnostic acquisition and motion and collision control in both, accelerators and beamlines.

EPS system is under continuous improvement, these are the most significant changes [2]:

- Upgraded to use Powerlink version 2.
- Implemented the possibility to have differential temperature interlock.
- The 512 storage ring temperatures are treated as interlock, for that reason there are no temperatures for diagnostics.

Adding more temperatures for diagnostics will require an upgrade of the current PLC infrastructure, which will consume a lot of intervention time inside the tunnel and high economic cost.

These are the characteristics that were taken into account for the study and evaluation of the different solutions:

- Price
- Wireless communication
- Hardware and software complexity.
- Documentation.

HARDWARE

ESP8266

ESP8266 [3] is a system-on-a-chip (SoC) based on a 32-bit RISC CPU at 80 MHz equipped with 64 KB (code) + 96 KB (data) of RAM. It features 2.5GHz Wi-Fi(800.11 b/g/n) with full TCP/IP stack, 16 general purpose input/output (GPIO), one 10-bit analog-to-digital converter (ADC), Inter-Integrated Circuit (I2C), Serial Peripheral Interface (SPI), UART, Integrated Interchip Sound (I2S), pulse-width modulation (PWM). Its price is ~10 euros.

Raspberry Pi

The Raspberry Pi family [4] is a series of small single-board computer (SBC). The Raspberry Pi 3 is bundled with on-board WiFi 802.11n, Bluetooth 4.1. It has 46 GPIO, I2C, I2S, SPI, UART, pulse-code modulation (PCM), PWM, USB 2.0 ports, 10/100 Ethernet port. The CPU is a 1.1 GHz ARM with 1GB of RAM. Its price is ~40 euros.

Xbee

Xbee is a family [5] of form factor compatible radio modules based on the IEEE 802.15.4-2003 (ZigBee) standard designed for point-to-point and star communications at over-the-air baud rates of 250 kbit/s. The Xbee Pro S2B includes 10 GPIO, 4 10-bit ADC, UART, SPI, PWM. Its price is ~ 30 euros.

Proof of Concept for ALBA

The three types of hardware evaluated are too different between applications. The most oriented to the industrial application is the Xbee, for that reason we implemented two systems: the first one to measure temperature inside the tunnel with a PT100 sensor, and the second one to measure a high current on CIRCE beamline, but, as they require a coordinator for each one, the cost of the components was ~400 euros and the configuration and installation is not friendly for the user. The Raspberry Pi is a powerful board, but the configuration of the operating system (OS) is more complex to use it as standalone device without monitor, keyboard, etc. The ESP8266 suits [6, 7, 8], as first proposal, to test a wireless diagnostic system. Hardware and software configuration is done in the laboratory and the installation will be carried on by the users, without any support of the computing section. The low cost and the reusability are the strengths of this chip.

ESP8266 FIRMWARE

To implement the firmware we used the Arduino framework [9, 10]. The main goal of the firmware is to be object oriented, to be more scalable, and reusable. The code is divided on three groups of classes: communication, sensors and helpers. The main loop of the program implements a telnet server based on ASCII commands, these commands are verified and processed by the communication classes.

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CS-STUDIO DISPLAY BUILDER*

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Abstract

The Display Builder started as a comprehensive update to the Control System Studio "BOY" panel editor and runtime.

The design was changed to a modular approach, separating the model of widgets and their properties from the graphical representation and the runtime. The model is fully multithreaded. The representation has been demonstrated in both SWT and JavaFX, for now intending to concentrate on the latter. The runtime, based on the thread-safe model, avoids user thread delays and improves overall performance for complex widgets like images as well as scripts and rules.

We present the current state of the development and initial deployments at beam lines of the Oak Ridge National Laboratory Spallation Neutron Source (SNS).

MOTIVATION

Control System Studio (CS-Studio) is a collection of control system tools [1,2]. Its most visible component to end users is typically the operator interface panel builder known as "BOY" [3]. Its versatility has led to the adoption of CS-Studio at several sites, sometimes replacing existing display technologies [4]. At SNS beam lines, the BOY support for scripting languages allows good integration between interactive and automated experiment control [5].

After about a decade of successfully using BOY at the SNS, we started to recognize limitations in the underlying architecture. Both the BOY display editor and the runtime are based on the Eclipse Graphical Editor Framework (GEF) [6]. While this greatly accelerated the initial development of BOY, it ties the software to the SWT [7] graphics library. Furthermore, the BOY widget model can only be accessed on the user interface (UI) thread, in part because of its tight integration with GEF and SWT, which limits access to widget properties to the UI thread.

