10 YEARS OF EXPERIMENT CONTROL AT SLS BEAM LINES: AN OUTLOOK TO SWISSFEL

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Abstract

The Swiss Light Source (SLS) at the Paul Scherrer Institute (PSI), the first 3rd generation synchrotron light source designed to operate in top-up regime, started user operation end of 2001 with four beam lines [1]. Today, after nearly 10 years of consolidated user operation with up to 18 beam lines, we are looking back to briefly describe the success story based on EPICS controls toolkit. From the experience gained at the SLS we outlook towards the X-ray free-electron laser SwissFEL, the next challenging PSI project, starting operation by 2016.

PTD EXPERIMENTAL ANATOMY

The EPICS-toolkit provided flexible and easy-to-scale distributed control system architecture, both for the beam line and experimental control setups. We briefly discuss the main elements of the distributed beamline control system rigorously based on "Positioner-Trigger-Detector" (PTD) anatomy. The bulk of the "Positioner" motion control is based on MAXv motor controllers hosted in VME systems which are attached to separate power amplifiers (motor box) giving 8-axis motion control per one MAXv and motor box. The motor device control is the EPICS *motor* record: the main building block on top of which the whole motorized functionality is build up mainly with SynApps [2]. To be more specific, *transform*, *sseq* sequential, *table* configurable optical table setups, combined with the *motor*-record wait-for-completion functionality, tremendously simplify the software integration of slits, monochromators and mirror units*.

The Concept of EPICS Positioner

The beamline "Positioner" is the most critical issue for reliable operation. Typically it is bundled multi-axis motion control functionality. For example slits, monochromators and mirror units are set of motors with precise physical meaning in engineering units such as slit width or pitch-tilt-yaw settings of an optical unit. A more complex example of multi-axis Positioner is the sample manipulator. The integration of a 6-axis Carving™ system (Fig.1) developed at PSI, meets the requirements for safe translation and user-friendly positioning inside vacuum chambers. Shutter interlocks and dynamic motion volume control are essential to prevent in-vacuum accidental crashes. A noteworthy fact is that positioning requirements for all five Carving™ systems at SLS are based on *select, fanout*, *transform*, *calcout* and *sseq* records with configurable behaviour instead of implementing dedicated solutions via programming or scripting.

In the earlier days of beamline commissioning, the spectroscopy beam lines success story started with a simple *transform* record that bundled the monochromator and insertion device "set-energy" command by simply typing in the desired photon energy. The Energy-Positioner has mandatory readback value. The *busy* record – a smart wait-for-completion flag – aggregates monochromator plus insertion device energy-positioners into one logical block with implicit callback for point-to-point scans. In *sscan* setup this functionality minimizes the effort for setting up arbitrary experimental setups. Our experience is that an adequate PTD *sscan* setup understands most experimental needs used for beamline commissioning and even more advanced experiments with image data acquisition (Fig.1). Since the *sscan* P-T-D links are possible to change dynamically, it is also a guideline for implementing experiments by adapting existing experimental schemes instead of rewriting them.

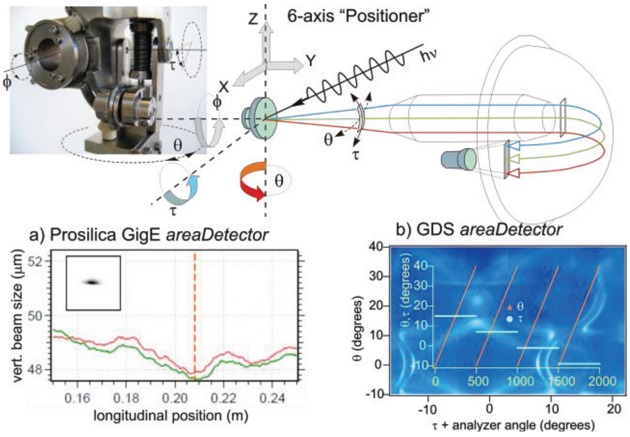

Figure 1: PTD experiment with *areaDetector* (AD). a) 1x1mm ROI (in-set) evaluating the vertical beam size by scanning the exit slit through the beamline focus (dashed line, courtesy M.Munthwiler). b) τ,θ-scan with VGScienta electron-analyzer for mapping zero-energy electronic states in momentum space with Carving manipulator (courtesy of L.Patthey). VGScienta AD credit: J. O'Hea and F.Yuan, Diamond Light Source Ltd.

