Development of an Open-Source Synchronous Multi-Axis Motion Controller Solution for Large-Scale Experimental Physics Projects

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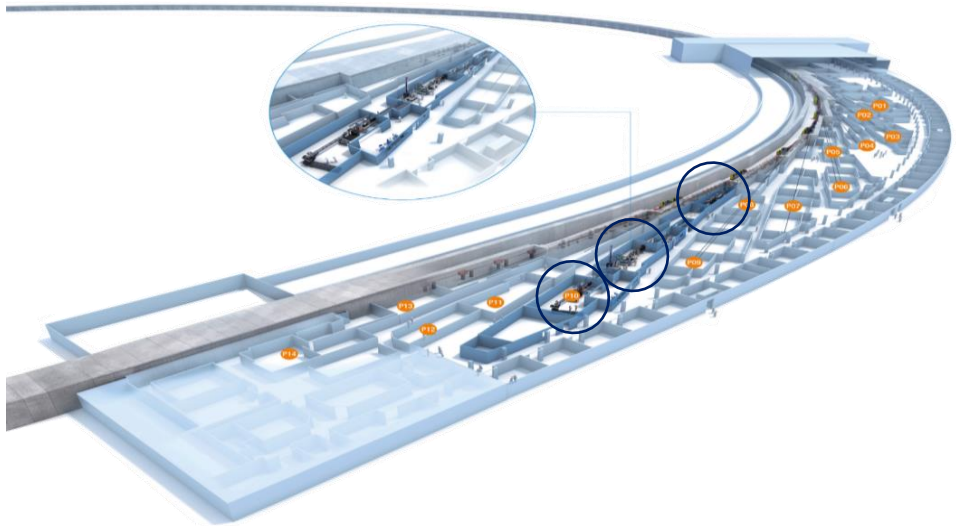
HELMHOLTZ

DESY.

Recapitulation: Motivation

DESY Experimental Needs:

- Requirement to move motors in experiments.

