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ETHERCAT OPEN SOURCE SOLUTION 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 defining and providing a control system for all the ESS facility. ICS decided to establish open-source EtherCAT systems for mid-performance data acquisition and motion control for accelerator applications. For instance, EtherCAT will be used when the I/O system needs to be beam-synchronous; it 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.

Following the ICS guideline, Motion Control and Automation Group developed EtherCAT Motion Control (ECMC) which is based on EtherLab open-source master. This solution was focused on Motion Control applications, but finally, data acquisition systems will be integrated into EPICS using the same approach. In this paper, we will present the ECMC solution and analyze its features showing some real applications at ESS.

INTRODUCTION

ECMC is based on EtherCAT (Ethernet for Control Automation Technology) developed by Beckhoff [2]. EtherCAT is a real-time Ethernet-based open Fieldbus that relies on conventional Ethernet frames to communicate with multiple devices in a synchronized away. Like many other Fieldbus applications, EtherCAT is based in one master/n-slave mode. 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 EtherCAT Master makes a 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 or MTCA.4 CPU as an EtherCAT master.

In the slave side dedicated HW (EtherCAT Slave Controller ESC) provides communication on the fly with standard CAT5 connection in line, star or ring topologies. Hundred of manufacturers coordinated in EtherCAT Technology Group [3] provide slave diversity (drives, I/O, sensors and robots).

Existent Etherlab IgH EtherCAT Master [4] open source solution and EPICS applications in other facilities such as Diamond Light Source (DLS) [5] and Paul Scherrer Institute (PSI) [6] did not fulfill ESS requirements, control of motion and mid range general IO within a single system. Thus, we develop a functional open-source motion control and mid-range general IO control framework integrated into ESS EPICS Environment [7].

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ECMC ETHERCAT MOTION CONTROLLER

ECMC is a open-source motion control and mid-range Generic IO controller module integrated into the ESS EPICS Environment (E3). E3 is a full software environment for deploying EPICS IOCs which contains the correct EPICS base, device support module, etc. The EPICS IOC and the ECMC work together in the same Linux based CPU providing a compact solution to control motion control systems within mid-range data acquisition systems (Fig. 1).

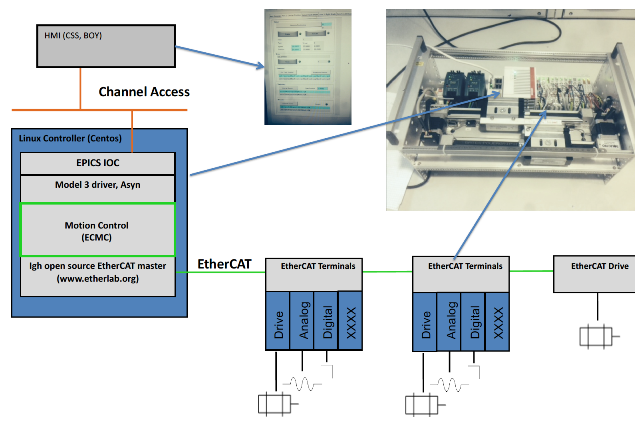

Figure 1: ECMC overview.

The ECMC communicates and configures the EtherCAT terminals through the EtherCAT protocol thanks to the tools provided by the open-source IgH EtherCAT Master. EtherLab is an open-source toolkit for rapid real time code generation under Linux. It 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 into Linux kernel it has realtime characteristics, anyhow, to meet real time performance PREEMPT Real Time patch should be used, but it is not mandatory. The master provides command line tools, providing an easy way to display the status of the master and the slaves, moreover, it displays available Process Data Objects PDO and Service Data Objects SDO.

ECMC Architecture

The architecture of the ECMC is available in Fig. 2. Two main parts are described in it: AsynPortDriver and ECMC Memory.

The communication between EPICS records and ECMC is performed using AsynPortDriver [8].The different interfaces of the AsynPortDriver have been implemented allowing transfer of data of both scalar and array types in an efficient way. Typical data that is transferred over these interfaces are EtherCAT process data and other data of the configured

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ECMC objects. As shown in Fig. 2, AsynPortDriver has several interfaces, such as, asynOctet, asynInt32, asynFloat64, aasynArrayXXX, etc. The asynOctet interface is reserved for configuration purpose of ECMC, realized through an extensive string based command-set being parsed, and then the corresponding setting are made in ECMC memory. The asynOctet interface can also be used for reading status of the ECMC system and the configured objects in runtime. This is how the motor record model 3 driver currently communicates with ECMC.

