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INTEGRATION OF EtherCAT HARDWARE INTO THE EPICS BASED DISTRIBUTED CONTROL SYSTEM AT iThemba LABS

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Abstract

iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) has, over the past 30 years, carried out several upgrades to its control electronics and software. This culminated in the adoption of EPICS as the de-facto distributed control system at the lab. In order to meet the changing technology and user requirements, iThemba LABS adopted EtherCAT as its new industrial communication standard. Building on an open EtherCAT master implementation and prior community development, iThemba LABS has successfully integrated a variety of EtherCAT hardware into its EPICS control system (Fig. 1). This paper presents the open source software toolchain that has been developed and is used at iThemba LABS and showcases several hardware installations at the facility and abroad. Community involvement and future plans for this initiative are also presented.

INTRODUCTION

iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) is a multidisciplinary facility conducting research in subatomic physics, material research, radiobiology, and the research and development of unique radioisotopes for nuclear medicine and industrial applications. The facility operates and maintains a number of accelerators, the largest of these a K=200 separated sector cyclotron can accelerate protons to energies of 200 MeV. The control systems of these machines have been continually upgraded over the last 30 years in order to keep equipment failure to a minimum and to enhance technical capabilities.

Evolution of the iThemba LABS Control Architecture

The original control system was developed in the late 1970s around a few mini-computers with the control electronics and instrumentation interfaced via CAMAC. This system was then upgraded in the early 1990s to a distributed PC-based system running OS/2 and communication over Ethernet LAN. An in-house “simple” interface (SABUS) was also developed to supersede the ageing CAMAC bus and an assortment of I/O cards were developed to gradually replace the existing CAMAC modules.

With the OS/2 operating system no longer being supported by IBM, the decision was made in the late 2000s to migrate the control system onto the EPICS platform. The SABUS hardware interface was retained on account of robustness, noise-immunity and the large amount of re-cabling that would have to be done if this was changed. The various EPICS client user interfaces were developed in MEDM and Qt. By the mid-2010s about 60% of the control hardware was under EPICS control using SABUS cards to control power supplies, stepper motors, pneumatic actuators, all aspects of the vacuum, slits and scanner systems [1–3].

Figure 1: 19-inch rack mountable EtherCAT enclosures designed at iThemba LABS.

Migration to EtherCAT

The long design cycles involved in developing custom in-house SABUS cards resulted in a number of legacy OS/2 CAMAC systems still remaining. CAMAC hardware was becoming increasingly difficult to find and the rapid rate of obsolescence of modern electronic components meant that the in-house SABUS cards had to be periodically redesigned. In light of these challenges, and after an investigation of various industrial bus technologies, iThemba LABS adopted EtherCAT as its new industrial communication bus in 2015 due to its high-speed performance, existing integration with EPICS and wide selection of commercial off-the-shelf hardware.

SOFTWARE STACK

EtherCAT is an open real-time Ethernet fieldbus developed by Beckhoff (Verl, Germany) and maintained by the EtherCAT Technology Group (ETG) [4]. The EtherCAT topology employs a master/slave principle, where the master node (typically the control system) sends Ethernet frames to the slave nodes, the slave nodes then extract data from and insert data into these frames with a few nanoseconds delay. Each EtherCAT slave includes a controller with a Fieldbus Memory Management Unit (FMMU). The FMMU allows the mapping of logical addresses in the Ethernet frame to physical ones within the slave modules. The registers in each slave that can be mapped by the FMMUs are known as either Process Data Objects (PDOs) or Service Data Objects (SDOs).

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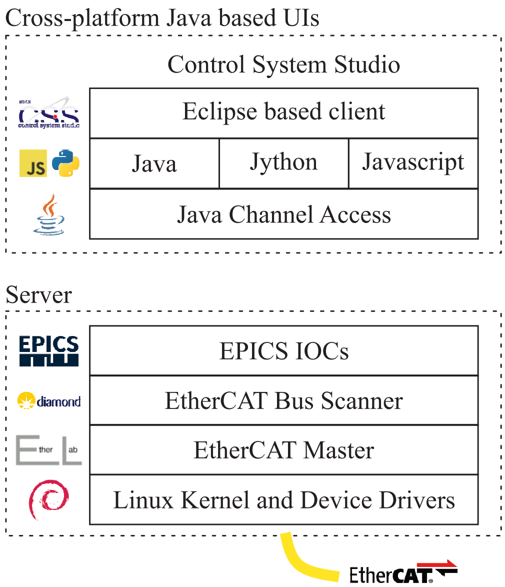

Figure 2: EtherCAT master/slave software stack used at iThemba LABS.

Figure 2 shows the server/client open-source software stack developed and used at iThemba LABS. The server, which implements the EtherCAT master, runs on a "headless" Debian Linux machine patched with a real-time kernel patch. The real-time kernel patch ensures the deterministic performance of EtherCAT can be achieved. The client user interfaces are based on Control System Studio (CS-Studio) and can be deployed on regular Windows/Linux machines as they are cross-platform.

The server stack is built on an open-source EtherCAT master from EtherLab.org and a bus scanner and Asyn drivers developed by Diamond Light Source UK (Diamond) [5, 6].

EtherLab EtherCAT Master

The EtherLab kernel module implements an EtherCAT master conforming to IEC/PAS 62407. The master provides, amongst others: the finite state machine that reads the slave states cyclically, dynamic slave configuration (including PDOs and SDOs), Userspace API via a C-library and a command-line tool 'ethercat' for diagnosis and maintenance of the bus.