Opening a new display file that resides on a busy file server may be slow. While scripts are very convenient to implement and update, their execution speed is often limited. In the BOY software architecture, the loading of displays and the execution of scripts needs to be handled on the UI thread, which can cause the whole user interface to temporarily stop updating, which end users then experience as a "freeze-up".

DISPLAY BUILDER DESIGN

The Display Builder is meant to offer the same basic functionality as BOY, but in a modified software design.

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Widget Model

The Display Builder Widget Model is a description of all widgets and their properties. At this time, we implemented 42 widget types, categorized as follows.

- Graphic widgets that display static content: Label, Rectangle, Polyline, Picture, ...
- Monitor widgets that display the value of a control system Process Variable (PV): Text Update, LED, Meter, …
- Control widgets that allow the user to modify the value of a PV: Text Entry, Knob, various buttons, …
- Plot widgets that show one or more PVs, including waveforms in various ways: X/Y Plot, Image, Data Browser
- Structure widgets that are used to arrange widgets within a display: Array, Group, Embedded Display, Navigation Tabs
- Miscellaneous widgets: Web Browser

The Widget Model is fully thread-safe, that is multiple threads can for example concurrently update the "text" and "foreground color" properties of a "Label" widget. Software that has subscribed to widget property changes receives immediate notification of updates. The widget model is not tied to any specific graphics library. This includes the description of colors or fonts, for which the Display Model implemented its own data objects to avoid outside dependencies.

Widget Representation

The Widget Representation module of the Display Builder renders the Widget Model with a specific graphics library. There are currently two implementations.

One is based on SWT, as in BOY. The SWT implementation is meant to demonstrate that our design is not tied to a specific graphics library, but it is limited to very few widget types and will at this time not be extended.

The second implementation is based on the newer JavaFX technology [8]. All widgets are fully supported by this representation, which is our emphasis for the foreseeable future of the Display Builder.

Widget Editor

The Widget Editor shown in Fig. 1 allows users to interactively create and modify displays by positioning widgets and adjusting their properties.

A widget is added to a display by dragging it from the widget palette into the display, and then adjusting its properties. The "Properties" lists all properties of a widget, grouped into sections. Key properties tend to be listed at the start of the list, including for example the position and PV Name, which are often the only properties that

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STATUS OF THE SQUARE KILOMETRE ARRAY

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Abstract

The Square Kilometre Array (SKA) is a international project to build a number of multi-purpose radio telescopes, operating as a single observatory, that will play a major role in answering key questions in modern astrophysics and cosmology. It will be one of a small number of cornerstone observatories around the world that will provide astrophysicists and cosmologists with a transformational view of the Universe. Two major goals of the SKA is to study the history and role of neutral Hydrogen in the Universe from the dark ages to the present-day, and to employ pulsars as probes of fundamental physics. Since 2008, the global radio astronomy community has been engaged in the development of the SKA and is now nearing the end of the *Pre-Construction* phase. This talk provides an overview of the current status of the SKA and the plans for construction, focusing on the computing and software aspects of the project.

INTRODUCTION

The Square Kilometre Array (SKA) is an international project that has the aim of building multi-purposes radio telescopes, with an equivalent collecting area of at least one square kilometre, and thus unprecedented sensitivity, so that key questions in modern astrophysics and cosmology can be answered.

The original SKA Science book was published in 2004 [1]. In 2015, *Advancing Astrophysics with the Square Kilometre Array* [2] was published with an update to the SKA science book after a decade of development of the SKA concept, incorporating more than 130 scientific use cases that will be possible thanks to the SKA telescopes.

Those science cases cover Galaxy Evolution, Cosmology and Dark Energy[1] [3–5], Strong-Field Tests of Gravity[2] [6], Cosmic Magnetism[3] [7], The Cosmic Dawn and the Epoch of Reionisation[4] [8], and research on the Cradle of Life[5] [9]. The amount of physical disciplines foreseen to be encompassed by the SKA telescopes is one of the largest for any ground based facility to date.

The SKA project is currently in what is known as SKA Phase 1, or SKA1, in which two telescopes approximately with 10% of the target collecting area are being built, namely SKA1-Mid, and SKA1-Low, in order to prove the feasibility of the techniques and derisk the construction of the next phase of the project, SKA Phase 2, or SKA2.

