ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBR04

CONTINUOUS SCANS WITH POSITION BASED HARDWARE TRIGGERS

H. Enquist, A. Bartalesi, B. Bertrand, J. Forsberg, A. Freitas, V. Hardion, M. Lindberg, C. Takahashi, MAX IV Laboratory, Lund, Sweden

Abstract

In traditional step scanning, repeated starting and stopping of motors leads to inefficient usage of the x-ray source. In addition to increasing measurement times, this also increases the risk of sample radiation damage. We have developed a system where scans are performed while continuously moving the motors. To ensure stable repeatable measurements, the detector triggers are generated, in hardware, from the motor encoder positions. Before the scan starts, a list of positions is generated. That is then used to generate the triggers when these positions are reached.

The solution is implemented with Tango and Sardana. The encoder signals from the motors are connected both to the IcePAP motion controller for closed loop operation, and a PandABox which is used as the trigger source.

The scan is controlled by a TriggerGate controller, that calculates the motor positions and configures the PandABox. The scanned motor can be either a single motor, for example a sample translation stage, or a combined motion like a monochromator. When combined motions are used, these are using the parametric trajectory mode of the IcePAP. This enables continuous scans of coupled axes with non-linear paths.

INTRODUCTION

Many experiments require performing scans to measure some quantity as a function of another. The easiest approach is to use a step scan, and therefore this is very commonly used. In a step scan each step consists of moving the scanned axis to a certain position, then arming and triggering the detector, waiting for acquisition to finish, and finally reading out the data. This process is repeated for every step. Only the time spent acquiring the data is useful, while the rest can be considered deadtime. The starting and stopping of the scan axis (typically one or several motors), and the arming of the detector can take a considerable amount of time. Under typical conditions, scans can run no faster than a few points per second. If the acquisition time is then in the millisecond range, the deadtime tends to make up for the majority of the time required to perform the scan.

An alternative solution is to keep the scan axis moving continuously during the scan. This has previously been implemented using combinations of software and hardware solutions [1-3]. In this case, the scanned axis needs only to be started and stopped once. The aqusition loop then consists of only triggering the detector, waiting for acquisition to finish, and readout. Many detectors are able to read out the data in millieconds, meaning the scan can run at hundreds of points per second. This is the approach taken in this work. We have chosen to implement a system that handles the motions and trigger generation completely in hardware.

CONTINUOUS MOTION

Letting the motion to run continuously during the scan is straightforward when the axis corresponds to a single motor that needs to run at constant speed. This is the case when for example scanning along the surface of a flat sample using a single motor. But in many cases the motion involves several motors, that can’t simply be moved at constant speed. To scan for example the energy of a plane grating monochromator, both the mirror and grating positions must move acording to some formulas. They also need to perform their motions synchronized, in order to keep the x-ray beam stable on the sample, with the right energy and properties. As illustrated in Fig. 1, a simple software pseudomotor will perform motions that start and end at the correct positions, but while moving, the path does not follow the ideal trajectory.

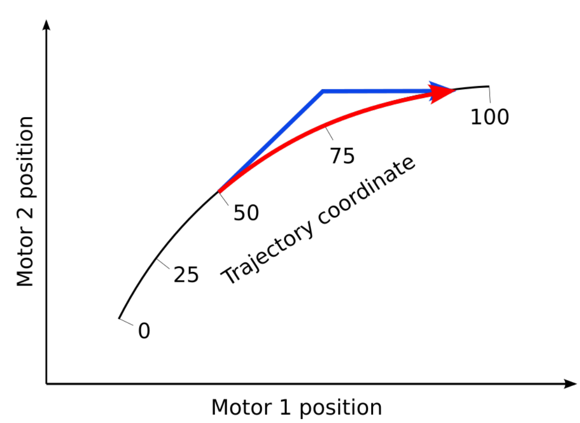

Figure 1: The difference between typical pseudomotions and parametric trajectories for a move along the parameter axis. The pseudomotor starts moving both motors at their nominal velocity. Once the first motor has reached it’s position, the second continues moving towards the target. The parametric trajectory on the other hand follows the trajectory the whole way by continuously adjusting the motor velocities.

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBR04

Parametric Trajectories

The non-linear motions and multi-motor synchronization can be solved by using a motor contoller that supports motions following parametric trajectories. In this work we have used the IcePAP system [4].