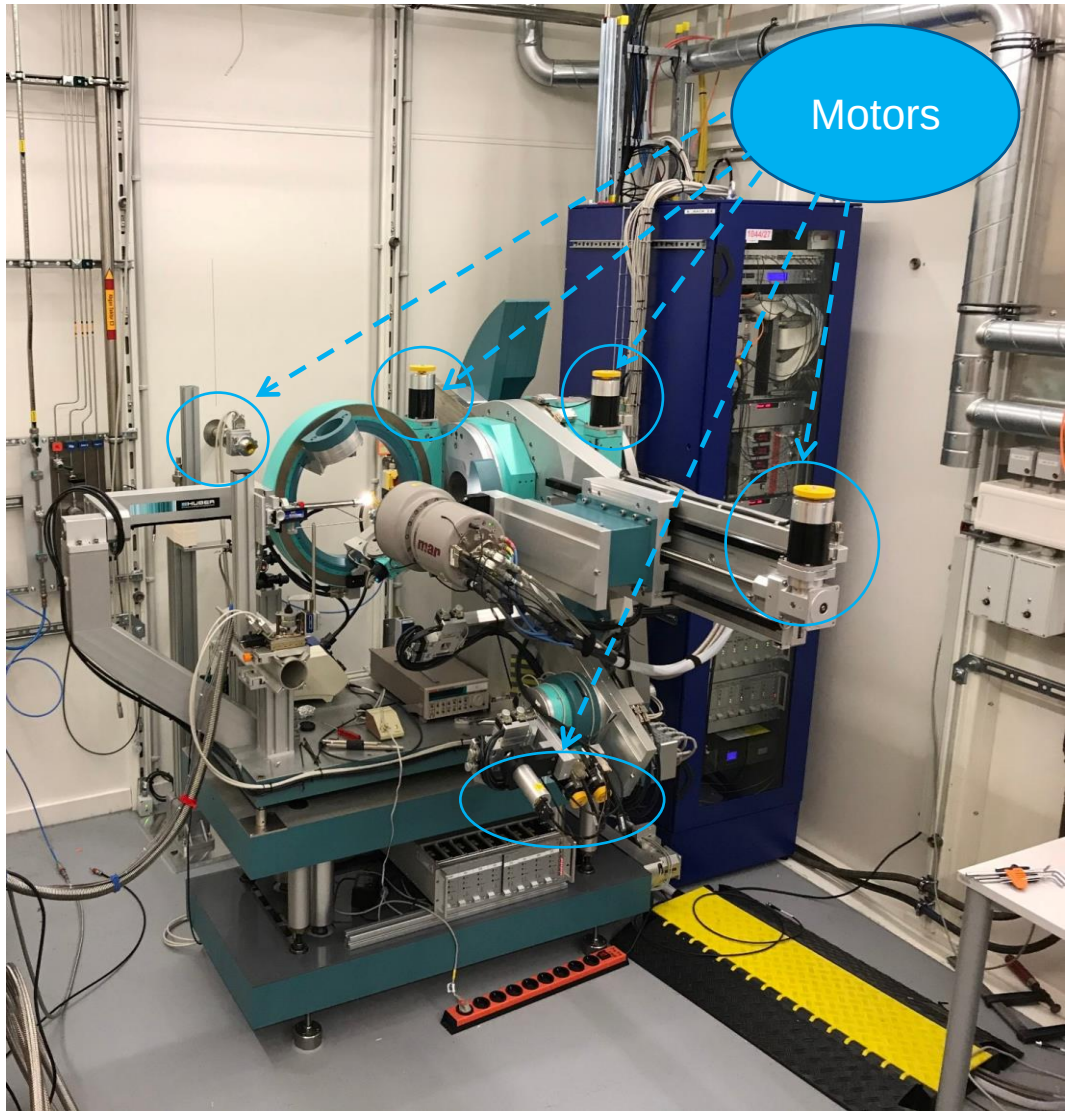


Petra IV MicroTCA Infrastructure:

- Planned replacement for VME systems.
- Lack of a suitable multi-axis motion controller.

Enhancements Needed:

- Increase the number of motors for synchronous motion.
- Address experiment-specific requirements, such as position-triggered data acquisition.



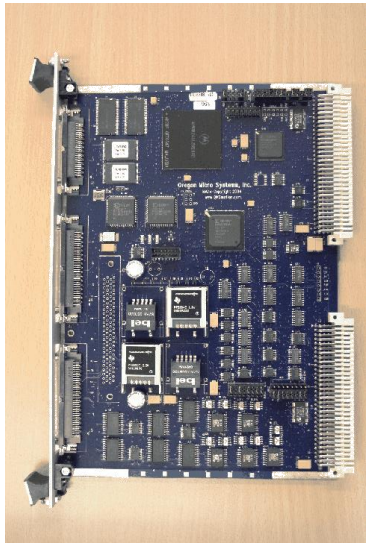
Diffractometer at Beamline
(Martin Tolkiehn)

Large Investments on DESY Campus

- Beamlines equipped with hundreds of existing motor drivers.
- Commercial drivers integrated into proprietary ZMX+ frame.

- Legacy hardware, but good enough to keep
- Incompatible interface:
  - Users complain about long, stiff cables.
  - Sensitive connectors (SCSI II).
  - 4 cables per motor driver frame.
  - Wide connector unsuitable for MicroTCA.
- Limited number of encoders.
- Need for a drop-in replacement due to the outlined issues.

SCSI connector on back panel of DESY ZMX+ frame

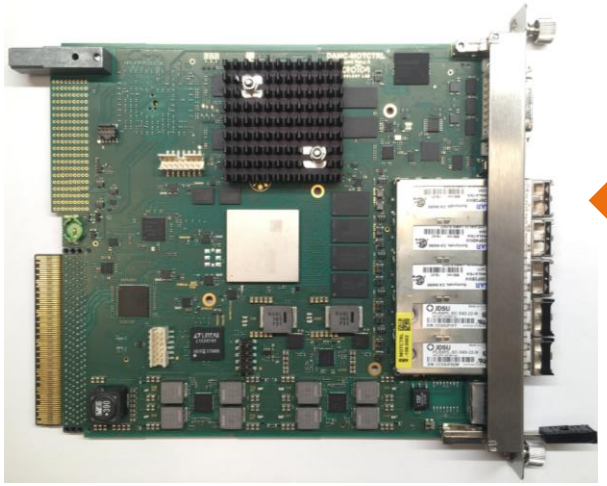


VME based Motion Controller - OMS MAXv

Petra IV Motion Control

Hardware

DAMC-MOTCTRL*:
- Funded by DESY Generator Program.
- MicroTCA.4 based Motion Controller.
- Controls up to **48 motors/axis** per card.
- Replaces six VME cards, i.e. three ZMX frames can be operated with one card.
- Four SCSI cables are replaced with a single fiber link.