The goal is to have a single observatory entity, that will construct and operate two SKA1 telescopes (SKA1-Mid and SKA1-Low), with presence in three sites: Australia (SKA1-Low), South Africa (SKA1-Mid), and United Kingdom (Headquarters and central operations).

This talk focuses on the progress and status of the SKA1 telescopes. It starts by describing the SKA Organisation itself (Sec.), and the SKA telescopes being designed (Sec.). We continue with details on the Pre-Construction phase (Sec.), the challenging Data Flow and Processing (Sec.), and the Software and control challenges (Sec.). We summarise the main results in the Conclusions(Sec.).

SKA ORGANISATION

The organisation overseing the SKA1 project is the SKA Organisation (SKAO), currently a limited liability non-for-profit company registered in England and Wales.

The SKAO is in the process of the becoming an Inter-Govermental treaty Organisation (IGO), not unlike the European Council for Nuclear Research (CERN), the European Molecular Biology Laboratory (EMBL), or the European Southern Observatory (ESO). The timeline for that process, and for the main design milestones, is detailed in Sec. .

Currently[6] there are ten countries that are Full Members of the SKAO (listed in alfabetical order): Australia, Canada, China, India, Italy, New Zealand, South Africa, Sweden, The Netherlands, and United Kingdom. Other countries are involved in the design of the SKA1 telescopes, and it is estimated that $\tilde{2}0$ countries and more than 100 organisations are contributed to that effort.

SKAO's headquartes are located within the boundaries of the Jodrell Bank Observatory, in the middle of the Cheshire plain.

As part of the UK commitment as host country for the SKAO HQ, and the IGO, an expansion to the HQ is being constructed with the intention of becoming a nexus for radio astronomy. The current status of the work, as of September 2017, can be seen in Fig. 1.

SKA1 TELESCOPES

As previously indicated, in this Phase 1 (SKA1) we intend to build two telescopes, SKA1-Mid, and SKA1-Low, within a cost cap for both telescopes of 674 MEur (2016 value).

The SKA1-Low will be located in Western Australia, within the Murchison Radio-astronomy Observatory (MRO), which defines a Radio Quiet Zone for the benefit of the SKA1-Low, but also the Australian SKA Pathfinder (ASKAP) and Murchison Widefield Array (MWA) precursor telescopes. Figure 2 shows where the MRO is located,

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[1] http://skatelescope.org/galaxyevolution/
[2] http://skatelescope.org/gravity-einstein-pulsars/
[3] http://skatelescope.org/magnetism/
[4] http://skatelescope.org/cosmicdawn/
[5] http://skatelescope.org/cradle-life/
[6] https://skatelescope.org/participating-countries/

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COMMISSIONING AND CALIBRATION OF THE DANIEL K. INOUYE SOLAR TELESCOPE*

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Abstract

The Daniel K. Inouye Solar Telescope (DKIST) is currently under construction on the summit of Haleakala on the island of Maui. When completed in late 2019 it will be the largest and most powerful optical solar telescope in the world with a 4 meter clear aperture and a suite of state of the art instruments that will enable our Sun to be studied in unprecedented detail. In this paper we discuss the current state and plans for testing, commissioning and calibration of the telescope and how that is supported by the DKIST control system.

INTRODUCTION

Figure 1 is a rendered image of the telescope at the site so that it is possible to see both the building and the telescope.

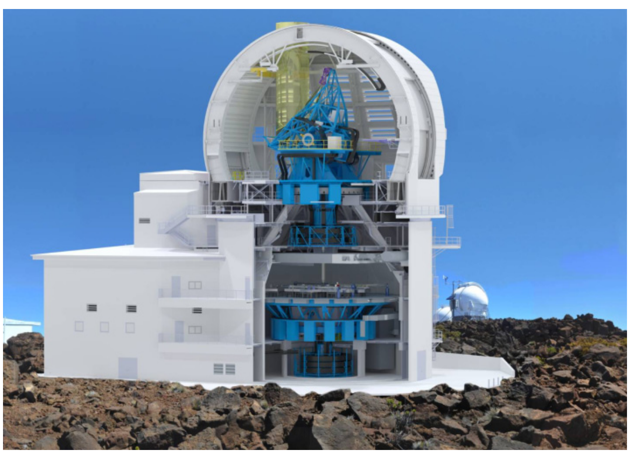

Figure 1: Cut-away image of telescope enclosure showing the telescope and coudé rotator.

