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BUDKER INSTITUTE OF NUCLEAR PHYSICS
NOVOSIBIRSK, RUSSIA

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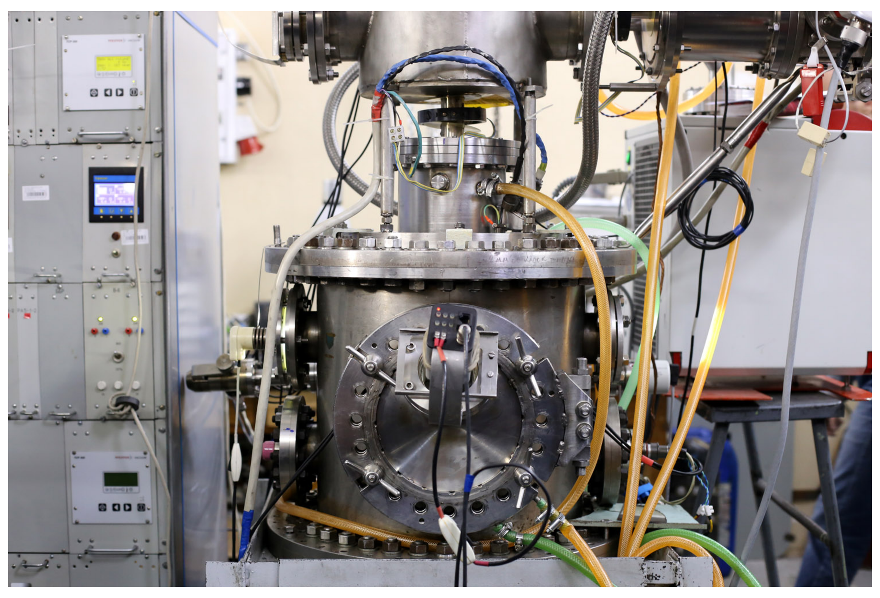
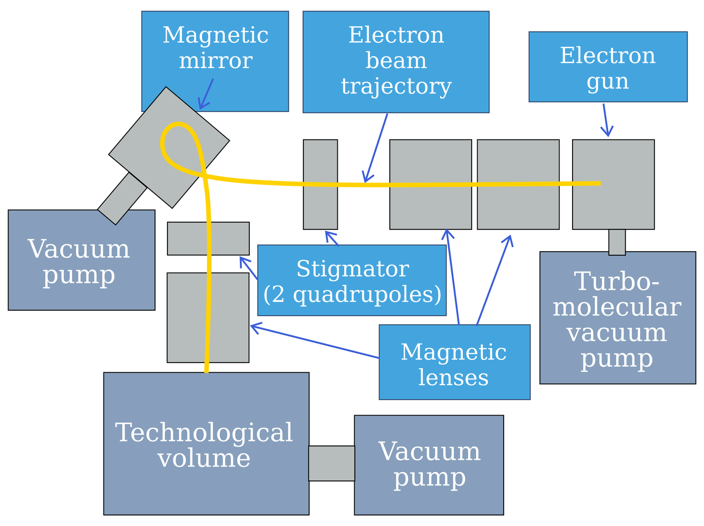
Control System for Fast Components of Electron Beam Welding Machines

Small Experimental Electron Beam Welding Machine at BINP



Small experimental electron beam welding machine at BINP



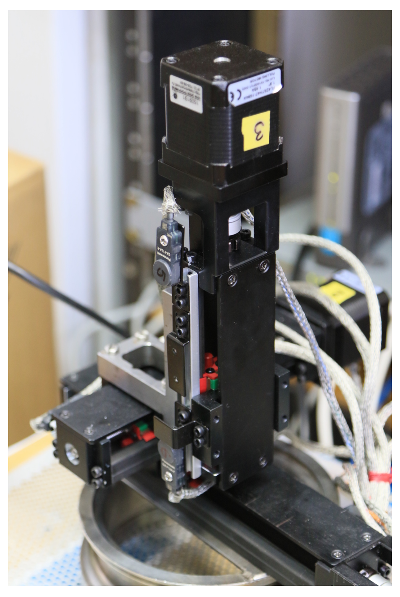
Block scheme of the machine

A research of electron beam technologies is conducted nowadays at BINP. Several electron beam machines have been constructed here including Small Experimental Electron Beam Machine which incorporates some interesting solutions like α-magnet and where experiments like 3D-printing with wolfram have been carried out.