The parametric mode presents one or several motors as a single axis, with a single position attribute. The position can be in any unit, for example nm or eV. This is achieved by generating a table for each motor, of physical motor position in motor steps versus trajectory position in the desired unit. These tables are then uploaded to each driver. Once all tables are uploaded, the motors can be moved together in the trajectrory unit. When moving to a position between the points of the table, the IcePAP interpolates the individual motor positions from each table. Either linear or spline interpolation can be used, and the step size of the tables must be chosen to keep the maximum interpolation error within acceptable limits.

Time-based Trigger Generation

During the scan, the detector must be triggered as the scan axis reaches the desired positions. The easiest approach is to use time-based triggers. The triggers are then generated from the estimated times for when the scanned axis will reach each desired position. This works for any motor, without the need for extra cabling for encoder signals. The disadvantage is that there is some uncertainty of exactly when the motor will arrive at the desired positions, and the positions where the data was recorded may differ somewhat from the desired ones. This can be improved by capturing the motor positions at each trigger event. However this still can make comparing different scans challenging, since they were taken at slightly different positions.

Position-based Trigger Generation

Instead of time ased triggers, it’s possible to monitor the motor positions, and generate the based on when the motors arrive at each position. This removes the uncertainty in the positions. In this work, we have used a PandABox [5] to generate the triggers. This device can support a very wide range of applications, and is easily configured by connecting and configuring functional blocks in a web-based gui. The blocks and connections between them are implemented in an FPGA. It can generate triggers based on numerous inputs, and is able to read standard motor encoder signals directly.

The employed configuration, or schema, for the PandABox is shown in Fig. 2. The “Sequencer” block of