DKIST has an off-axis 4m diameter primary mirror (M1) to provide an un-obstructed light path to minimize scattered light. The heat stop at prime focus passes a 5 arcminute diameter circular beam to the secondary mirror (M2) which forms a second Gregorian focus and then a further 8 mirrors (M3 – M10) direct the beam into the coudé laboratory where the light is further directed via dichroic beam splitters to the instrumentation. The all reflective design will allow exploration of the wavelength range from 0.3 to 35 micron.

Although the primary mirror is "only" 4 meters and so small relative the latest class of night time optical telescopes, the off-axis design results in a structure on the scale of an 8 to 12-meter telescope. The height of the building in Fig. 1 is 44 meters and the dome diameter is 26 meters.

Control of thermal effects is a major issue for the telescope. It is not obvious from the figure but the enclosure is shaped to minimize the surface area directly facing the sun. The outside of the enclosure is covered with plate coils to actively cool the enclosure during observations and unlike a night time telescope the entrance aperture for the light beam is a circular aperture rather than a slit to avoid any direct solar radiation illuminating the telescope structure. The heat loads on the mirrors are considerable and so must be actively cooled. M1 for example receives about 14 kW and the irradiance at the heat stop at prime focus is about 3 kW cm^{-2}.

The coudé laboratory is the large structure sitting beneath the telescope. This environmentally controlled room has a diameter of 16.25m and houses the mirrors M7 to M10. M10 is the deformable mirror used by the Adaptive Optics System to correct the beam for atmospheric distortions before being passed to the instruments. It is 210 mm in diameter and has 1600 actuators. Figure 2 shows the layout of instruments and the Wave Front Correction System (WCCS) in the coudé laboratory.

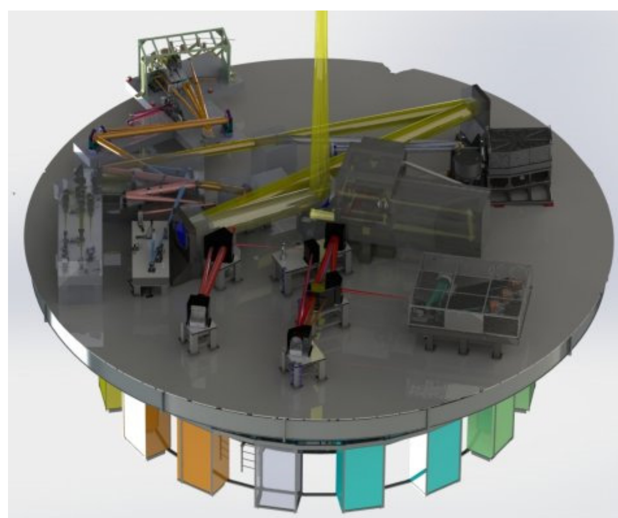

Figure 2: Layout of instruments in coudé laboratory.

First light instruments consist of the Visible Broadband Imager (VBI) which has both a read and a blue arm, the Visible Spectro-Polarimeter (ViSP), the Visible Tunable Filter (VTF), and two Near Infra-Red Spectro-Polarimeters, one Diffraction Limited (DL-NIRSP) and the other cryogenically cooled (Cryo-NIRSP). This instrument suite will allow high resolution spectral, temporal and spatial observations over a wide wavelength range. Further details of the telescope and its instrumentation can be found in [1].

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STATUS OF THE CONTROL SYSTEM FOR THE SACLA/SPring-8 ACCELERATOR COMPLEX

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Abstract

At the SPring-8 site, the X-ray free electron laser facility, SACLA, and the third-generation light source, SPring-8 storage ring, is operated. The SACLA generate brilliant coherent X-ray beams with wavelength of below 0.1nm and the SPring-8 provides brilliant X-ray to large number of experimental users. On the SPring-8 upgrade project we have a plan to use the linac of SACLA for a full-energy injector of the storage ring. For this purpose, two accelerators should be controlled seamlessly and the SACLA has to provide low emittance electron beam to generate X-ray laser and injector for the SPring-8 simultaneously. We start the design of control system to meet these requirements. We redesign all of a control framework such as Database, Messaging System and Equipment Control include with NoSQL database, MQTT and EtherCAT. In this paper, we report the design of control system for SACLA/SPring-8 together with status of the SPring-8 upgrade project.