The machine consists of so-called slow and fast subsystems. Slow subsystems successfully handled by CX control system with frequency about 1 Hz. Fast subsystems of the machine like beam deflectors or mechanical moving plates require to be controlled with frequencies from 100 Hz to 2 kHz.

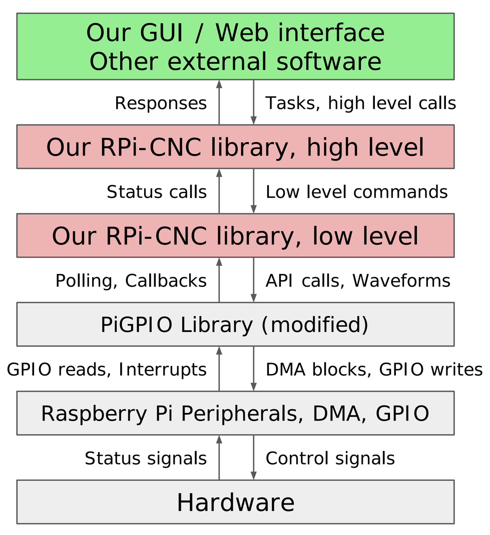
Also the machine frequently undergoes reconstruction and improvements so its controls system should be easily updated too.

We decided to implement this fast control system using Raspberry Pi.