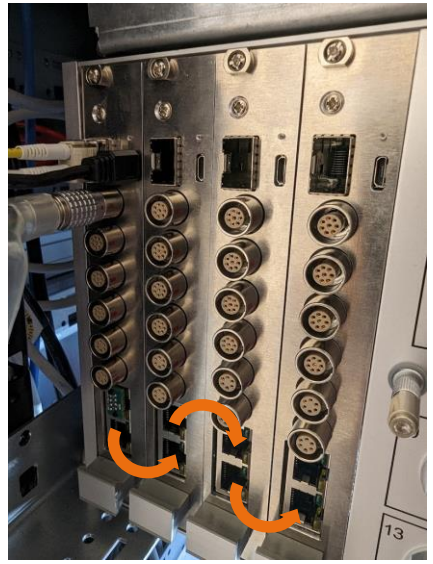
Heterogeneous Processing:
- Zynq UltraScale+ (XCZU2EG) with 2GB DDR4 32-bit.
- Kintex (XC7K160) with 4GB DDR3 64-bit.

SFP+ Ports (5 in Total):
- 3x Motor interfaces.
- 2x Ring topology (EtherCAT, SERCOS).

GPIOs:
- 26-pin connector supporting 3.3V/5V GPIOs.

*Check out the 11th MicroTCA Workshop Talk about the Multi-axis Motion Controller

ZMX+ Connection Board:
- Drop-in replacement for the deprecated interface card of the ZMX+ frame.
- Artix (XC7A50T)
- 6 LEMO 8-pin:
  - 4x Encoder Inputs
  - 2x Direct Motor Step & Direction
- 2 RJ45:
  - Interconnection between boards within the ZMX+ frame (daisy chain).



