SARDANA BASED CONTINUOUS SCANS AT ALBA - CURRENT STATUS

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Abstract

A significant part of the experiments run at Alba Synchrotron [1] involve scans. The continuous scans were developed first ad hoc and latter the controls group dedicated important efforts to standardize them across the Alba instruments, enhancing the overall performance and allowing the users to better exploit the beamtime [2]. Sardana[3, 4], the experiment control software used at Alba, among other features, aims to provide a generic way of programming and executing continuous scans. This development just achieved a major milestone - an official version with a stable API. Recently the Alba instruments were successfully upgraded to profit from this release. In this paper we describe the evolution of these setups as well as the new continuous scan applications run at Alba. On the one hand, the most relevant hardware solutions are presented and assessed. On the other hand the Sardana software is evaluated in terms of its utility in building the continuous scans setups. Finally we discuss the future improvements plan designed to satisfy the ever-increasing requirements of the scientists.

BEAMLINE CONTROL SYSTEM AT ALBA

Alba is a third generation synchrotron located near Barcelona, Spain. Currently its eight beamlines host user experiments regularly, another beamline is under construction and two more under design.

An important part of the ALBA beamline control system is controlled directly by Tango. This includes numerous subsystems like vacuum, equipment protection, archiving or alarm handling [5, 6]. Likewise, some of beamline instruments still come with their own control software. However, both of these cases are out of the scope of this paper.

Sardana

The beamline control system at ALBA [7] is based on Sardana, a highly modular software package implemented in Python, built on the client-server model on top of Tango [8]. On the client side reside the GUI applications developed with Taurus library [9] and a CLI application called Spock built on top of IPython [10]. The server side is formed by two key components, the Macroserver and the Device Pool. The first one provides a controlled environment to develop and execute user procedures, written in Python, called macros and comes with a catalogue of standard and parameterizable macros which also includes generic scans. The second one offers a set of interfaces to the most common elements of the laboratory like, for example, motors or experimental channels and implements the hardware access layer by means of the plug-in controller classes also written in Python. Higher abstraction elements, like pseudo elements or groups, can be built on top of the physical elements e.g. the beam energy or mirror's angle pseudo motors which offer the possibility to optimize access to the hardware. Sardana is in charge of storing the experimental data and supports various data formats. We recommend the HDF5 [11] following the Nexus [12] conventions to our users but still, Spec [13] format is widely used. Even custom data recorders can be easily added for different data files or applications.

Each of the ALBA beamlines uses Sardana in its own way depending on the beamline design and the involved hardware. Usually, two Device Pool instances are defined per beamline, one to control the beamline elements and the other one to control the elements shared with the accelerator e.g. insertion device (ID) motors. One instance of the Macroserver with multiple Spock profiles is used in order to allow simultaneous macro executions. However, the number of Sardana elements differs significantly between the beamlines, for example, the number of moveables varies between 29 and 169, the number of experimental channels varies between 14 and 139, and the number of macros in some cases reaches 924.

Hardware

One of the aims of the ALBA's beamlines control system design was to limit the variety of hardware by choosing the standard models that could fulfill most of the requirements. This approach saved the significant amount of time necessary for their integration with the control software. Furthermore, the narrower the number of hardware, the more time the engineer can dedicate to deepen the specific knowledge [14]. For these reasons the vast majority of the moveable axes are stepper motors driven by the Icepap motion controllers. Just few of the servo DC axes are in use and all are driven by the Pmac motion controllers. Each of the beamlines has at least one industrial PC with a set of DAQ cards. The most popular are the 4-channels (16bit at 500kS/s) Analog to Digital Converter (ADC) card - ADLINK 2005 and the 8-channels counting/timing card (80 MHz) - NI 6602. These cards together with the ALBA Electrometer (AlbaEm) [15] - low current ammeter (from 1mA down to few pA) and the voltage to frequency converters (VTF) are the most common experimental channels in use. Other standard hardware was chosen for the CCD cameras, PLC, vacuum controllers, etc.

SARDANA GENERIC SCAN FRAMEWORK (GSF)

A scan is a measurement process that consists of acquiring experimental channels while varying one or more parameters, typically a moveable or a group of them. Sardana provides an advanced scan framework, which is commonly used in all the beamlines of ALBA as well as other institutes. This framework provides standard macros in various scanning modes: step, hybrid, continuous and time, and a set of utility classes that may be used to program custom scans.