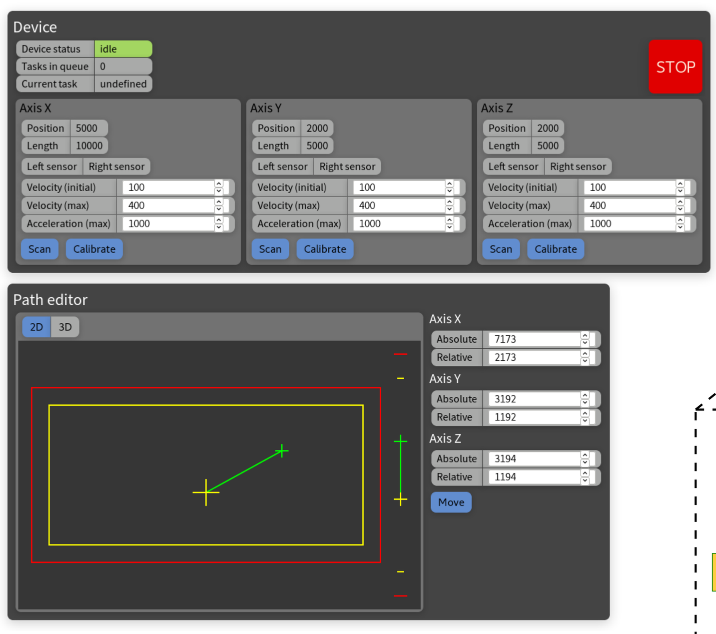


Mechanical moving plate

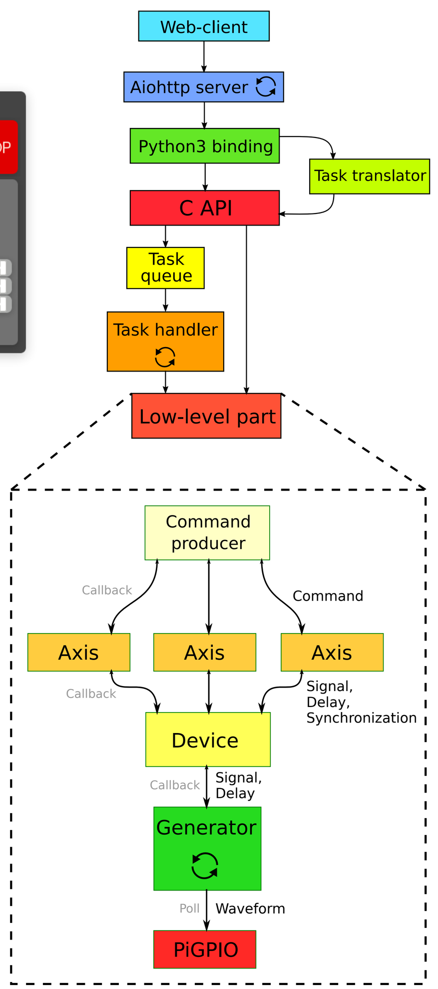
RPi-CNC Control System



Abstraction level stack

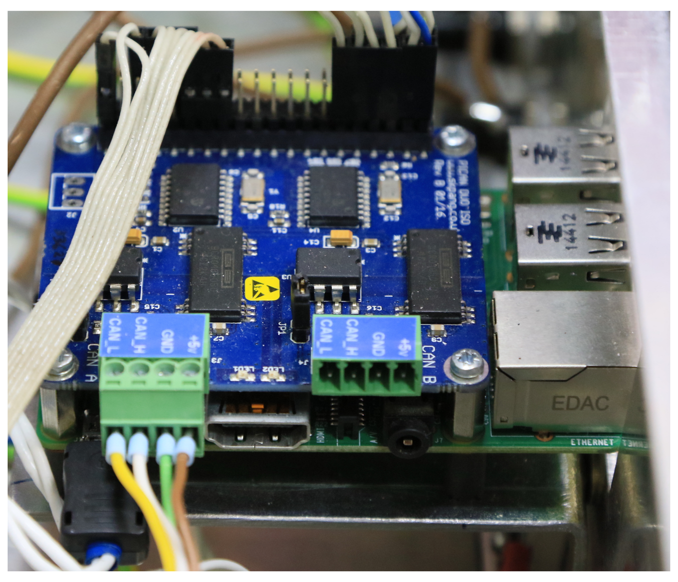


Web-interface example screenshot



Control system block scheme

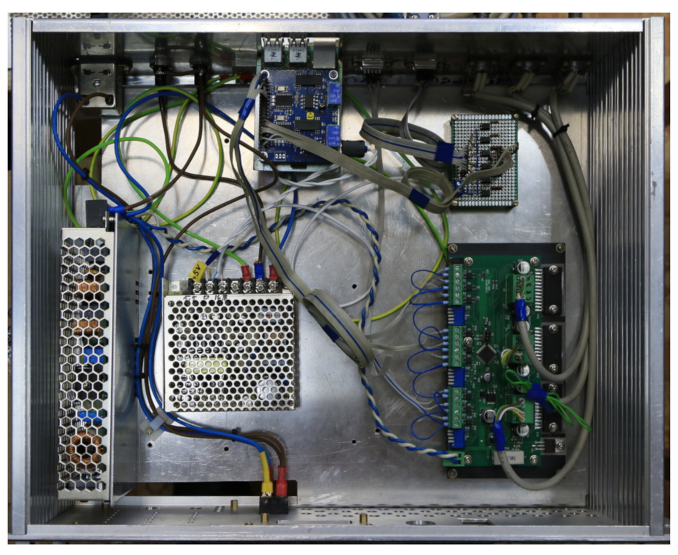
The control system for fast components of Small Experimental Electron Beam Machine was called "RPi-CNC".
Its software part was designed to be modular and easily extendable. It has layered structure with increasing abstraction level and specified interface of each layer.



Raspberry Pi as the core of the control system with CAN adaper mounted on top.