INTRODUCTION

Last twenty years, the SPring-8 as the highest electron energy, large scale third generation synchrotron radiation facility in the world. Construction of the SPring-8 facility was started in 1991 and it has been open for user experiments since October 1997. At the SPring-8 site, the SACLA (SPring-8 Angstrom Compact Laser) project started in 2006 with 5-year construction schedule and and it has been in operation for user experiments since 2012. Figure 1 shows a bird-eye view of SPring-8 site. We designed the SACLA linear accelerator to be used for a full-energy injector for the SPring-8 storage ring. An ultra-low-emittance electron beam delivered from the SACLA should be compatible with the future upgraded SPring-8 facility.

The SACLA is delivering pulsed X-ray laser beams whose pulse duration is as short as a few femtoseconds. The peak brilliance of the SACLA is so high. The complementary use of storage-ring light sources and pulsed X-ray laser is essential for opening new frontiers in science and technology. However, there is a wide gap between the current SPring-8 emittance and SACLA's equivalent emittance. The SPring-8 upgrade should narrow the gap from the storage ring perspective. In 2013, we have decided to aim for an ultra-low emittance ring with an emittance value of ~100 pmrad. The conceptual design report on upgraded SPring-8, which called SPring-8-II, was published in September 2014 [1].

At the SPring-8-II the dynamic aperture is markedly narrower than the current SPring-8. We cannot use the existing injector system without a large-scaled modification. In addition, long injection interval during top-up operation it is necessary to keep the injector system in a stand-by condition. In the result, it is increasing the operation cost. On the other hand, the linac of SACLA is always running for its own user experiments independently from SPring-8-II. Therefore, if the injection beam is delivered from SACLA, the operation cost will be minimized. To achieve the SACLA's users operation and the beam injection to SPring-8-II in parallel, it is necessary to control of the beam energy and the peak current on a bunch by bunch basis.

Figure 1: The SPring-8 facility and the SACLA. The transport line.

OVERVIEW OF SACLA AND SPring-8

Figure 2 shows the machine layout of SACLA and SPring-8. The SACLA consists of an electron gun [2], beam deflector, prebuncher cavity (238MHz), booster cavity (476MHz), L-band correction cavity (1428MHz), L-band buncher, C-band (5712MHz) correction linac, S-band (2856MHz) linacs, and main C-band linacs [3]. The electron beam repetition rate is 60 Hz. A peak current of several kA is generated by compressing the bunch length in the injector (prebuncher, buncher and booster) and in three stages of the magnetic-chicane bunch compressors. We use 128 units of the C-band accelerating structure. The beam energy will reach 8 GeV and the X-ray laser wavelength is below 0.1 nm. A number of in-vacuum undulators of 4.5 m length are aligned after the accelerator. There are 22 units of the undulator on BL3 and 18

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HARDWARE ARCHITECTURE OF THE ELI BEAMLINES CONTROL AND DAQ SYSTEM

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Abstract

The ELI Beamlines facility is a Petawatt laser facility in the final construction and commissioning phase in Prague, Czech Republic. End 2017, a first experiment will be performed. In the end, four lasers will be used to control beamlines in six experimental halls. The central control system connects and controls more than 40 complex subsystems (lasers, beam transport, beamlines, experiments, facility systems, safety systems), with high demands on network, synchronisation, data acquisition, and data processing. It relies on a network based on more than 15.000 fibres, which is used for standard technology control (PowerLink over fibre and standard Ethernet), timing (WhiteRabbit) and dedicated high-throughput data acquisition. Technology control is implemented on standard industrial platforms (B&R) in combination with uTCA for more demanding applications. The data acquisition system is interconnected via Infiniband, with an option to integrate OmniPath. Most control hardware installations are completed, and many subsystems are already successfully in operation. An overview and status will be given.

INTRODUCTION

ELI Beamlines [1] is an emerging high-energy, high-repetition rate laser facility located in Prague, Czech Republic. Four laser beamlines (ranging from the inhouse developed L1 with <20fs pulses exceeding 100mJ at 1kHz based on DPSS technology to the 10PW-L4, developed by National Energetics) will supply six experimental halls which provide various secondary sources to users. Facility commissioning, and installation work of lasers and experiments is progressing, and first user experiments are expected in 2018.