Interconnected ZMX+ Connection boards

Petra IV Motion Control

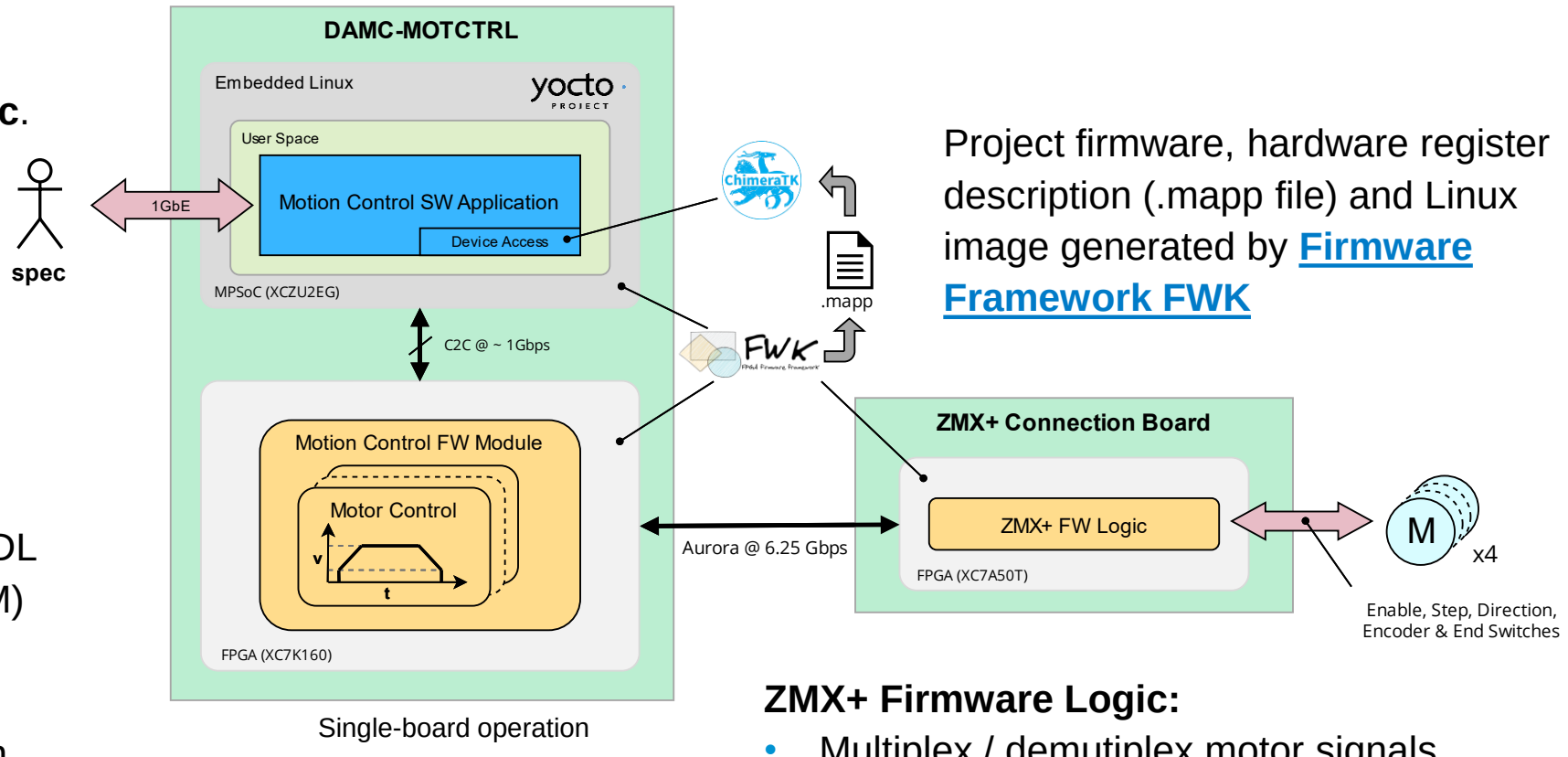
Firmware Overview & Current State

Motion Control SW Application:

- Interface to external high-level instrument control software **spec**.
- Parses motion commands and orchestrates axis logic.
- Uses UIO backend of **ChimeraTK-DeviceAccess**.

Motion Control FW Module:

- Generic multi-axis controller
- Verified using the Universal VHDL Verification Methodology (UVVM)
- Wraps per-axis submodules
  - Linear acceleration profile
- Clock-edge synchronous motion
- Per-axis encoder and limit switches



Single-board operation

Project firmware, hardware register description (.mapp file) and Linux image generated by [Firmware Framework FWK]

ZMX+ Firmware Logic:

