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CONTROL AND DATA ACQUISITION USING TANGO AND SARDANA AT THE NANOMAX BEAMLINE AT MAX IV

P. Bell*, V. Hardion, J. Jamroz, J. Lidón-Simón, Max IV Laboratory, Lund, Sweden

Abstract

The MAX IV synchrotron radiation facility in Lund, Sweden, received its first external commissioning users in November 2016 at the Nanomax hard X-ray beamline. All components of the beamline, including the motorisation, vacuum and diagnostic elements, were integrated into the TANGO-based control system, which through the SARDANA layer also managed the collection of diffraction and fluorescence data from one- and two-dimensional detector channels. Hardware-synchronised continuous scanning ("fly-scanning") of the sample, mounted on a piezo stage, was achieved using a system built around a standard pulse generator and acquisition board controlled by a dedicated TANGO device. SARDANA macros were used to configure and execute the continuous scanning, and position data from the piezo controller were buffered in synchronization with triggers sent to the detectors, with all data subsequently written to HDF5 files. After successful initial operation, the system is currently being revised and expanded for the users expected in 2018.

INTRODUCTION

The first two beamlines on the 3 GeV storage ring at the MAX IV laboratory opened for external users in autumn 2016. The hard X-ray nanoprobe beamline, Nanomax, is designed to take full advantage of the low emittance of the storage ring and the resulting coherence properties of the X-ray beam. Nanomax will eventually provide two experimental stations; a Fresnel Zone Plate (FZP) station to reach the smallest focal spot down to 10 nm, and a second using Kirkpatrick-Baez (KB) mirrors offering greater flexibility and various scattering geometries at the expense of a larger beam size. The final end-stations are under construction, but users have already been received to perform diffraction and fluorescence experiments using non-final sample stages and detectors.

Following the MAX IV standard, the control system is based on TANGO [1]. Where possible, equipment is interfaced to TANGO via TCP/IP and for the client layer physicists can interact with TANGO via its Python binding or through SARDANA [2], which brings a macro server and standardised Graphical User Interfaces based on TAURUS [3]. From a control system point of view, the beamline upstream of the end-stations is fully commissioned, as described in the first section of this report. The end-stations are being integrated into TANGO as they are developed. The second section of the report describes the equipment controlled in the current developmental end-station and the hardware-synchronised continuous scanning system that was provided for the first users.

* paul.bell@maxiv.lu.se

BEAMLINE CONTROL

An overview of the beamline is shown in Fig. 1. Its long length, approximately 100 m, results from the goal of achieving the small 10 nm spot size. The control system was installed for the commissioning of the optics section during 2015 and 2016. At MAX IV the TANGO control systems run on virtual machines (VMs), unless local computers are required in conjunction with physical hardware. As for the other beamlines, several VMs are used at Nanomax, separating the TANGO and archiving databases from multiple equipment controllers. In the control room several physical client computers are used to run TAURUS GUIs and the SPOCK SARDANA client; most of the user control is done via the latter. A single synoptic GUI shows all optical, vacuum and diagnostic elements of the beamline; a screenshot of this is shown in Fig. 2 and the technology behind this device has been described in [4]. The main aspects of the beamline that have already been commissioned are briefly described below.

Motorisation of optics. There are approximately 30 motorised axes for the control of the monochromator, mirrors, slits and various diagnostic equipment. The standard motion control system at MAX IV, the IcePAP [5], has been employed throughout. All axes are exposed as motors in SARDANA and configured in the appropriate physical units. Pseudo-motors allow the operators to steer the monochromator in terms of photon energy and Bragg angle.

Vacuum PLC system. The vacuum system comprises many valves, over 20 ion-pumps and over 50 temperature sensors, controlled and read out by an Allen Bradley PLC. The PLC tags are exposed as attributes of a single TANGO device that communicates with the PLC over Ethernet. This device acts as a server for a suite of higher level TANGO devices that represent the individual pieces of equipment. The higher level devices all inherit from a single "facade" type device which has been developed based on reactive programming principles and is described in detail elsewhere [6]. The PLC implements the machine and personal safety systems and the alarms are reported using PyALARM and the PANIC GUI [7].