The Concept of EPICS Trigger and Detector

Strictly speaking, triggers are usually associated with some hardware TTL signal in order to measure voltage, CCD, pixel detectors or channeltron. In the latter case the COmplete PHotoEmission Experiment, a world class 3D

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* To illustrate the wealth of EPICS records we shall henceforth denote them in cursive writing

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spin-polarimetry setup, is in-fact a slick *sscan* masterpiece example reliably working since 2001 without any modification. The Positioner is here the electron analyzer low/high voltage window; the Trigger is a *scaler* record acting also as a Detector by counting TTL pulses from Mott detectors. A more basic example is *e.g.* triggered voltage readout from current amplifier. Based on Hytec ADC VME cards with buffered sampling and averaging, they are soft-triggered (Fig.3). The integration time is adjustable by feeding the readout into *compress* records for adjusting the signal averaging. To make this *sscan*-aware, auxiliary *calcout* and *busy* records linked with the *compress* record provide the desired effect.

To summarize, the rich variety of EPICS records are "nuts" and "bolts" for the PTD experimental approach. An adequate PTD design opens the doors for *sscan* solution for most experimental demand.

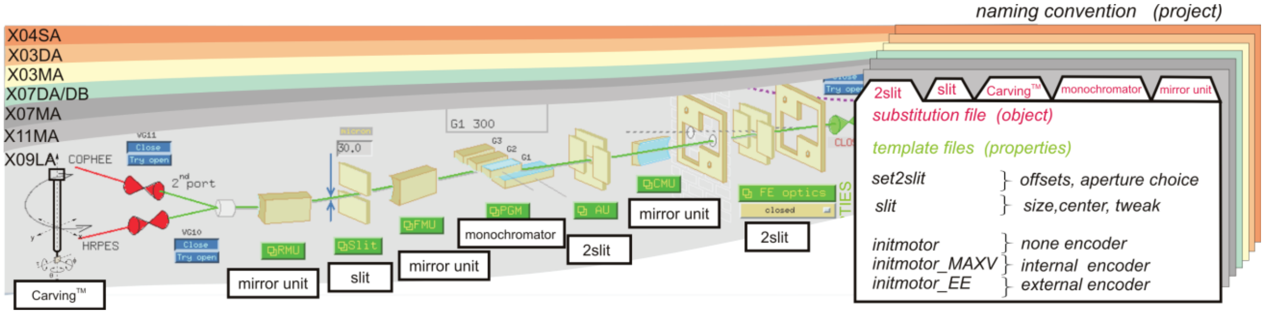


Figure 2: EPICS naming convention, substitution and template files related to Project-Object-Property object oriented paradigm for beamline motion control configuration and installation (see text).

Configuration and Installation

EPICS has no object oriented capabilities but individual "nuts" and "bolts" are grouped according to their functionality. There is a way to mimic a class hierarchy between them at least on the configuration side with Project-Objects-Properties weakly related by naming convention, substitution and template files (Fig.2). For the beamline motion control, template files implement motion axes with well defined properties (*e.g.* mandatory initialization procedure to position the axis in a defined state). The substitution file groups axes into one logical block and naming convention ensures that an installation procedure deploys the whole project or a part of it into the target VME or Linux IOC system [3].

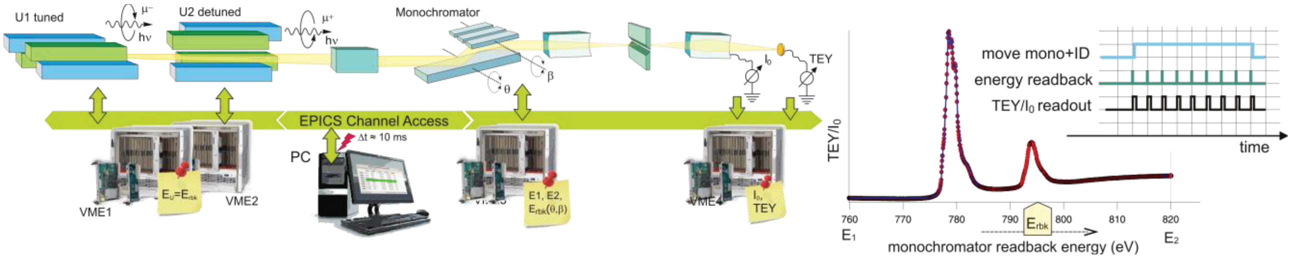


Figure 3: Schematic layout of the SIM beamline with underlying computer control for on-the-fly XAS data acquisition. E_{rbk} is the master energy-cursor that drives ID and reads low-current signals resulting in XAS fast data acquisition (see text).