Continuous Scan vs. Step Scan

A continuous scan, in which motion and acquisition are executed simultaneously, speeds up the measurement process, making it a great asset for most experiments and due to time constraints, mandatory for a few of them. A continuous scan reduces the natural time overheads of a step scan: the ones related to the motion, like for example the acceleration and deceleration time or the instability time as well as the ones related to the software state transitions: motion - acquisition and vice versa. While the continuous scan synchronized by software eliminates the motion related overheads, the acquisition state transition overheads can not be reduced. Due to that, the hardware synchronized continuous scans are the fastest ones and the most desirable. These gains are not for free. In order to execute the data acquisition while moveables are at constant speed, the effective motion range needs to be extended on both sides, exposing the scan on the risk of hitting moveables' limits and adding an extra time for handling these displacements. Also, the acquired data corresponds to time and position intervals in contrast to the step scan where the position is unchanged during the acquisition. Having these differences in mind, Sardana provides transparency and equality of both step and continuous scans to the user, in terms of the input parameters and the output results.

Generic Continuous Scan Workflow

Three main actors participate in the continuous scan: the moveables, the experimental channels and, the synchronizers. The scan starts with the configuration phase, initiated by the user request accompanied with the input parameters, like the range, the number of intervals and the integration time per point. In order to configure the involved elements, a set of calculations are performed involving the user input parameters and the nominal characteristics of the involved hardware e.g. acceleration and deceleration times of the moveables or latency time of the channels. Once the moveables are correctly positioned and all the actors configured, they are started in the following order: first the channels, then the synchronizers and at the end the moveables. During the scan, apart from the monitoring of the involved elements' states, two other important actions take place. The software synchronizer receives the master moveable position updates as frequently as possible in order to provide the best achievable software synchronization in the position domain. The acquired data are extracted from the hardware as soon as they are available in order to provide the results online. Before transferring data to the final destination, usually a file, they are temporarily buffered in the software. A first optional buffering takes place in the Device Pool for the needs of pseudo counters. Pseudo counters values are the results of calculations that involve the acquired data of one or many channels. A second buffering is done in the Macroserver where the channel results arrive independently and need to be merged in records corresponding to the scan points. At the end of the scan, the moveables' overshoots get corrected and the previous configuration of the actors gets restored.

Necessary Customizations

The scan macros can not be used without a prior definition of the system and the experiment configuration. The specific hardware involved in the scan, responsible for motion, acquisition, and synchronization (optional), must be integrated into the Device Pool by means of the plug-in controller classes and the corresponding instances of controllers and their elements must be created. The experimental channels to be acquired must be explicitly assigned to the measurement group and in case the hardware synchronization is desired their corresponding synchronizers and synchronization modes, either trigger or gate, must be selected. The experiment configuration may be complemented by eventual enabling of the online visualization tools or saving data to a file with a proper format. The continuous scan can handle software and/or hardware synchronized channels at the same time. Due to the nondeterministic software synchronization and the varying duration of the software synchronized acquisitions, a risk exists to miss software triggers and, as a consequence, the corresponding acquisitions. For that reason, optional data interpolation and extrapolation mechanisms were implemented.

CONTINUOUS SCAN APPLICATIONS AT ALBA

Powder Diffraction at MSPD

MSPD [16] is a high-energy beamline with two experimental stations. It is devoted to high-resolution powder diffraction (HRPD) and high-pressure powder diffraction (HPPD) experiments. The main instrument of the HRPD end station is a three circle diffractometer with two X-ray photon detectors. On the outer circle (OC) it resides a MAD26 detector.

The continuous scan involving the MAD26 detector consists of moving the OC rotational axis on a total range of approximately 40-120 degrees (diffraction angle) while simultaneously acquiring on 13 channels of the MAD26 (diffraction pattern) and one monitor channel used for data normalization. These channels are implemented using the NI6602 counters which acquire both the angle and the pattern synchronized internally by hardware in the time domain. The experimental samples are normally

exposed to variable environmental conditions that are included in the measurement and synchronized by software for further correlation with the acquired diffraction pattern.