The hierarchy of software part of RPi-CNC is the following:

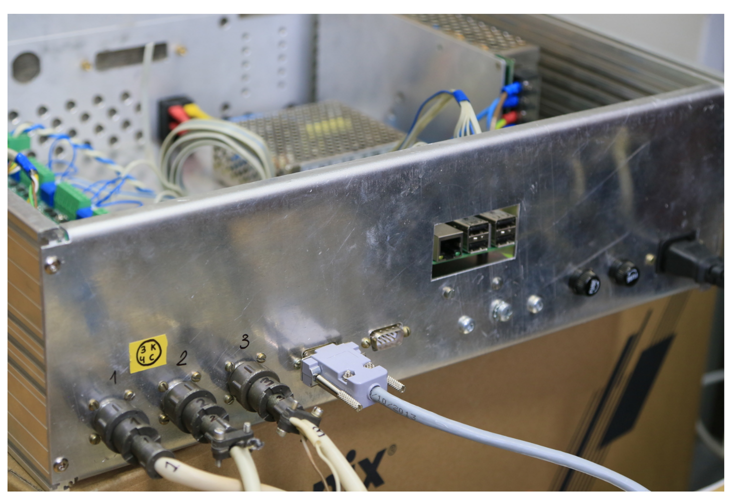
- Web-client with graphical user interface written in Javascript communicating with the server via Websocket.
- Python3 web-server written in asynchronous manner using Aiohttp library. The server interacts with underlying Python3 binding of RPi-CNC library.
- Python3 binding wrapping the C API of the library.
- RPi-CNC library high-level part. It performs task managements, receives signals from underlying low-level part and prepares command sequence for device control.
- RPi-CNC library low-level part. It is written in C with optional modules written in Rust. It generates waveforms and signals and receives signals from sensors. It interacts with the Raspberry Pi SoC hardware via pigpio library.
- Pigpio third-party library. It provider rich Raspberry Pi hardware management capabilities including tricky way of playing waveforms in real-time with frequency up to 10 kHz using DMA and PWM controllers.



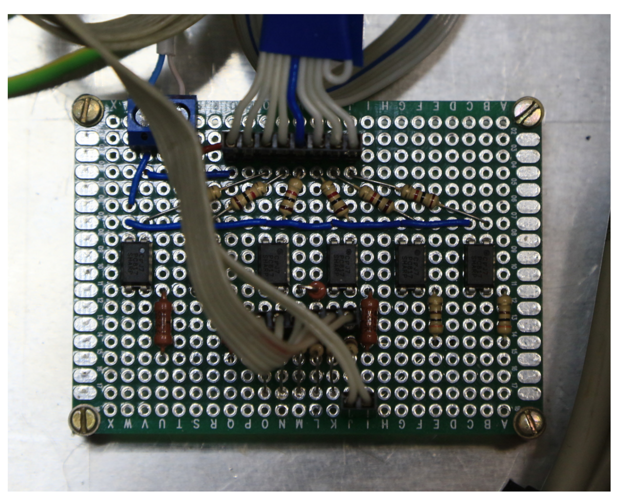
The content control systems hardware module

The hardware part includes CAN adapter for Raspberry Pi , stepper motor driver, custom proximity sensors adapter and power supplies for all this electronics and stepper motors. All the hardware was assembled into standard 19-inch rack mount chassis and integrated in experimental electron beam machine infrastructure.

RPi-CNC C library: https://github.com/binp-automation/librpicnc
RPi-CNC Python3 server:
https://github.com/binp-automation/rpicnc-host

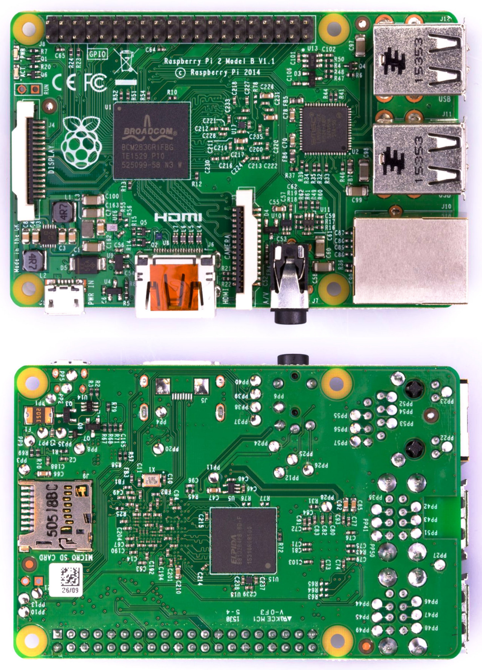


Connectivity of the control systems hardware module



Custom adapter for proximity sensors.