On-the-fly Scans

A trajectory scan with coordinated monochromator and insertion device (ID) is the experimental workhorse for studying magnetic phenomena where I_0 and TEY detectors are two strictly simultaneously acquired low-current signals. Technically a precise monochromator-ID synchronous trajectory scan is not possible due to limitations in the motion control. However, it turns out that the channel access latency (~10 ms) was sufficient for a quasi-synchronous operation in which the actual monochromator readback energy was the "master" setting the ID "slave" and reading the I_0 and TEY signals (Fig.3). Since the ID-harmonics in soft-X regime are quite broad, the fact that the ID-energy was "running after" the monochromator with a small energy difference did not produce any sizeable effect in experimental data. [4].

The on-the-fly scans are implemented is a Python portable channel access server (PCASPy) [5]. This choice was not only dictated by the increasing Python popularity among the users, but it turned out to be a very fast and straightforward EPICS implementation of complex control. Moreover, in the field of magnetism research with polarized light the experiments are well defined sequences for which the users feel comfortable in Python especially when implementing sensitive control such as tuning/detuning ID for fast polarization switching. The PCASpy has few EPICS channels such as start/end-energy, total amount of time (typically 2 min) and the START/STOP that executes the whole control and data acquisition machinery (~2000 XAS points). Of course, a *waveform* is used for on-the-fly spectra visualization.

PTD WITH IMAGES

Most experimental setups with 2D detectors such as CCD cameras, electron analyzers or pixel array detectors for X-rays, are in-fact PTD experiments ranging from simple commissioning tasks (Fig.1a) to more complex setups such as state-of-the-art optics metrology [6].

areaDetector: the Art of EPICS 2D Imaging

The *areaDetector* (AD) is a modular system that simplifies the EPICS implementation of new imaging-detectors providing standard control interface and plug-in extension capabilities [7]. For example the "Acquire" command is common for all AD drivers and is *sscan*-aware, *i.e.* it waits until data acquisition is finished. Besides this a plug-in concept for device-independent real-time data analysis is the key feature promoting EPICS 2D-imaging into art where complexity becomes simplicity. A typical example is illustrated in Fig.1a where the beamline focus is *on-line* evaluated with GigE CCD images in *sscan* setup. A cartoon view of this setup is seen in Fig.4 where we anticipate a FEL commissioning example in which a lased pulse is examined in a spectrometer setup.

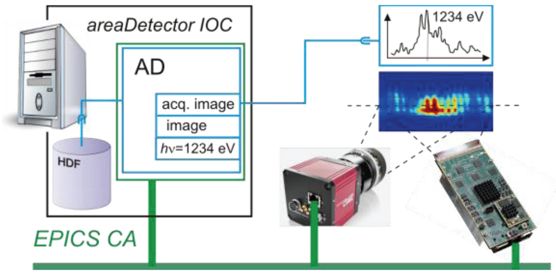


Figure 4: Cartoon view of AD-setup with a Prosilica GigE CCD or Gotthard 1D pixel detector for on-line evaluation of lased FEL pulse spectrum and energy by means of energy dispersive optics.

areaDetector for SwissFEL

There are two charge-integrating detectors in preparation for the SwissFEL: the Gain Optimizing microsTrip sysTem witH Analog ReaDout (Gotthard) 1D and adJUstiNg Gain detector FoR the Aramis User station (Jungfrau) 2D pixel detectors [8]. The second is a 2D-version of first one having 50 μm pitch and 1280 channels. Both have a TCP/IP control link and separate GBit Ethernet data transfer for readout. In this contribution we focus on the Gotthard detector useful for XFEL beam diagnostics, powder diffraction or XES/XAS spectroscopy, as already successfully tested at LCLS.

There are two limiting factors in using AD-software for SwissFEL. First, the AD must cope with 100 Hz operation rate. Second, every FEL pulse carries a unique bunch marker that needs to be associated with detector data. In order to achieve this in 100 Hz shot-to-shot operation, the Gotthard-AD must connect to the SwissFEL timing system on top of which a real-time beam synchronous data acquisition (BSDAQ) has been developed [9]. There are two BSDAQ hardware options supported: (i) VME; (ii) Linux. The latter opens the door to merge the AD with the BSDAQ, as schematically seen in Fig.5.