Diagnostic cameras. Several Basler cameras are used for the beam diagnostics. These are integrated to TANGO using their Lima [8] drivers. A dedicated TAURUS GUI was developed for viewing the live image.

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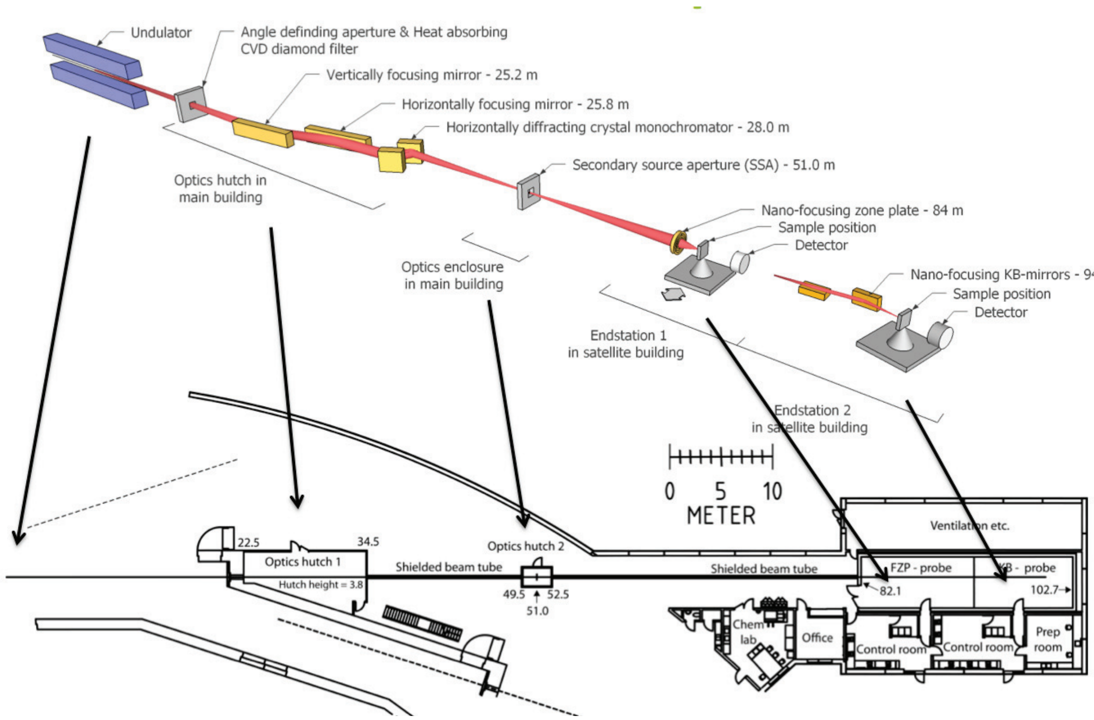

Figure 1: Overview of the Nanomax beamline showing the long optics section and the two end-stations.

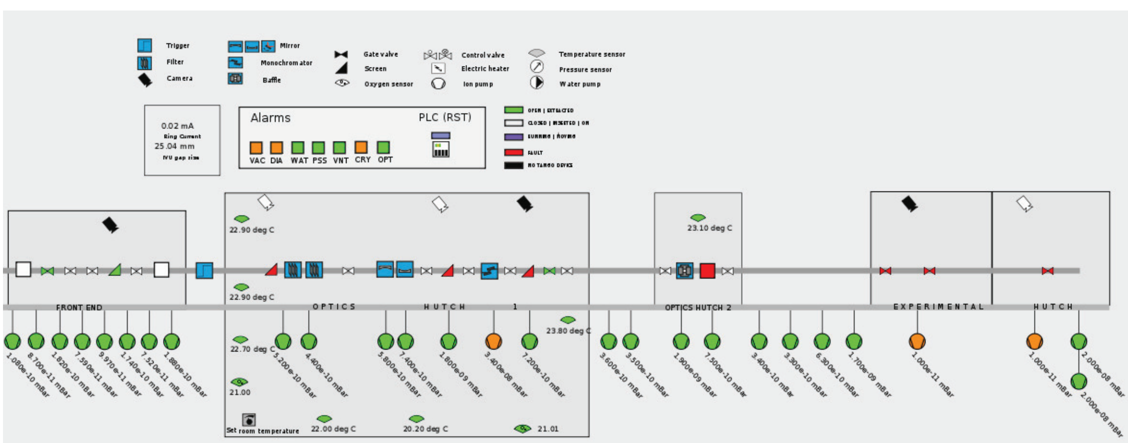

Figure 2: The Nanomax beamline as represented in the synoptic application. The coloured icons correspond to TANGO devices representing vacuum, diagnostic and optical elements, with the colour reflecting the value of the TANGO state.