Diamond Bus Scanner and Asyn Drivers

The Diamond bus scanner generates the cyclical EtherCAT packets. On start-up it reads an XML configuration file, configures the FMMUs, and puts the slaves into operational (OP) mode. A Python script is used to generate the XML configuration file from the EtherCAT Slave Information (ESI) files and the active bus topology.

Finally, Asyn drivers deliver the slave I/O data and configuration information on each bus cycle to the EPICS application layer through asynInt32 parameters. Sample EPICS hardware templates are generated from the ESI file for each slave device using the Python libxml2 library.

EPICS IOCs

The majority of the development undertaken at iThemba LABS has been on the application layer using EPICS (low level hardware control) and a combination of State Notation Language (sequencing and state machine) and Java/Python (high level scripting). Using these tools, real-time control of various field sensors and actuators have been developed, including: pneumatic control of Faraday cups, harps etc.; movement of slits, trolleys, tape stations and various RF elements using motors; water flow, temperature monitoring and heat exchangers systems; interfacing with in-house and commercial meters such as radiation sensors and vacuum gauges; serial communications with third party devices and power supplies; and vault clearance and safety interlocking systems [3, 7–10].

Closed loop PID motion control algorithms have also been developed for various servo, DC and stepper motors. Positioning of these systems are done using potentiometers, encoders or using the drive's internal counters[1]. Motion systems have also been developed that use multiple feedback sensors simultaneously to ensure failsafe operation should a particular sensor fail mid-movement.

Large Scale Software Architecture A range of hardware expertise and software applications were developed through the upgrade of the RF motion control elements of the iThemba LABS cyclotrons. With the procurement of a 3 MV Tandetron from High Voltage Engineering Europa B.V. (HVE) in 2016, these tools were used to develop the complete beamline control, man-machine, safety, vault clearance and interlocking systems for the Tandetron. It is also envisioned that future projects such as the Low Energy Radioactive Ion Beam facility (LERIB) and the South African Isotope Facility (SAIF) will utilise these tools.

User Interfaces

All present user interfaces for new installations are being developed in CS-Studio. CS-Studio is a product of the collaboration between different laboratories and universities and provides a collection of tools to monitor and operate large scale control systems [11].

Concurrently, iThemba LABS is also developing a browser based user interface development framework called React Automation Studio [12]. This framework implements a modern tool chain with a React [13] front-end and a PyEpics [14] back-end as a progressive web application. This enables efficient and responsive cross platform and cross device operation. We hope to release it to the community soon.

HARDWARE INTEGRATION

Once EtherCAT was adopted as the new industrial communication bus, a selection of vendor hardware was tested with the open source master stack. The Beckhoff range of modular EtherCAT terminals was chosen as the preferred

[1] Internal counters only applicable for stepper motor drives.

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Figure 3: Unistrut EtherCAT cabinets designed at iThemba LABS.

hardware vendor for three reasons: (1) 25 years hardware support on all modules; (2) wide selection of I/O modules catering for most of our process control requirements; and (3) ease of integration and stability with the open master software stack.

A variety of EtherCAT slave I/O have been successfully interfaced into EPICS using customised hardware templates at iThemba LABS, these include:

- **Analogue inputs/outputs -** ±10 V and 0 to 20 mA; 12 to 24-bit
- **Digital inputs/outputs -** 5 to 24 V, potential free contacts and negative switching I/O
- **Temperature -** thermocouples and resistance thermometer devices (RTD)
- **Communication -** RS232, RS485 and RS422
- **Motion -** Servo, DC and Stepper motors
- **Position measurement -** potentiometers, absolute mechanical encoders and incremental optical encoders

SYSTEM INSTALLATIONS

iThemba LABS utilises the 19-inch racking standard for mounting most of its electronic enclosures and equipment. The EtherCAT terminals attach to commercially available 35 mm mounting rails (DIN rails according to EN 60715). Several form factor electronic enclosures, with DIN rail mounted slaves, have been developed at iThemba LABS, both to fit within the 19-inch rack standard and for alternate applications. Figures 1, 3 and 4 show some of the electronic enclosures installed at iThemba LABS.

International Collaborations

iThemba LABS has also, through collaborations, deployed a dual DC motor motion control system at Helmholtz-Zentrum Berlin (HZB) Germany and is jointly developing the control system for the SPES tape station at Laboratori Nazionali di Legnaro (LNL) Italy using EtherCAT hardware and the above mentioned software tools [8, 9].

Figure 4: Custom 19-inch rack mountable EtherCAT cabinets designed at iThemba LABS.

CONCLUSIONS AND FUTURE DEVELOPMENT

Building on the work done by EtherLab and Diamond, a stable and mature EtherCAT software stack has been developed at iThemba LABS. A variety of hardware I/O modules have been successfully integrated and deployed with this software architecture. The move to industrial off-the-shelf hardware has mitigated our obsolescence risk, shortened product development time and increased product life cycles. This process has also expedited the migration of our control system onto the EPICS platform.

Further investigations are needed into integrating I/O cards from other vendors and integrating the new ELM series of modules from Beckhoff (built for laboratory and testing technology environments) with the EtherCAT software stack. iThemba LABS will also be working to prepare a release candidate of its React Automation Studio front end software framework. The framework is cross device and cross platform. The operational readiness and stability of this software has been demonstrated and we encourage the EPICS community to test, evaluate and contribute to React Automation Studio.

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