ECMC: Open Source Motion Control at ESS

Based on the open source EtherCAT master by IgH (etherlab)

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Outline

• EtherCAT fieldbus
• Previous work
• EtherCAT at ESS
• ECMC (EtherCAT Motion Control):
  - Overview
  - Architecture
  - Axis class
  - Synchronization
  - Example 2 axes slit set
  - Hardware
• Summary
• Acknowledgments
• References
EtherCAT Fieldbus

- EtherCAT = Ethernet for Control Automation Technology
- Open fieldbus standard originally developed by Beckhoff GmbH [1].
- Maintained by EtherCAT Technology Group [2].
- Hardware requirements:
  - Master: standard computer hardware (NIC)
  - Slaves: dedicated hardware, EtherCAT Slave Controller (ESC)
- Masters: Commercial (e.g. Beckhoff TwinCAT) and open source masters available.
- Slaves: Several 100 manufacturers of slaves (drives, I/O, sensors, robots).
- Topologies: Line, Star, Ring.
- Media: Cat 5 cable, plastic fiber, glass fiber.
- Bandwidth utilization: 80%-97% (100 Mbit/s, Ethernet, Full-Duplex).
- Supports Distributed Clock (DC) in slaves with a max. of 100ns synch error.
- Cycle times > 50μs.
- Applications: Motion, large or long distance systems, synchronized systems.
Previous work

• Diamond Light source “dls-ethercat” driver [7, 8]:
  – Data acquisition and control

• Paul Scherrer Institute “ecat2” driver [9]:
  – Data acquisition and control

• Other facilities are using EtherCAT as well but based on commercial software / hardware platforms.

We have focused on Motion Control!
EtherCAT at ESS

• Chosen as a medium performance platform for data acquisition and control [3, 4].
• Ideal for Motion Control.

Hardware strategy

• Three levels of performance
• MTCA
  – High-speed front-end processing
  – Digital Frontend Platform
• EtherCAT
  – Mid-range, beam synchronised I/O
  – Used mainly as a fieldbus
• PLC
  – Industrial, process I/O
  – Safety systems, high reliability
• Selection of platform based on requirements and cost

Source: [5]
ECMC is an open source motion control framework for EPICS environment [10].

Functionalities:

• Motion (with EPICS Motor Record support):
  – Positioning (absolute, relative)
  – Constant speed
  – Referencing sequences

• Motion (extension to Motor Record)
  – Motion interlocks
  – Triggering, latching positions
  – Synchronization axis to axis
  – Synchronisation to external source (timing system)

• General
  – Data acquisition (analogue <100kHz, digital <1Mhz)
  – General I/O + low level control
ECMC: Architecture

Controller (Linux)

Epics IOC (softloc)
- Asyn model 3 driver [12]
- Asyn [12]

Motion Controller (ECMC)
- Communication Thread
  - Command parser
- Motion Thread (1kHz)
  - Axis 1
  - Axis 2
  - Axis 3
  - Axis 4
  - Axis N
- EtherCAT process image

EtherCAT master [6]
- Master n

Direct access

EtherCAT
ECMC: Axis class

Axis types (normal, virtual)

- Encoder
  - EC master
  - Encoder Y
  - Optional link: Sync. External
  - ECPdoEntry

- Trajectory
  - Transform / Expression
  - Optional link: Sync. Trajectory
  - Trajectory Z

- PID-Control
  - Transform / Expression

- Monitor
  - EC master
  - ECPdoEntry

- Drive
  - EC master
  - ECPdoEntry
**ECMC: Synchronization**

- **Synchronization of axes by expressions (exprTk) [14].**
  - `setPosx` = Trajectory generated setpoint for axis x
  - `actPosx` = Actual position of axis x
  - `enx` = Enable amplifier of axis x
  - `ilx` = Motion interlock of axis x (allowed to move if true)

- **Update of expression at runtime possible (evaluated in 1kHz).**

**Examples:**

Slaving: `setPos2:=actPos1;`
Synchronization: `setPos2:=setPos1;`
Gearing: `setPos2:=0.5*setPos1;`
Phasing: `setPos3:=setPos1+setPos2;`
Advanced: `setPos1:=10*sin(setPos2+actPos3);`
Interlocks: `il1:=il2 and il5 and actPos4>actPos3;`
Enable: `en2:=en1;`
ECMC: Example 2-axes slit set

- 2 virtual axes
  - Slit center position
  - Slit gap/opening
- 2 normal axes (blade positions)

Forward Kinematics:
setPos3 := setPos1 - setPos2/2;
setPos4 := setPos1 + setPos2/2;

Inverse Kinematics:
actPos1 := (actPos3 + actPos4)/2;
actPos2 := (actPos4 - actPos3);

Amplifier enable:
En3 := En1 or En2;
En4 := En1 or En2;
ECMC: Example 2-axes slit set

Axis 4

Axis 1 (Centre)

Axis 2 (Gap)

Axis 3
ECMC: Hardware Platforms

- Standard computer hardware (NIC needed for EtherCAT Master).
- Flexible hardware choice:
  - μTCA (not tested yet)
  - Industrial computer
  - DIN rail computer
- Virtually any commercial EtherCAT slave (terminal) can be used, but needs to be evaluated and manually integrated into the framework.
Summary

• A motion control framework for use within EPICS environment has been presented.

• The framework utilizes the open source EtherCAT master from IgH Etherlab to configure and communicate with EtherCAT hardware.

• Basic motion functionalities as well as more advanced have been implemented.

• Framework can also be utilized for general control and data acquisition.

• Next steps:
  – Apply the framework to ESS accelerator applications
  – Continue to evaluate hardware and add to the framework
Acknowledgments

- IgH open source EtherCAT master
- EPICS community (base, motor, asyn, stream device)
- Mathematical Expression Toolkit Library (ExprTk)
- ESS Motion Control & Automation Group:

Questions?
References

[14] Arash Partow, C++ Mathematical Expression Toolkit Library (ExprTk), www.partow.net/programming/exprtk