DEVELOPMENTAL END-STATION

Control System Setup

Between the first user experiments at the end of 2016 and the second round in spring 2017, the end-station evolved from a purely temporary arrangement to the skeleton of what will become the final KB station. The movable elements and the detectors have remained the same, however, so from a control system perspective the system that was developed during 2016 is expected to serve until the end of the next data taking campaign in spring 2018.

There is currently no sample environment, so the sample is mounted on a stage from PhysikInstrumente (PI) which can be scanned in any direction in a 100 μm range. The piezo controller is a PI E727 digital controller for which a TANGO device has been developed, communicating over Ethernet. Depending on the type of experiment, diffraction data are recorded using Dectris Pilatus 100K or Pilatus 1M detectors, or fluorescence data from an Amptek XR-100 silicon drift detector. The XR-100 was initially read out using an Amptek PX5 pulse processing unit and later an Xspress3 from Quantum Detectors. Lima drivers exist for the Pilatus and the Xspress3 detectors, each of which have their own detector control computer (DCU) with a TANGO installation where the Lima device runs. A diode detector is also read out using a National Instruments (NI) 6602 counter card via a voltage to frequency converter.

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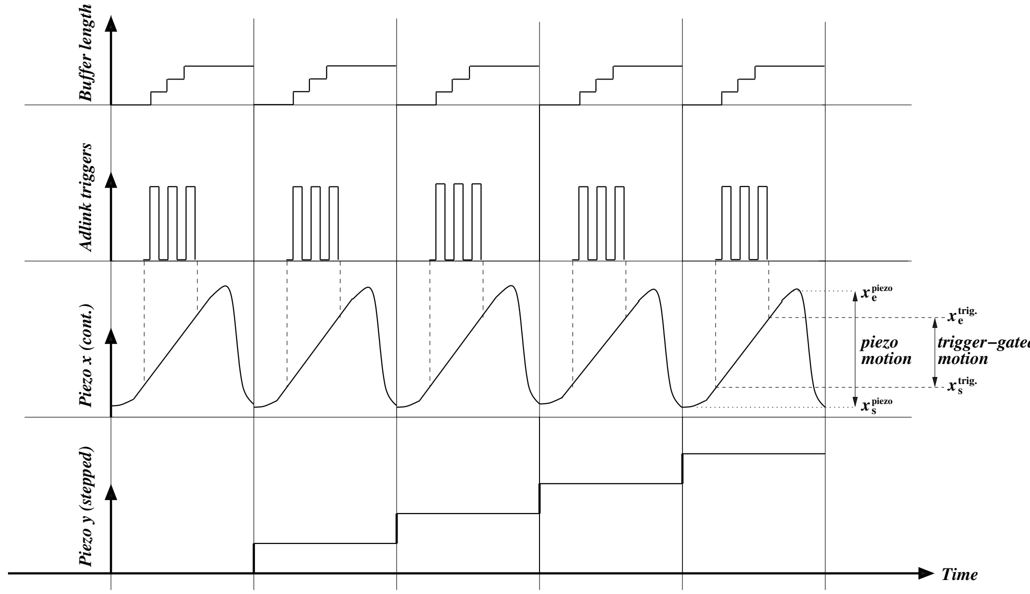

Figure 3: Generation of the time-based triggers by the Adlink 2005 card within the trigger-gated portion of the motion of the piezo x axis. In this example, three triggers are sent so the analogue input of the Adlink card also buffers three position measurements. After each continuous motion in x the buffer is read-out and the piezo is stepped in y.