Raspberry Pi



Raspberry Pi 3 front and back

Raspberry Pi is a fully featured single board computer with GNU/Linux support.

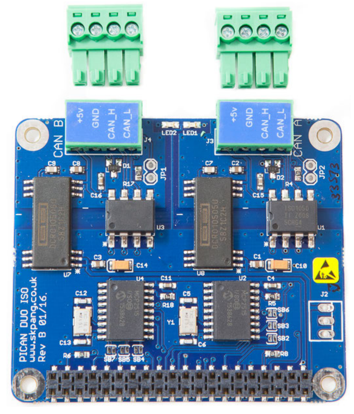
It is very suitable for quickly implementing a programming control for experimental hardware.

Version 3 is based on a BCM2837 SoC with 64-bit 1.2 GHz quad-core ARM Cortex-A53 and has 1GB LPDDR2 RAM on board.

It includes following interfaces:

- Ethernet
- 4 x USB
- WiFi and Bluetooth
- 40-pin GPIO
- HDMI
- 4 x SPI
- 2 x UART
- PWM,
- I²C
- PCM / I²S

Also there is a wide range of external adapters for Raspberry Pi to be put on top of GPIO.



PICAN2 Duo Iso adapter for Raspberry Pi

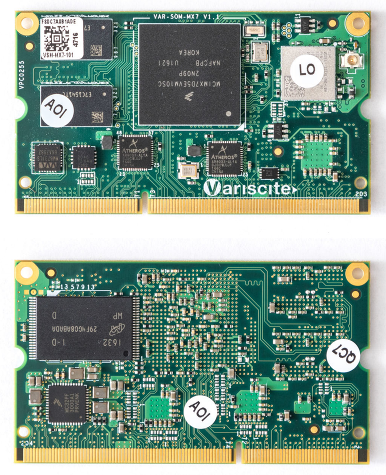
Variscite VAR-SOM-MX7 System on Module

Variscite VAR-SOM-MX7 is based on NXP/Freescale i.MX7 SoC.

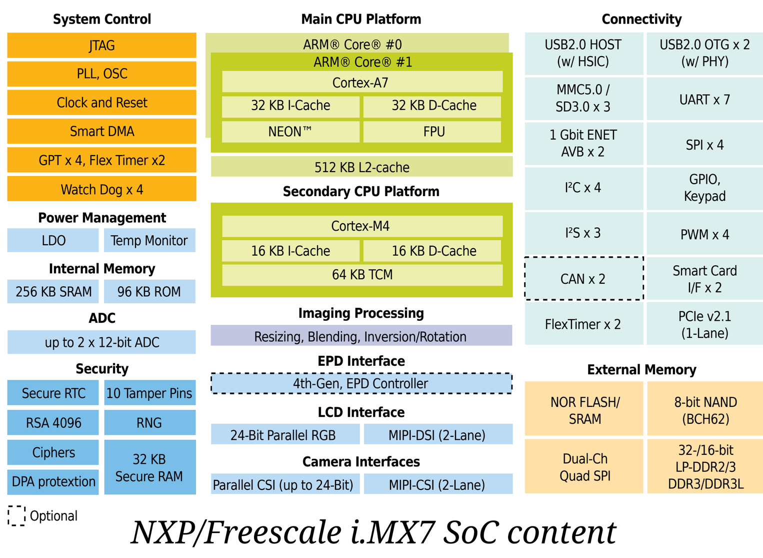
i.MX7 is asymmetric multiprocessor system - it has both:
- Dual-core 1 GHz ARM Cortex-A7 with GNU/Linux support.
- Real-time 200 MHz ARM Cortex-M4 with FreeRTOS support.