- Multiplex / demutiplex motor signals
- Apply user front panel interface

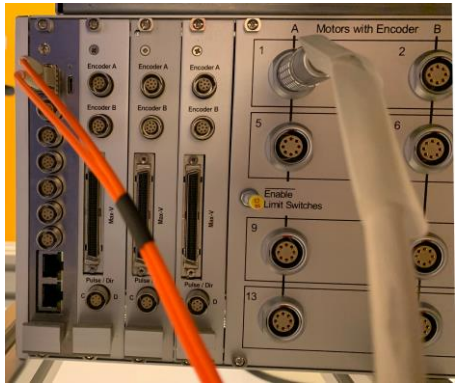
Petra IV Motion Control

Alpha Version Tests

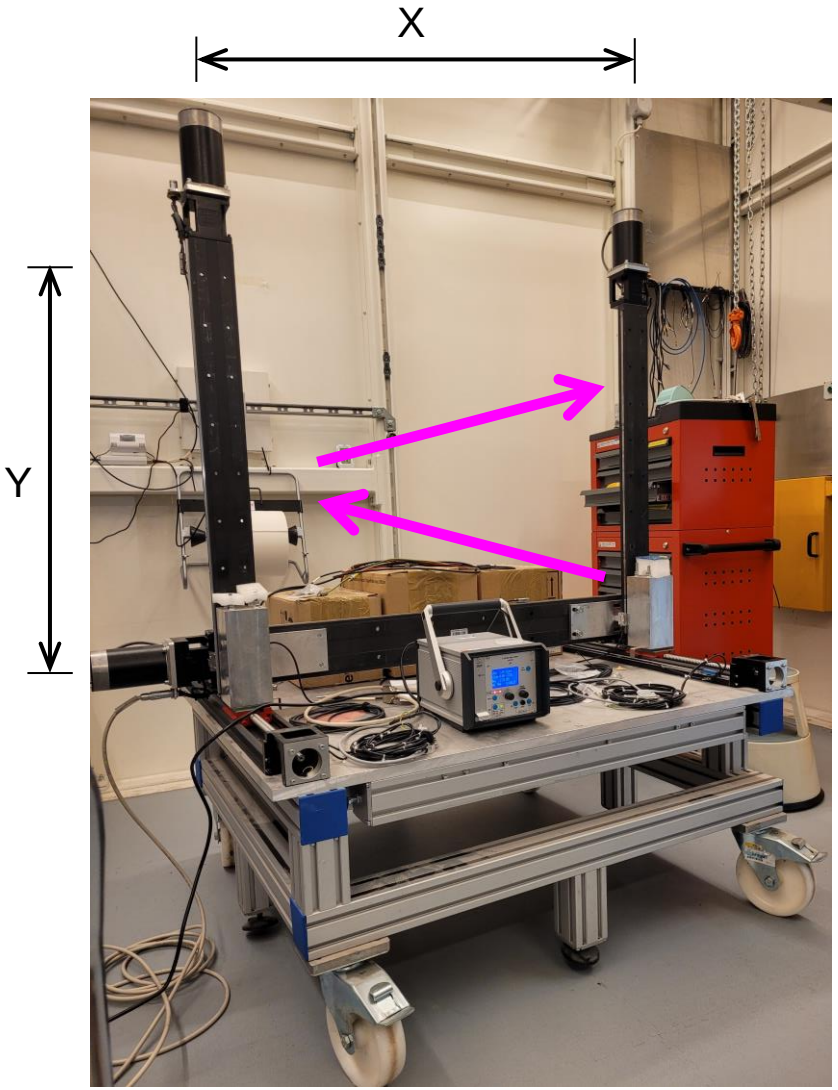
- **Firmware release:** Version 1.0.0 released by the end of September.
- **Test System Deployment:** Set up two test systems for user feedback.

- **Testing at Petra 3 Beamline Lab of FS-PETRA-D group (DESY):**
  - Executed single-axis movements using the **spec** software.
  - Verified the expected behavior of limit switches.
  - Successfully **performed synchronous motions** in the XY-direction, involving three stepper motors on a linear stage.
  - Gathered feedback regarding missing features.

MicroTCA Crate



ZMX+ Frame (backside)



XYZ Motorized Linear Stage

Petra IV Motion Control

Alpha Version Tests

- **Collaborative Testing with FS-EC Group (DESY):**

- The Tango server, designed for testing, serves as a model for the development of a generic control system interface.

- Development of a Python Tango server.
- Execution of test scans using 'spock' (Sardana command line tool).

```
p09/door/haso107d10.01 [1]: ascan eh_mtca01 0 1 10 0.1
Operation will be saved in /home/kracht/Misc/IVP/temp/tst_[ScanId].fio (fio from FIO_FileRecorder)
Scan #25452 started at Mon Nov 20 15:19:52 2023. It will take at least 0:00:13.298900
 #Pt No   eh_mtca01   eh_t01    eh_c01   sig_gen   pilatus   eh_mca01     dt
   0          0        0.1     66.9997   4.03657e-08   (2, 1)   (2048,)   9.15583
   1         0.1       0.1     2.16509   2.62186e-07   (2, 1)   (2048,)   12.3689
   2         0.2       0.1     9.43935   1.57693e-06   (2, 1)   (2048,)   15.5001
   3         0.3       0.1     31.1944   8.78257e-06   (2, 1)   (2048,)   18.6312
   4         0.4       0.1     78.0972   4.52935e-05   (2, 1)   (2048,)   21.7556
   5         0.5       0.1     149.482   0.0002163   (2, 1)   (2048,)   24.8861
   6         0.6       0.1     218.324   0.000956493   (2, 1)   (2048,)   28.0028
   7         0.7       0.1     243.102   0.00391663   (2, 1)   (2048,)   31.1157
   8         0.8       0.1     206.674   0.0148508   (2, 1)   (2048,)   34.2271
   9         0.9       0.1      134.02   0.0521425   (2, 1)   (2048,)   37.3476
   10         1        0.1     66.3115   0.169527   (2, 1)   (2048,)   40.4639
Operation saved in /home/kracht/Misc/IVP/temp/tst_25452.fio (fio)
Scan #25452 ended at Mon Nov 20 15:20:33 2023, taking 0:00:40.873867. Dead time 97.3% (motion dead tim
e 88.8%)
```