A SARDANA macro is used to configure each SPOCK session using the Scientific Data Management (SDM) tools described elsewhere [9]. The SDM creates a directory in a bulk storage disk for each new user. The data path in the SARDANA file recorder and all Lima devices are then set accordingly, the Lima devices being configured to write their data directly to the storage.

A typical two-dimensional scan of the sample covers of a grid of several hundred points by several hundred points in two piezo axes, with an exposure time at each point of some tens of milliseconds. In the standard software-synchronised step-scan of SARDANA, the data acquisition takes place while the piezo is stationary at each point. The speed of data collection is therefore significantly improved if the acquisition can take place during a continuous motion of the piezo. The design of the "fly-scan" system to achieve this is described in the following section.

Fly-Scanning

In fly-scanning the step-by-step motion of one of the piezo axes is replaced by a continuous movement, during which the experimental channels are triggered to acquire a series of acquisitions. The piezo then makes one step in the orthogonal direction before the continuous movement and concurrent data acquisition are executed again. This is repeated until the required sample area has been scanned. From the user point of view, the requested scan parameters are the start position x_s, end position x_e and number of triggers n_x in the continuous dimension, the start position y_s, end position y_e and number of triggers n_y in the stepped dimension, and the integration time t per point. (The integration time is constant for each point and is given by $t = t_\mathrm{e} + t_\mathrm{l}$ where t_e is the exposure time and t_l is the latency time of the detectors). A method to synchronise the reading of the piezo position as it moves continuously in x with the triggering of the detectors has been developed based on a DAQ-2005 card from Adlink Technology. The timing scheme is shown in Fig. 3 and the connections between the different components in Fig. 4.

Piezo controller An axis of the PI E727 can execute a continuous motion following a programmable "waveform" described by a series of position set-points held in memory, the set-points being applied successively every integer number of 50 μs servo cycles. For the continuous motion in the x direction, a simple linear ramp is used from $x_\mathrm{s}^\mathrm{piezo}$ to $x_\mathrm{e}^\mathrm{piezo}$. By varying the number of points used to describe the ramp the duration of the motion can be governed, up to a certain maximum time limited by the number of set-points that can fit into the hardware memory. During the ramp, the x position can be read from the analogue output of the PI E727. An output trigger gate is configured to be high while the piezo position is within a trigger window $x_\mathrm{s}^\mathrm{trig.}$ to $x_\mathrm{e}^\mathrm{trig.}$. The trigger margin is needed to ensure that the gate does not go high while $x = x_\mathrm{s}^\mathrm{piezo}$, before the motion is executed, due to fluctuations in the position.

Adlink 2005 pulse generation The Adlink 2005 card has two counters which also function as pulse generators, each controlled by its own TANGO device. The first generator is seeded by the internal clock to produce a low frequency seed for the second, which can then be configured to generate output pulses with the required period in the milliseconds to seconds range. These output pulses are used to synchronise the reading of the piezo position and the trig-