System on module also incorporates:
- up to 2 GB DDR3L RAM,
- up to 512 MB SLC NAND
- up to 64 GB eMMC

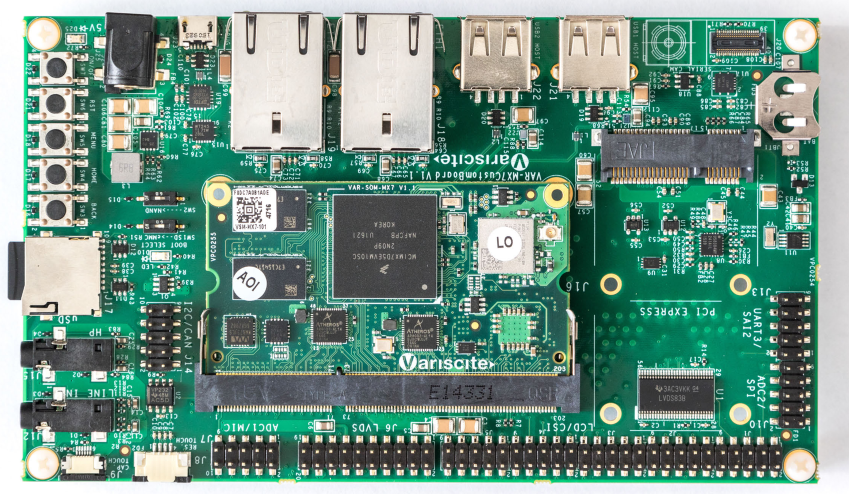
We are planning to use this platform as digital part of next-gen power supply controllers for accelerators at BINP which is another part of our work.



VAR-SOM-MX7 front and back



NXP/Freescale i.MX7 SoC content



Carrier board with VAR-SOM-MX7 installed

EPICS on Embedded Electronics

Next-gen power supply controllers is another part of our work. Among other functionality they should be integrated into EPICS control system being used at BINP accelerators.
Because EPICS could be built for ARM architecture and i.MX7 is equipped with relatively high-performance Cortex-A7 cores it is reasonable to consider the possibility of running EPICS device support directly on the controller without using any intermediate gateways between the device and control system.

We have made a simple stress test for EPICS device support. The setup was the following: a simple device support program was ran on a VAR-SOM-MX7 and multiple clients were connected to the server via 1 Gbps Ethernet. The clients physically were ran on a single machine but used different MAC- and IP-addresses. One client wrote a new waveform containing 20000 point of DOUBLE type into PV and the server broadcast these data to other subscribed clients, and this operation was repeated continuously. The delay between the sending of the waveform and its receiving by the last client was measured along with Cortex-A7 CPU load.

There were ran two attempts: for 20 and 256 connected clients. For 20 clients (this number is usual number of clients connected to such kind of device on VEPP-4) the delay was equal to about 100 ms and the CPU load was 40-60% (the full load of dual-core CPU is 200%). For 256 clients the delay was about 1 second and the load was 80-120%.

Testing program could be found here: https://github.com/binp-automation/epics-stress-test

Rust Programming Language for Control Systems

Rust is a modern programming language. It is declared to be fast and memory-efficient, because it is compiled to native code and has no runtime or garbage collector. Rust is designed to be safe - it guarantees memory- and thread-safety at compile-time. Also Rust is actively developed and has a wide range of tools.

Because of these advantages Rust is a good candidate to use in physics control systems development which require stability and performance. Also because of its resource efficiency it is reasonable to use Rust in embedded devices and moreover this application is one of the main efforts of Rust development team.

For now we use Rust in device support development for EPICS control system. The advantages of using Rust in such case is that it helps to develop more reliable software and reduces time spent for debugging. We have created EPICS binding for Rust and implemented the framework for writing EPICS device supports and drivers in Rust.

You may learn more about Rust on its website: https://www.rust-lang.org/

EPICS to Rust bindings: https://github.com/binp-automation/epics-rs
EPICS device support template in Rust: https://github.com/binp-automation/devsup-template
Keysight 53220A frequency counter device support using this template:
https://github.com/binp-automation/ksfc-devsup