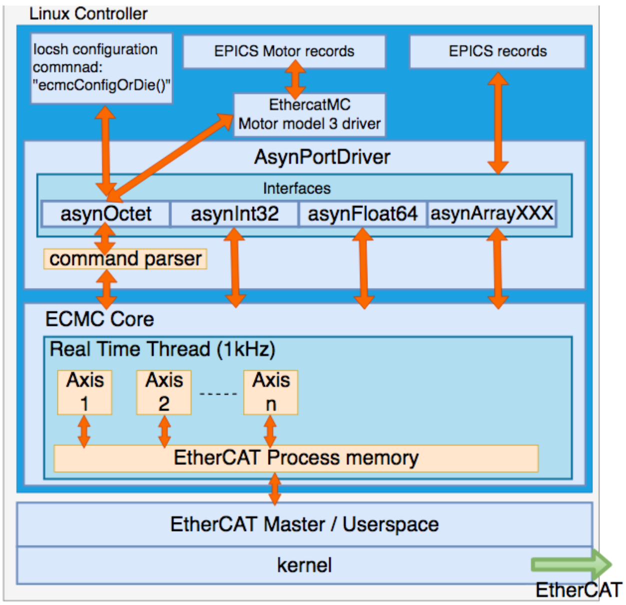

Figure 2: ECMC Architecture.

The Real Time Thread handles all the real time task within ECMC Memory. It communicates with the EtherCAT process memory keeping up to date the communication (read/write) with the EtherCAT slaves, provided by etherlab master. The Thread then executes motion control, general I/O control, plc objects, data storage. etc.

Axis Class objects execute all algorithms related to motion control in real time thread (1 kHz) for each axis. This axis objects can be real (linked to real HW) or virtual (for synchronization purposes). The axis class object is divided into 5 objects; the `Encoder`, the `Trajectory`, the `PID`, the `Monitor`, and the `Drive` object. The `Encoder` objects are typically linked to an analog input value (encoder, analog input, frequency input, etc.) from a slave. The `Trajectory` object generates the trajectory set points for the motion. The `PID` object makes a control based on the error between the trajectory generated set point and the actual value from the encoder object. The `Monitor` object evaluates motion (overspeed, position lag, etc.) and limit switches. And finally, the `Drive` object links to an output value of a slave (stepper, servo, analog output, pulse direction). This is how the motion is handled inside ECMC.

When it comes to general I/O control systems, AsynPortDriver reads/writes data directly from/to ECMC memory. This allows single values or arrays to directly pass to EPICS records using I/O interrupt with an optional configuration sample rate.

ECMC Features

ECMC has embedded into one system the motion control and data acquisition at ESS, and integrated them into EPICS. Looking deeper into the ECMC features, ECMC has integrated the main features of Motor record, like absolute positioning, relative positioning, constant velocity, evaluation of limit switches and homing procedures. Moreover, some of this features can be resumed in interlock support; virtual and real axis creation to handle synchronisation; data acquisition (100kHz analog, 1MHz digital); PLC objects handled in real time; support for different commercial suppliers (Beckhoff, Technosoft, Kuhnke, MicroEpsilon); the supported EtherCAT hardware slaves allows ECMC to be configured with a wide variety of sensors and motors, like, stepper, servos, BISS-C encoder, analog, etc.

To make the best out of this features, one must configure the system according to its requirements. For that purpose a ecmccfg [9] configuration framework for ECMC Motion Control Module for EPICS has been created. This framework wraps the ecmc commands (addSlave, addMaster, addAxis, loadPLC, etc.) into EPICS iocsh commands. This is handled by the Communication Thread to configure motion settings, ethercat bus configuration, slave configuration, PLC configuration, synchronization, etc. making easy to configure an EPICS IOC dedicated to motion control or data acquisition purpose.

The synchronization between axes is configured by expressions/equations provided C++ Mathematical Expression Toolkit Library (ExprTk) [10]. These mathematical expressions are executed within the Motion Thread ensuring true synchronization. These expressions allow the user to synchronize real axes wth other real axes or virtual axes; phasing and slaving axes, interlocking; enabling amplifiers. etc.

Another interesting feature is the PLC control embedded into ECMC. PLC objects can be created with a custom sample rate where logic can be loaded and updated in realtime. This feature allows the user to create state machines (execute motion, IO access, etc) within ECMC and have access to PLC variables trough EPICS, to control their application.

ETHERCAT BASED CONTROL APPLICATIONS WITHIN ESS ACCELERATOR

In this chapter, we will focus on the main significant ESS systems delivered with open source EtherCAT providing motion control and mid-range general IO control to various systems.

The Aperture Monitor (APTM) and Grid has been tested in the 3 GeV proton beam transport (3NBT) Dump line at Japan Proton Accelerator Research Complex (J-PARC), Tokai, Japan. The APTM is designed to measure the fraction of the beam that goes through the defined aperture to cover the range of time from intra-pulse at μs sampling rate to many pulses over second. The Grid measures the projected horizontal and vertical profiles. Two linear units moved by stepper motors in close loop, provide linear movement to the slits and two type K thermocouples provide temperature readout for protection system [11].

The Ion Source and the Low Energy Beam Transfer (ISrc & LEBT) line is installed and is being commissioned at ESS, Lund, Sweden. During the commissioning phase, Beam Diagnostic group provides beam accounting through the LEBT diagnostic system [12] (Fig. 3). We integrated many of these systems into EPICS using ECMC. The Faraday Cup (FC) provided beam current measurements. The Non-Invasive Profile Monitor (NPM) measure the transverse profile of the high power proton beam [13]. Emittance Measurement Units (EMU) is used intensively during the commissioning phase to characterize the ion source. Doppler Shift Measurement diagnostic system provides an accurate measure of the intensities of the different ion species produced by the source.