The central control system connects, supervises and controls all technical installations used for the operation of this facility, which are more than 40 complex subsystems (lasers, beam transport, beamlines, experiments, plant systems (HVAC, vacuum), safety systems) with high demands on network, synchronisation, data acquisition, processing, and storage.

This paper describes the hardware architecture of this control and data acquisitions system, and addresses the challenges to be faced in the upcoming years.

APPROACH

There are three factors that make the development of the ELIs' control system challenging:

First, ELI has been designed to be multifunctional, and to provide a highly diverse selection of lasers and secondary sources to researchers. In practise this means that we have to integrate a **multitude of very diverse subsystems** developed by internal and external suppliers; leading to an initially very inhomogeneous technical landscape, and complex system interfaces.

At the same time, ELI is **building groundbreaking technology** and its demands on synchronisation and data acquisition are pushing the boundaries on what is possible with current technology. Demands are especially high on safe operation, synchronization, and data acquisition.

Third, in ELI **commissioning and operational phases overlap**. While one part of the facility is still under development, others are being installed, and again others will be already serving early users (whose experiments need to be supported technically, and for whom laser and beam transport operation, safety, timing and data acquisition services must be provided).

We are using three approaches in our hardware architecture to deal with these challenges:

- **Standardization of hardware interfaces,** for example for camera interfaces [2], but also more complex interfaces like our lasers. This reduces complexity and software development effort, and allows us to integrate new systems with less or at least known effort.
- Use of **common hardware based on open standards**, which allows common just-in-time procurement (taking advantage of high-volume pricing), gives us full control and documentation, and flexibility for future updates and maintenance.
- **Implementation of a test-bed infrastructure**, which provides a representative system with all technologies used within the central control system for testing of new equipment, development of hard- and software and the opportunity to integrate subsystems in a controlled, offline environment.

Combined with model-based and standardized software development [3], we see promising early successes with this very streamlined and industrial approach.

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THE LASER MEGAJOULE FACILITY: CONTROL SYSTEM STATUS REPORT

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Abstract

The Laser MegaJoule (LMJ) is a 176-beam laser facility, located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy to targets, for high energy density physics experiments, including fusion experiments.

The first 8-beams bundle was operated in October 2014 and a new bundle was commissioned in October 2016. The next two bundles are on their way. There are three steps for the validation of a new bundle and its integration to the existing control system. The first step is to verify the ability of every command control subsystems to drive the new bundle using a secondary independent supervisory. It is performed from a dedicated integration control room. The second is to switch the bundle to the main operations control room supervisory. At this stage, we perform the global system tests to validate the commissioning of the new bundle. In this paper we focus on the switch of a new bundle from the integration control room to the main operations control room. We have to connect all equipment controllers of the bundle to the operations network and update the Facility Configuration Management.

LMJ FACILITY

The LMJ facility covers a total area of 40,000 m2 (300 m long x 150 m wide). It is divided into four laser bays, each one accommodating 5 to 7 bundles of 8 beams and a target bay holding the target chamber and diagnostics. The four laser bays are 128 m long, and situated in pairs on each side of the target chamber. The target bay is a cylinder of 60 m in diameter and 38 m in height. The target chamber is an aluminium sphere, 10 m in diameter, fitted with several hundred ports dedicated to laser beams injection and diagnostics introduction. A Supervisory and integrated computer control systems ensure the LMJ control system.

LMJ CONTROL SYSTEM

LMJ Control System Functions

The main functions of the control system are shots execution and machine operations: power conditioning controls, laser settings, laser diagnostics, laser alignment, vacuum control, target alignment, target diagnostics [1].

The control system has also a lot of other major functions: personnel safety, shot data processing, maintenance management.

General Architecture

The LMJ control system has to manage over 500 000 control points, 150 000 alarms, and several gigabytes of data per shot, with a 2 years on line storage.

Hardware Architecture

From the hardware point of view the LMJ control system is constituted of two platforms located in two different buildings:

- one for system integration (PFI), which is in operation in a dedicated building and consisting of a clone of the operational control system at the supervisory levels and a mixture of simulators and real controllers for representing low levels controls and real equipment [2];
- The operational platform, consisting of two sub-platforms: a small one for integrating the laser bundles (integration control room) and one for normal operations (main control room).

For each platform, two redundant cabinets provide redundant Gigabit attachments to twelve subsystems backbones and main servers.

On each platform, virtual independent contexts are configured using Virtual Routing and Forwarding technologies (VRF): on the operational platform this allows simultaneous operation from the main control room and the integration one.