Absorption and Emission Spectroscopy at CLAESS

CLAESS [17] is a high-energy beamline implementing X-ray absorption and emission spectroscopic techniques. The experiment consists in the continuous scanning of the beam energy using a double crystal monochromator (DCM) controlled by a TurboPmac2 motion controller and acquiring on various detectors: ionization chambers, position sensitive and fluorescence detectors. The ionization chambers acquisition chain, used in the absorption spectroscopy in transmission mode, is built from the low current amplifier of the AlbaEm and one of two signal digitization methods: the Adlink2005 or the VTF and the NI6602. Two detectors: Xspress 3 (multichannel) and Amptek PX5 are used in the absorption spectroscopy in fluorescence mode. The first one is interfaced with the Lima library [18] which facilitates the acquisition process and performs software region of interest (ROI) operations on the acquired spectrums. The second one is used together with the NI6602 that counts the hardware ROI events. The position sensitive detector - Mythen is used by the CLEAR reflectometer in emission spectroscopy. The hardware synchronization in the time domain is achieved by the NI6602 and the TurboPmac2 that starts the synchronization signal when motors achieve the constant velocity. Usually, the acquisition is done simultaneously on all the available detectors - approx. 40 channels of which some slow channels, like for example the storage ring current or the sample environment attributes, are synchronized by software.

Resonant Absorption and Scattering at BOREAS

BOREAS [19] is a soft X-ray beamline mainly devoted to polarization-dependent spectroscopic investigations: magnetic circular and linear dichroism (XMCD/XMLD) and resonant scattering and reflectivity. The beamline is equipped with two end-stations, a high-field vector magnet (HECTOR) for absorption methods and a UHV reflectometer (MARES) for scattering and reflection approaches.

The XMCD/XMLD experiment is based on scanning the beam energy using a plane grating monochromator (PGM). In order to ensure the best photon flux during the scan, the insertion device (ID) energy must closely follow the PGM energy change. In XMCD absorption method, the detection is achieved by total electron/fluorescence yield measurements using the low current amplifier together with the Adlink2005 and in some experiments the fluorescence detector Amptek PX5. All the channels are synchronized by hardware in the time domain using the NI6602.

The reflectivity experiment consists of simultaneous scanning of the sample and the detector angles (theta and 2-theta) while maintaining the specular angle. In the mag-

netic reflectivity, in addition, the High-Temperature Superconducting Magnet (HTS) must follow the specular angle to maintain the sample under a constant magnetic field. The reflectivity is measured with the diode current amplified by the Keithley 6517 and digitized with the Adlink2005. Currently, the synchronization is achieved by software in the position domain.

Magnetic Measurements of Magnets and Insertion Devices

The Magnetic Measurements Laboratory [20] is responsible for characterizing the magnetic fields of the magnets and IDs. One of the workbenches present in the lab uses scans to measure the magnetic field map of the magnets which allows calculating with high precision the trajectory of electrons in the accelerator. This setup comprises a 3D robotic arm controlled by PowerPmac motion controller. Three Hall probe sensors are used to measure by Keithleys 2001 the output Hall voltage, which is used to determine the induction magnetic field in 3D. Position of the probes respect to the Hall bench reference system is synchronized by PowerPmac. Due to the high temperature sensitivity of the measurement, the sensors and the environmental temperatures have to be tracked while scanning. These are controlled by a nanoDAC controller synchronized by software. To acquire the magnetic field map, multiple reversible scans need to be executed, for example, the measurement of one of the IDs required a total of 26 scans.

EVALUATION AND RESULTS

Generic Scan Framework

Developing a generic solution for the continuous scans is a challenging project whose scope tends to be constantly extended due to the ever-increasing requirements of the scientists and the new possibilities of the hardware. This trend was also observed while enhancing the Sardana GSF and at some point, its scope was limited by the following constraints in order to finally deliver a consistent and stable version:

- All the elements, but slave motors, participating in the scan are defined in the same Device Pool.
- All the motors maintain uniform velocities while scanning - nonlinear trajectories are not supported.
- All the experimental channels share the same integration time across the scan point.
- All the synchronizers share the same synchronization description across the scan.
- Configuration parameters like integration time and number of repetitions are configured at the controller level and not per channel.

Nevertheless, the current implementation fulfils all the basic requirements of ALBA beamlines. The greatest achievement of this project is that the same experiment configuration is totally reusable (if the hardware allows that) between step and continuous scan. In case a particu-

lar setup or requirement do not fit to the standard scan there exist entry points in the code where a particular solution can be applied in a standard way in order to modify the default behavior. In the current state, neither the two-dimensional channels, nor the external attributes i.e., those directly read from the Tango or the EPICS control system, are supported by the continuous scan. The last limitation can be however easily circumvented by instantiating a generic controller class and a channel.