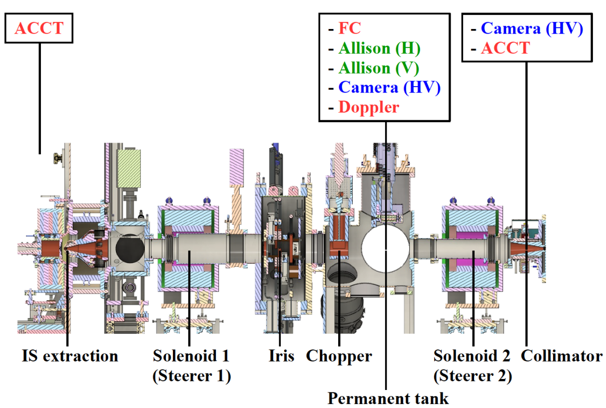

Figure 3: LEBT diagnostic system.

The IRIS is composed of 6 linear stages with special stepper motor for ultrahigh vacuum, controlled in an open loop in the LEBT. The IRIS sets the aperture adjusting the light intensity of the proton beam (6.3 mA–62.5 mA). One of the features requested from the IRIS is the synchronization between axes. Where the 6 axes are grouped in 3 slits. With ECMC, it is reasonably easy to implement an application where the slits follow the center position and the gap distance of the virtual axes. On top of that, a PLC object prevents the collision between the blades in a real-time thread.

Figure 4 represents the IRIS slit system, two real axes are represented in the image, where, real axes are homed to the aperture position of the IRIS and they are synchronized with the center and gap positions. Axis 7 (center position) and Axis 8 (gap distance), they are linked to the virtual axes `Encoder` object. Axis 1 (left blade) and Axis 2 (right blade) are linked to the real axes `Trajectory` object. The real axes `Trajectory` objects follow the gap and the center set position values. Meanwhile, the center and gap `Encoder` objects measure their position reading the actual positions of the real axes `Encoder` objects. On top of that, in order to

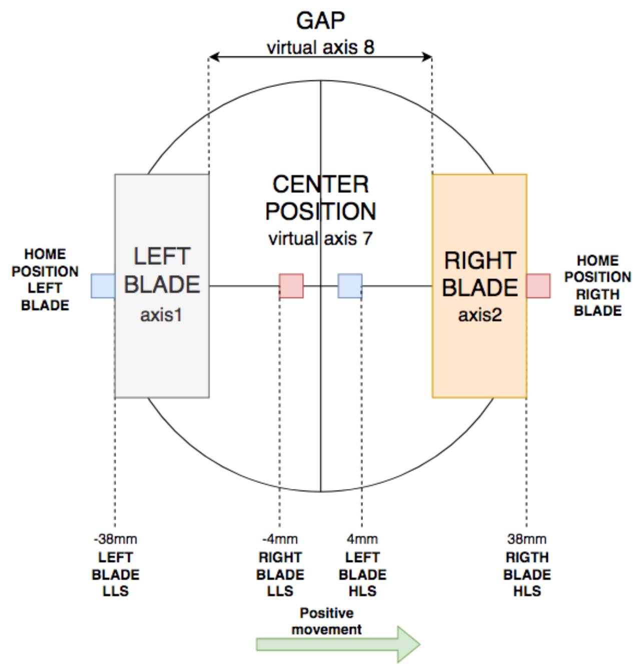

Figure 4: IRIS slit layout. LLS is Low Limit Switch. HLS is High Limit Switch.

avoid collision of the blades, a PLC object is monitoring at real time thread the real blade `Encoder` objects.

Temperature stabilization of the RF Phase Reference Line (PRL) is based on feedback control from measurements of the surface temperature of the copper coaxial line. Moreover, heating cables are wound around the phase-reference line and then insulation is applied. This is a distributed system spread all around the linac accelerator (600 m), controlling the temperature acquired by interconnected EtherCAT technology through ECMC generic I/O controller [14].

Gamma Blockers (GB) will protect the personnel in the accelerator tunnel against residual activation from activated target and tuning beam dump [15]. That means, the stepper motor will be in high radiation area, it will be controlled in open loop and since GBs have bigger torque requirements than standard motion systems within the linac, Technosoft Intelligent Drive iPOS8020 BX-CAT has been chosen instead of Beckhoff.

SUMMARY AND OUTLOOK

ICS is using ECMC open source motion control and generic I/O controller to integrate EtherCAT based systems into EPICS. ECMC has evolved within ESS, supporting many of the requirements for ESS stakeholders and has proved that it is a reliable technology for the EPICS community [16]. Looking into the near future of ECMC, the evaluation of Real Time PREEMPT kernel patches is already ongoing. Moreover, we are looking for collaborative work with other facilities, like PSI, who has developed a configuration framework to configure EPICS IOC for EtherCAT based motion control and general I/O using ECMC.

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