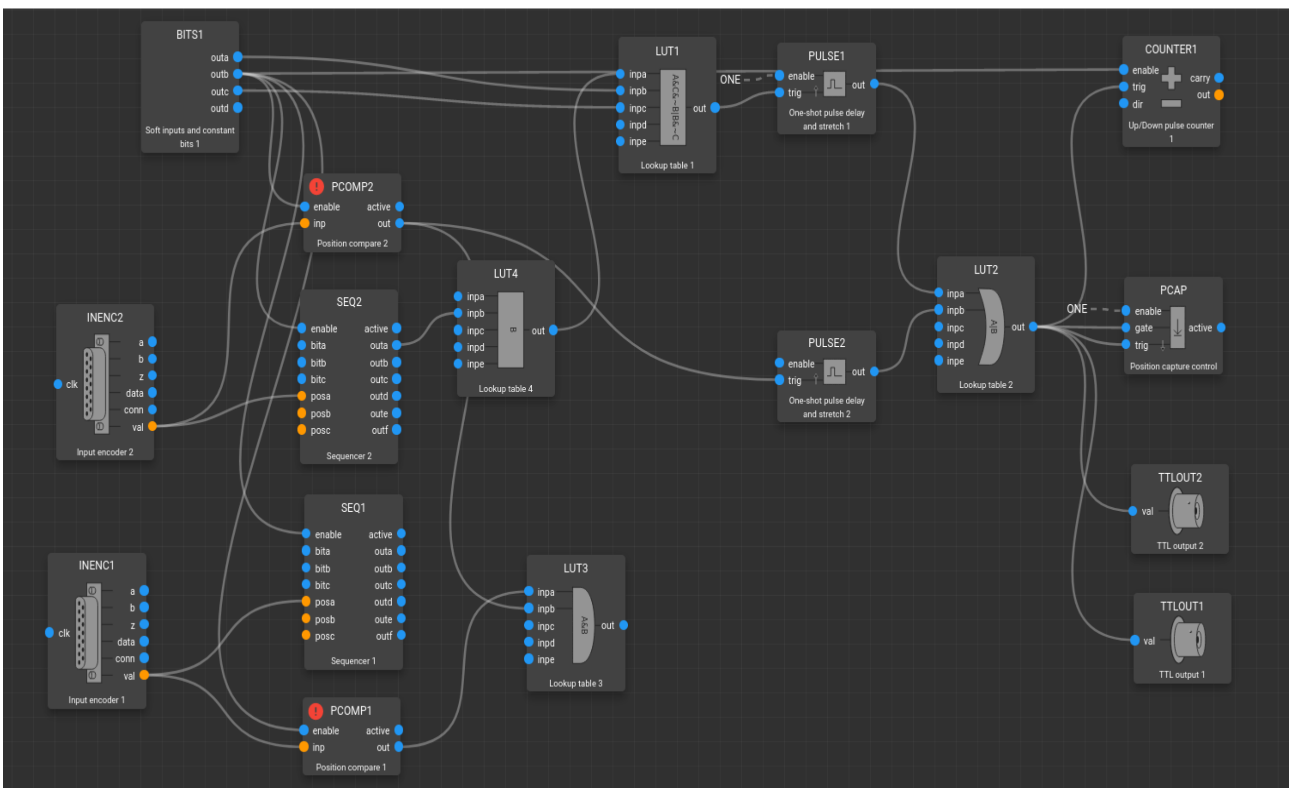

Figure 2: The PandABox schema. The encoder signals from the monochromator are connected to the INENC blocks. Currently the 2nd input, INENC2, is used for trigger generation. The sequencer block, SEQ2, is responsible for generating the triggers, based on a list of positions and the value from the encoder block. The output of the sequencer is connected to the TTL output via some logic blocks for selecting other operation modes, controlled via the BITS block. The COUNTER block keeps track of the generated triggers, and is useful for diagnostics. The PCAP block captures the values of selected variables when triggered. This is used to record the encoder signal values for both monochromator motors, as well as the undulator (not shown in the schema).

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the PandABox compares its input value against a list, and generates output pulses as each value is reached. The input is wired to the encoder input block, and the output is routed to a TTL output for the detector. Additionally it's wired to the "PositionCapture" block, which is configured to capture the encoder values. This is used to record the positions for the motors in the scan data.

The values of the sequencer table are calculated using the same formulas as for generating the parametric tables for the motor controller. The equidistant trajectory positions are calculated from the scan parameters.

SOFTWARE IMPLEMENTATION

The software for this project was developed as Sardana [6] controllers. Sardana is a scan framework based on Tango [7]. A total of three Sardana controllers were developed for this project.

- A TriggerGate that configures the PandABox to generate the expected timing. The timing system can be position based, if the scanned motor encoder is connected to the PandABox (the current implementation uses the monochromator mirror encoder), or time based, where the encoder is either not connected or there are no motors involved in the scan.
- A MotorController that enables motions using the parametric trajetory mode of the IcePAP. This is implemented to control the energy of a plane-grating moochromator via the mirror and grating angles.
- A CounterTimerController for reading out the captured encoder positions from the PandABox.

Procedure of a Scan

Before a scan can be started, the parametric trajectory mode of the monochromator is initialized. This procedure is automated in the controller. It generates a list of motor positions for the two motors, for a range of energies configured by properties. It then uploads these to the motor drivers, and moves the motors onto the trajectory at a chosen energy value. To avoid collisions, this energy value must correspond to motor positions near where the motors are curently standing.

When launching a continuous scan of the monochromator energy, the following steps are performed:

- Sardana: Pass scan parameters to the TriggerGate (TG) controller and all involved detectors.
- TG: The list of energies is created. These are equidistant values from the start to the end position, with one value per step.
- TG: The corresponding motor encoder positions for the mirror is calculated for each step.
- TG: This list is sent to the Sequencer block of the PandABox.
- Sardana: Calculates start and end positions based on the motor acceleration and deceleration times, to allow the motor to accelerate and decelerate outside of the scan range.
- Sardana: Move the motor to the start position.
- Sardana: Arm detector and TriggerGate controllers.
- Sardana: Sets the correct velocity of the monochromator motor in eV/s, and starts motion.
- TG: Each time the motor reaches the next position in the list it generates a trigger pulse.
- Sardana: While the scan is running Sardana polls the detectors for new data and appends the new points to it's record list. Depending on the speed the scan runs at, Sardana may receive zero, one, or several values from each detector per polling interval.
- Sardana: After the motion stops and all detectors finish their acquisition, Sardana saves the data to file.

Once the scan starts running, the motions and triggers are controlled completely in hardware by the IcePAP and PandABox. This allows scans to run at high rates without risk of missing or delayed triggers because of external factors such as network traffic or other load on the Sardana system. The role of Sardana during this stage of the scan is just to collect the recorded measurement values. Any delay that occurs during this loop will not affect the running scan.

This example did not include the undulator movement. For very short scans, the undulator can be left in one position if its bandwidth is sufficient to cover the scan range. Optionally, the undulator can also be moved during the continuous scan. In the present scope, the scans are limited to a small enough range to allow the undulator to move on a linear trajectory. The undulator is controlled by a dedicated IcePAP system. Sardana calculates and sets the velocity and acceleration time for this motion to match the scan parameters, and sends the command to start the motion to the motor controllers for monochromator and undulator at the same time. Because of possibly different network latencies this means the undulator and monochromator will not start at the exact same time. This can be overcome by letting one IcePAP trigger the motion of the other via a dedicated trigger cable. However, the relatively wide bandwidth of the undulator relaxes the mono-undulator synchronization requirements, and the uncertainty from the network falls well within acceptable limits.