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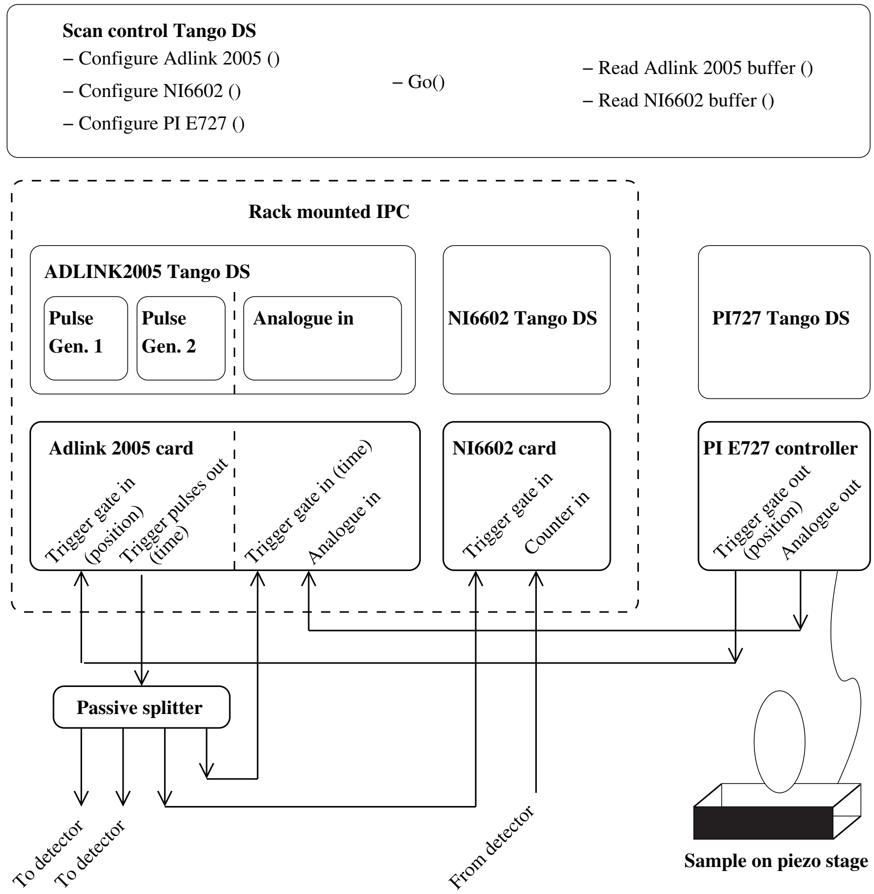

Figure 4: Schematic of the fly-scan system showing the connections between the physical components, and their TANGO devices. The Adlink 2005 and NI6602 cards are located in a rack-mounted Industrial PC. The PI E727 outputs a position-based trigger signal which gates the generation of constant time-based triggers by the Adlink 2005 card. The same Adlink 2005 card reads the analogue position from the PI E727 on receipt of the time-based triggers. The same time-based triggers are also sent to all detectors and the NI6602 card. The Scan Control TANGO device manages the TANGO devices for the piezo controller and Adlink and NI cards, preparing them for one linear ramp of the piezo and reading their buffers after the execution of the ramp.

gering of the detectors. The position gate sent from the piezo controller is applied to the first generator, such that the pulses are only produced while the piezo position is inside the trigger window $x_s^{\text{trig.}}$ to $x_e^{\text{trig.}}$. Thus the read-out is synchronised in time, but the time-based triggers are gated on the piezo position. Assuming that the motion is linear, the required period of the pulses can be calculated such that the n_x requested triggers fit into the duration of the motion that takes place within the trigger window.

The time-based trigger output from the Adlink card is sent via a passive splitter to the detectors and the NI6602 card. The output pulses follow a square wave, starting low, with a configurable duty cycle. Thus, the square wave signal can be used to gate the detectors, with the high time corresponding to the exposure and the low time to the latency. The time-based trigger signal is also sent to the external trigger of the analogue input of the same Adlink card, which is used to capture the piezo positions.

Adlink analogue input The analogue input of the Adlink card records the piezo position at each trigger. For each trigger, 100 samples of the position are taken, with the sampling rate being set so that the time taken to collect these 100 samples will equal t_e, thus giving an averaged position measurement during the exposure of the detectors. The Adlink card buffers these averaged values which are then read by the Analogue Input TANGO device, at the end of the continuous motion in x.

NI6602 device The triggers generated by the Adlink pulse generator are used as the gate for one of the NI6602 counters. A count from the diode detector is therefore collected during each exposure of the imaging detectors, and the counts are buffered in the NI6602 card. The buffer is read by TANGO at the end of the continuous motion.

Scan Control TANGO device Summarising the above, from the scan parameters entered by the user, the waveform motion in the PI E727 must be configured to run from

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x_s^{piezo} to x_e^{piezo} with a motion time $n_x \times t$ while the position is within the trigger window $x_s^{\mathrm{trig.}}$ to $x_e^{\mathrm{trig.}}$. The Adlink pulse generator must be configured to generate the n_x time-based trigger pulses in the trigger-gated motion time, and the Adlink analogue input, the NI6602 and all detectors must be configured to expect n_x triggers. The waveform motion is then executed, and when it is complete the Adlink card will have buffered n_x position values and the NI card will hold n_x counts. The three steps (configure, execute, read buffer) of a single continuous scan are managed by the Scan Control TANGO device. It implements configuration methods for the PI E727, Adlink and NI6602 devices, a "Go" method that arms the Adlink pulse generator and starts the waveform motion, and read methods to read the Adlink and NI6602 buffers.