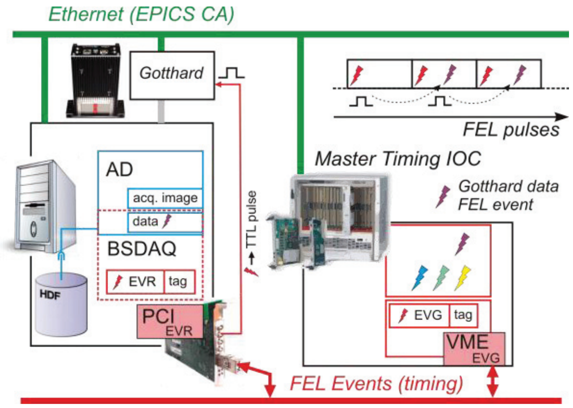


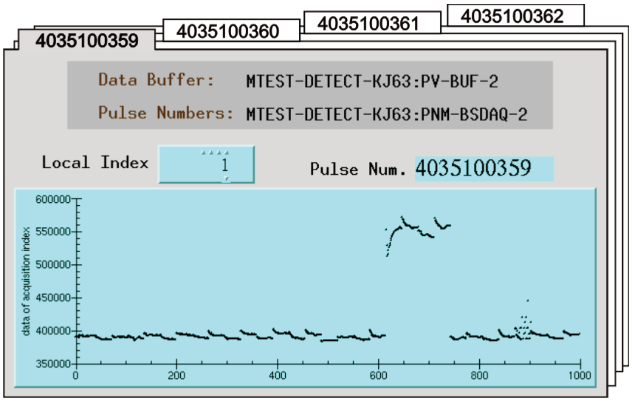
Figure 5: A cartoon view of the Gotthard *areaDetector* (AD) integration with the SwissFEL timing system. BSDAQ has EPICS device for bunch marker (tag) which is associated with Gotthard data with EPICS *calink*. The event generator EVG is posting events to the EVR receiver, and *vice versa*, the master timing IOC might receive a new event from the Gotthard AD (see text).

The Linux-BSDAQ is based on the PCI event-receiver which translates timing events into a TTL signal. The Gotthard AD in trigger mode is waiting for the TTL; it acquires and process data by posting them into EPICS channels. Besides decoding the trigger events, the event receiver decodes the bunch-marker generated by EVG and transmitted to EVR through the same timing system network. In this way the bunch-marker under BSDAQ is guaranteed to be unambiguously associated with the FEL event associated with unique FEL pulse. Since the BSDAQ and the AD software is running inside the same Linux IOC, Gotthard data are safely tagged with the bunch markers — a crucial point for providing meaningful Gotthard diagnostics for the machine.

Shot-to-shot Operation with areaDetector

A test setup with Start/Stop data acquisition of four Gotthard frames acquired at 100 Hz rate is seen in Fig.6. "Data Buffer" and "Pulse Numbers" are EPICS *compress* circular buffers local to BSDAQ holding spectra tagged with corresponding bunch markers. We note that more advanced setups are foreseen to export these data into the timing system. For example in a spectrometer setup the on-line evaluated energy is going to be related with a new FEL event that carries photon energy scalar value from the current pulse. This is schematically explained in Fig.5: the timing system is holding a new "Gotthard data" FEL event. Such functionality could be used for optimizing the

FEL shot-to-shot photon energy in feed-forward feedback schemes.



Data Buffer: MTEST-DETECT-KJ63:PV-BUF-2
Pulse Numbers: MTEST-DETECT-KJ63:PNM-BSDAQ-2
Local Index 1
Pulse Num. 4035100359

Figure 6: *cursorX* data from the Gotthard *areaDetector* tagged with corresponding pulse numbers. A cartoon view shows the index scrolling effect in which individual pairs can be inspected

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CONCLUSIONS

After 10 years of SLS operation we conclude that EPICS toolkit became a mature environment for distributed control needed for synchrotrons. Many synchrotrons joined the EPICS community; we greatly appreciated the vivid collaborative effort for instrumentation control. On the experimental side the SynApps *sscan* functionality understands almost every experimental need used in synchrotron laboratories. Its Position-Trigger-Detector anatomy is in-fact a guideline for deploying experimental control with EPICS distributed control. This applies also for FEL experiments for which the *areaDetector* package is a feasible approach for building imaging experimental setups at 100 Hz operation. "Flying blind" experiments – a typical problem in FEL experiments without on-line data inspection – are minimized. As a proof-of-principle example, the integration of the Gotthard strip-detector with the existing SwissFEL timing system was successfully tested.

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