A great amount of feedback was provided by the beamline teams and the framework has still a lot of room for improvement. The identified limitations will certainly be removed in the future releases. Below are listed the most important ones:

- Due to the common configuration among all the synchronizers, and the assumption of the post-trigger acquisition, the captured position of the moveable(s) does not correspond to the middle acquisition interval. This makes the scans executed on the same range but in the opposite direction nonequivalent.
- The interpolated values are not easily distinguishable from the real values making it hard to the end user to ultimately evaluate the measurement process. Furthermore, in some applications, the zero-order interpolation is not accurate enough and the higher order interpolations are desired.
- Scans involving multiple waypoints e.g. mesh scan or region scan are yet not optimized - a part of configuration is repeated unnecessarily and the measurement data are stored in multiple scan entries.
- The hardware captured moveables positions are not reported as moveable values but as channel values. This may cause difficulties in less flexible data post-processing scripts or be simply not intuitive to the final user.
- In some complicated synchronization scenarios, a direct relation between the synchronizer and the channel may become a limitation. A missing role of the master synchronizer was identified.

ALBA Applications

First ad-hoc continuous scans were deployed at ALBA beamlines: MSPD, CLAESS and BOREAS (XMCD/XMLD) in 2013 and allowed to reduce the experiment times by factor of 20. The same software solution was used among these setups with important customizations implemented as hooks. At that time, the most desired improvements were: access to the scan results online, software synchronized acquisitions and more general stability of the system. While these and other features were being delivered incrementally at each of the setups on its own pace, in 2017 all of them have been upgraded to the official release. In comparison to 2013 all of the three setups had slightly reduced the experiment time thanks to reading the data online instead of doing it at the end of the scan (Table 1). From the code maintenance point of view an important achievement was the

reduction of the hooks code - now these experiments could be performed with just the standard scan macros.

In the Magnetic Field Map setup, a significant amount of the experiment time was saved. In case of the BOREAS (reflectivity) setup only a factor of 3 could be achieved due to the used software synchronization and the poor repeatability of the acquisition time of one of the experimental channel controllers (Table 1).

Table 1: Achieved Improvement in the Current Experiment Duration in Comparison to the Step Scan and Results Achieved in 2013

	Step Scan	Continuous Scan 2013	Continuous Scan 2017
MSPD Angular range: 100° Integration time: 25ms Intervals: 10000	~9 h 26 min	~42 min	~41 min 45 s
CLAESS Energy range: 1keV (8969 keV – 9969 keV) Integration time: 29 ms Intervals: 4000	~1 h 3 min	~3 min	~2 min 40 s
BOREAS (XMCD/XMLD) Energy range: 65 eV (755eV – 820eV) Integration time: 124ms Intervals: 4000	~1 h 25 min	~3 min	~2 min
BOREAS (reflectivity) Specular range: 47° Integration time: 0.2 s Intervals: 470	~17 min	-	~6 min 30 s
Magnetic Field Map Z axis range: 2.7 m Integration time: 0.06s Intervals: 2700	~7 h 30 min	-	~4 min

Software Development Approach

Software development in an iterative and incremental way has many well-known advantages over the traditional waterfall approach, especially in the complex domain projects [21]. In our case, the continuous delivery of increments gave early benefits both to the scientists by saving a great amount of beamtime, and to the developers by means of a test on a real setup. However, some additional costs of this approach had to be paid. The mainte-

nance of different branches of the Sardana software and its controllers, including difficult merges or fixing the same bugs in multiple places are just some of them. We believe that performing the upgrade processes in all the setups more frequently could have mitigated this drawback. We also missed a testing framework for the controllers' classes that would have allowed developing and optimizing them without the need to run the whole Sardana system and a scan each time we wanted to verify them.

FUTURE ROADMAP

The generic continuous scan was recently added to Sardana and is still pending to be introduced in all the ALBA beamlines. In the following months, we expect to apply it to more experiments with both hardware and software synchronization. Other institutes in the Sardana community are also planning to evaluate it for their needs.

Some parts of the Sardana codebase are burdened by technical debt. We plan to clean it up and refactor before new features will be built on top. Afterwards, we plan to dedicate the next efforts to:

- Fully integrate the two-dimensional experimental channels in Sardana with the aim to use them in the step and continuous scans transparently. In the first place, we will concentrate on detectors already integrated with Lima. The minimum scope will include proper saving configuration and simple operations on images like, for example, ROI or binning.
- The waypoint generator implementation necessary for developing advanced scans e.g. mesh or region scan. This will require refactoring of the motion paths calculations and migrate this code from the GSF to the Device Pool.