Petra IV Motion Control

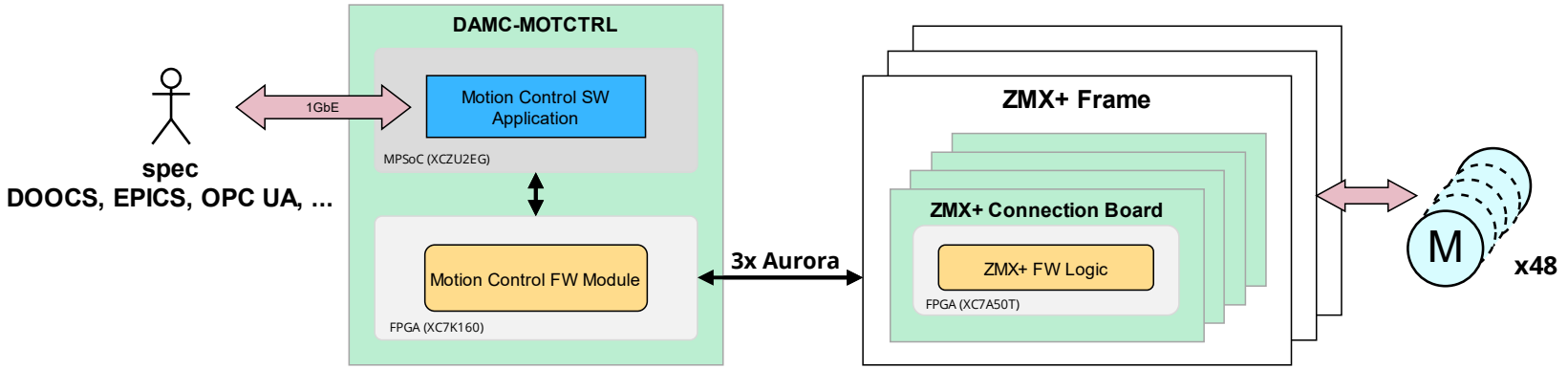
Next Steps

Motion Control SW Application:

- Develop and specify process variable interface.
- Utilize ChimeraTK – ApplicationCore.
- **Control system integration** (DOOCS, EPICS, OPC UA, …).

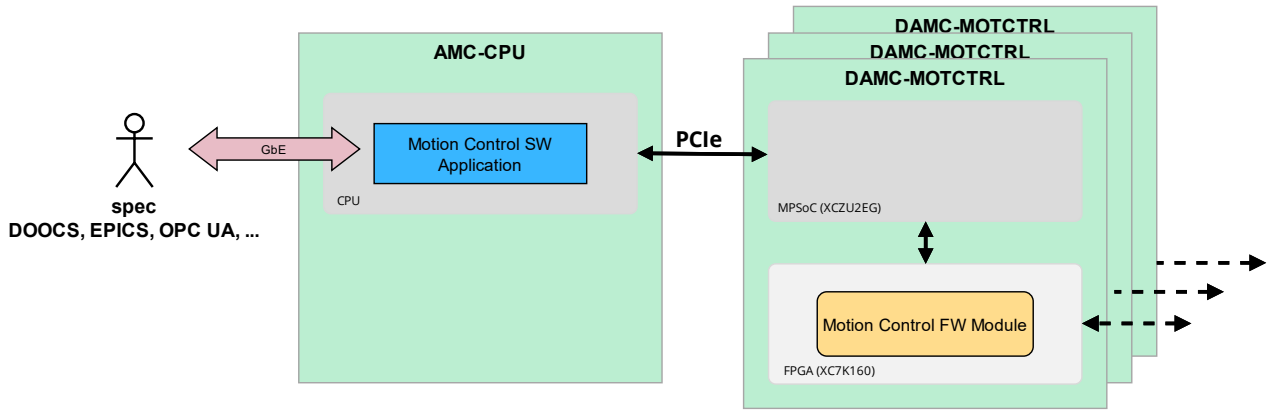
Motion Control Firmware:

- Missing features: Homing procedure, …
- Introduce **trigger functions**
- Extend to 16 synchronous motors per ZMX+ frame.
- Extend to 3 ZMX+ frames per DAMC-MOTCTRL.



Inter-Board-Synchronous Motion:

- Utilize AMC-CPU and synchronize through Backplane for intra-crate synchronization.
- Utilize timing module and external trigger for distributed systems.



Petra IV Motion Control

Check out the source code and documentation:

- **Open-Source Petra IV Motion Control Project**
- **Open-Source Motion Control Firmware Module**

Contact

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Thank you