The LMJ control system architecture is architecture with four layers:

- N0 layer: the equipment control;
- N1 layer: subsystems supervisory that allows operators to drive subsystems;
- N2 layer: the System supervisory;
- N3 layer: global LMJ facility (Laser configuration, shot data processing, maintenance management, network management).

N1, N2 and N3 layers are virtualized using VMware and DataCore solutions. Each platform consists of one virtualization infrastructures composed of:

- 2 DataCore servers, each one managing 20 To of disks;
- 11 ESX Dell PowerEdge R815 servers, with 4x12 cores and 256 Go of RAM;
- 1 VCenter Server to manage the VMware infrastructure.

Each of these infrastructures is dimensioned to execute more than an hundred of virtual machines.

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THE ESRF EXTREMELY BRILLIANT SOURCE – A 4th GENERATION LIGHT SOURCE

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Abstract

After 20 years of operation, the ESRF has embarked upon a very challenging project - the Extremely Brilliant Source- (EBS). The goal of this project is to construct a 4th generation light source storage ring inside the existing 844m long tunnel. The EBS will increase the brilliance and coherence by a factor of 100 with respect to the present ESRF storage ring. A major challenge is to keep the present ring operating 24x7 while designing and pre-constructing all the elements of the new ring. This is the first time a 4th generation light source will be constructed inside an existing tunnel. This paper concentrates on the control system aspects. The control system is 100% TANGO based.

PRESENTATION OF THE EBS

The ESRF is running an accelerator complex based on an electron linac, a synchrotron booster and an 844m long, 6.04 GeV storage ring. It operates 42 beam lines. The Extremely Brilliant Source (EBS) project, officially started in January 2015, aims to substantially increase the source brilliance and the coherent fraction of the X-ray beam. It consists of constructing a new 844m circumference storage ring with a new magnetic lattice to replace the current storage ring. About 90% of the existing infrastructure will be re-used and the new EBS design has been conceived with greatly improved energy efficiency.

The hybrid multi-bend achromat (HMBA) lattice design for the EBS will give a horizontal emittance roughly 29 times lower than the emittance provided by the current double-bend achromat lattice [1] [Fig 1.]. As second order effect, the small size of the beam makes the insertion device more efficient in creating coherency, and this will lead to a gain of around 100 on the brilliance of a monochromatic beam on the sample at the experimental station.

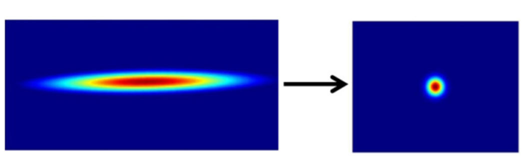

Figure 1: Reducing emittance for increasing brilliance.

The lattice is composed of 32 cells, each cell composed of 7 permanent magnets dipoles and 27 electro magnets. A total of 1180 magnets had to be designed, developed and procured.

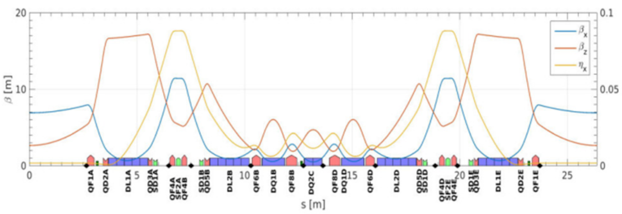

Figure 2: Arc cell optics layout.

Because the vacuum chamber is extremely small, the stability of the beam is critical. This will lead to an increase by an order of magnitude in both the mechanical precision required as well as the control of magnetic field.

CONTROLLING NEW HARDWARE

In addition to the physical hardware elements composing the ring, a large number of new controllers and sensors have been designed, developed or procured to control the new equipment. Their prototype versions need to be properly validated before launching the procurement on a large scale.

Lattice Control

Each of the 32 cells is composed of 27 electro magnets and 33 corrector channels, each one fed by a dedicated power supply channel (totalling 1920 channels to be remotely controlled).

In order to increase the MTBF of the power supplies a hot swap system has been designed. The aim is to detect any problem with a magnet current circuit in order to perform, in real-time, a swap over of the faulty power supply to a spare one, without interruption to the strength of the corresponding magnet. Each hot swap system manages 33 power supply channels for 27 magnetic circuits of 3 different families [Fig. 3]. Such a system will be installed in each of the 32 SR cells.