We may also take a look on few new projects and features in order to achieve better performance and user experience. Especially interesting seems to be the asyncio module recently included in the standard Python that may help to achieve a better performance when it comes to blocking I/O operations, like communication with the hardware, currently solved with the use of threads. Running Spock/Macroserver in the Jupyther kernel could help to achieve a better user experience. Finally, the pipe events recently added to Tango project could be an alternative to the data transfer currently based on the attribute events.

The most interesting new setups where we plan to develop continuous scans are:

1. Emission spectroscopy experiment with the use of CLEAR reflectometer at CLAESS
2. Flipping Coil workbench in the Magnetic Measurements Laboratory
3. Hardware synchronized timescan for the photoemission electron microscopy experiments at CIRCE [22]

The first two will require extending the Sardana moveable interface to be able to handle nonlinear motion trajectories (the scan of the CLEAR reflectometer will re-

quire simultaneous movement of 10 motors) and the linked-axes feature of the Icepap motion controller for referring to multiple physical motors as one on the hardware level. Our beamlines will certainly benefit from the recently released Em# with its 18bit ADC at 400 kS/s card and new possibilities when it comes to synchronization and data timestamping [23]. Soon we will also start market research and look for alternatives to the NI6602 which is not supported on the newer versions of the Linux kernel anymore. Our plan is to improve the known time overheads present in the controller classes that currently slow down the step scans and will still slow down the software synchronized continuous scans (Table 1).

ACKNOWLEDGEMENT

REFERENCES

[1] ALBA, http://www.albasynchrotron.es

[2] Z. Reszela *et al.*, "Implementation of Continuous Scans Used in Beamline Experiments at Alba Synchrotron", in *Proc. ICALEPCS'13*, Melbourne, paper TUB3O02.

[3] Sardana, http://www.sardana-controls.org

[4] T. Coutinho *et al.,* "Sardana, The Software for Building SCADAs in Scientific Environments", in *Proc. ICALEPCS'11*, Grenoble, paper WEAAUST01.

[5] S. Rubio-Manrique *et al.*, "Unifying All Tango Control Services in a Customizable Graphical User Interface", in *Proc. ICALEPCS'15*, Melbourne, paper WEPGF148.

[6] S. Rubio-Manrique, "PANIC, a Suite for Visualization, Logging and Notification of Incidents", PCaPAC2014, Karlsruhe, FCO206.

[7] D. Fernández-Carreiras *et al.,* "The design of the Alba Control System. A Cost-Effective Distributed Hardware and Software Architecture", in *Proc. ICALEPCS'11*, Grenoble, paper FRBHMUST01.

[8] Tango, http://www.tango-controls.org

[9] Taurus, http://www.taurus-scada.org

[10] IPython, http://ipython.org

[11] HDF5, https://www.hdfgroup.org

[12] Nexus, http://www.nexusformat.org

[13] SPEC, http://www.certif.com/spec.html

[14] G. Cuní *et al.*, "BL13-XALOC, MX Experiments at AL-BA: Current Status and Ongoing Improvements", in *Proc. ICALEPCS'13*, San Francisco, paper TUPPC061.

[15] J. Lidon-Simon *et al.*, "Low Current Measurement at Alba", in *Proc. ICALEPCS'11*, Grenoble, paper WEPMS025.

[16] MSDP beamline, http://www.albasynchrotron.es/en/beamlines/bl04-mspd

[17] CLAESS beamline website: http://www.albasynchrotron.es/en/beamlines/bl22-claess

[18] A. Homs, L. Claustre, E. Papillon, S. Petidemange, "LI-MA: A generic Library for High throughput image acquisition", in *Proc. ICALEPCS'11*, Grenoble, paper WEM-AU011.

[19] BOREAS beamline, http://www.albasynchrotron.es/en/beamlines/bl29-boreas

[20] Magnetic Measurements Laboratory, http://www.albasynchrotron.es/en/technology/magnetic-measurements-laboratory

[21] Kenneth S. Rubin, "Essential Scrum: A Practical Guide to the Most Popular Agile Process", Addison-Wesley Signature Series (Cohn)

[22] CIRCE beamline, http://www.albasynchrotron.es/en/beamlines/bl24-circe

[23] J. Avila-Abellan *et al.*, "Em# Electrometer Comes To Light", in *Proc. ICALEPCS'17*, Barcelona, paper TUAPL04.