The Scan Control device must account for some other effects that complicate the timing scheme described above. For example, since the time-based square wave trigger pulses from the Adlink card always start low, as can be seen in Fig. 3, the pulse train must be initiated early (by t_1) such that the rising edge of the first trigger arrives when the piezo is at the requested starting point x_s. To achieve this, the gate on the piezo position must be offset in x, meaning that the start of the position trigger gate $x_s^{\mathrm{trig.}}$ is not the same as the user parameter x_s, instead being $x_s^{\mathrm{trig.}} = x_s - \Delta x_{\mathrm{offset}}$. The offset $\Delta x_{\mathrm{offset}}$ is estimated as $t_1 \times v$ where v is the piezo velocity, assuming the motion is linear. It comes in addition to the trigger margin already described. The need for an offset in x restricts the fraction of the full 100 μm piezo range available for scanning. If no more than a certain fraction of the the maximum scan range is to be lost, there becomes instead a limit on the relation between the scan range and the number of triggers. The x attribute in the TANGO Scan Control device is therefore confined to a restricted range of the full 100 μm, and the Scan Control device enforces the relations between the scan range and the number of triggers.

SARDANA Integration The Scan Control TANGO device prepares and executes a single continuous motion in the x direction and subsequently reads the buffered data from the Adlink and NI cards. To perform the two-dimensional scan, a stepped motion is also required in the y direction. This is achieved in SARDANA by exposing the Scan Control TANGO device as a "one-dimensional experimental channel controller". The controller calls the "Go" method of the Scan Control device which means that in the execution of a standard step-scan of the piezo y axis, for each point in y a continuous scan in the x direction will be initiated. At the end of the scan line the buffered data are returned to SARDANA and the piezo is stepped in y before the continuous motion is repeated. A custom macro wraps the standard step-scan macro and passes the additional user parameters for the motion in x to a pre-scan configuration where the configure methods of the Scan Control device are called.

CONCLUSION

The optics section of the Nanomax beamline has been commissioned and the construction of the first experimental end-station is well underway. The commissioning of the optics, including the motorisation, vacuum and diagnostic elements, was performed with the TANGO control system, including SARDANA control of the IcePAP motors, and aided by a custom synoptic interface. The control system for the first end-station was sufficiently developed for external users to take data from imaging and fluorescence detectors in autumn 2016 and spring 2017. The integration of the detectors to TANGO via Lima and the use of the SDM tools allowed data to be written to the bulk storage, indexed according to the experiment. A fly-scanning system was developed to allow fast acquisition of detector data in time-based synchronisation with the sample position when continuously scanned in one direction. This fly-scanning system is expected to be used again in the spring 2018 data-taking campaign, before major enhancements, for example permitting spiral scans, may be developed.

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REFERENCES

[1] The TANGO Control system website: http://www.tango-controls.org

[2] SARDANA software website: http://www.sardana-controls.org

[3] TAURUS website: http://www.taurus-scada.org

[4] J. Forsberg *et al.*, "A graphical tool for viewing and integrating with a control system", in *Proc. ICALEPCS'15*, Melbourne, Australia, Oct. 2015, paper WEM309.

[5] The IcePAP motion controller from ESRF http://www.esrf.eu/Instrumentation/DetectorsAndElectronics/icepap

[6] V. Michel, "Facade devices, a reactive approach to TANGO", Presented at ICALEPCS'17, Barcelona, Spain, October 2017, paper MOBPL06, this conference.

[7] S. Rubio-Manrique *et al.*, "Extending alarm handling in TANGO", in *Proc. ICALEPCS'11*, Grenoble, France, Oct. 2011, paper MOMMU001.

[8] Lima: A Library for Image Acquisition http://www.lima.blissgarden.org

[9] V. Hardion *et al.*, "The MAX IV laboratory Scientific Data Management", Presented at ICALEPCS'17, Barcelona, Spain, October 2017, paper TUBPA04, this conference.