MEASUREMENTS

A set of measurements were performed to validate the performance of the continuous scans against normal step scans. The measuerments were performed at the FlexPES beamline at MAX-IV Laboratory [8].

The sample was nitrogen, and the scan measured the absorption at the K-edge in the 400 – 402.5 eV range. The scans were done in steps of 0.01 eV, with 250 steps, a 100 ms exposure time and a 100ms latency time between points.

The data was collected using an Alba EM# electrometer [9].

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For the particular measurement shown in Fig. 3, the step scan took 248 seconds, while the continuous took 57 seconds. The minimum possible time is 250*(0.1+0.1) = 50 seconds. The continuous scan comes close to this value, the extra time is spent on setting up all controllers, and the acceleration/deceleration phases of the motors.

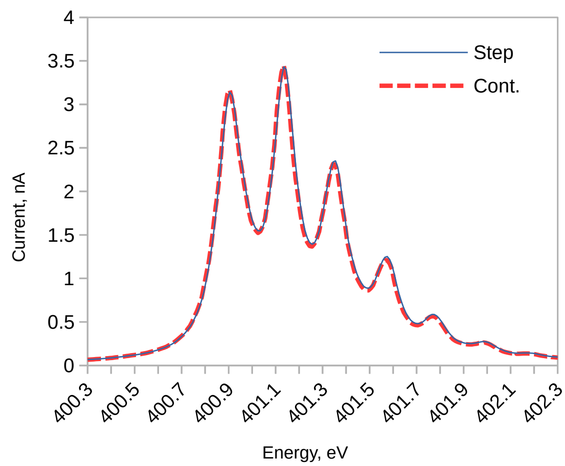

Figure 3: Comparison of two absorption scans of the Nitrogen K-edge. The solid blue line shows a standard step scan, the dashed red line shows a continuous scan.

For the step scan, the scan took 248 seconds, meaning that about 80% of the time was spent on moving to the next point. Figure 4 illustrates the differeces in how the time is spent during these two scans. Because only a minor part of the time during the step scan is spend on aquiring data, it cannot be made much faster by reducing the exposure time. If the exposure and latency times had been reduced by a factor 2, the step scan would have taken an estimated 223 seconds, while the continuous would have taken 32 seconds.

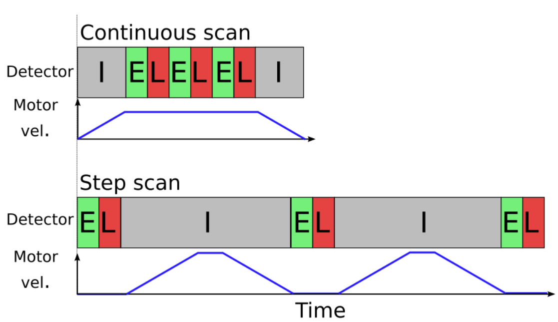

Figure 4: Illustration comparing how time is spent during a continuous scan and a step scan. For the detector, “E” denotes exposure, “L” latency (which also includes reading out the detector), and “I” idle. For clarity, this illustation shows a scan of only 3 steps.

FAST ACQUISITION CHALLENGES

Continuous scanning, especially when acquiring at high rate, puts higher requirements on the used components than step scans.

Detectors

Fast continuous scans means that the used detectors must sample the signal at a high rate. This can cause issues if the bandwidth of the equipment is too low. The Alba EM# electrometer has an optional low-pass filter in the analog path which is useful for illustrating this issue. This filter can be configured for a 10 Hz cutoff. It is then tempting to use this filter to reduce the noise in the recorded signals when aquiring at any rate below 10 Hz. When aquiring at frequencies approaching 10 Hz, it is then logical to assume a slight smoothing of sharp features. But a low-pass filter changes the phase of the signal, meaning that the value captured at each trigger will have been delayed by the filter. This effectively leads to a shift of the data along the scan axis, where the amount of shift is difficult to predict. The solution is to ensure that the analog bandwidth of each instrument is sufficiently high to keep this effect within acceptable limits.

Motors

In case of sensitive equipment like a monochromator, the precision requirements are high already for step scans [10]. Adding the condition that these requirements must also be fulfilled while in motion leads to new challenges.

One is that the motions can create vibrations that may disturb sensitive equipment like monochromators. Vibrations tend to worsen with increased speed, and this may ultimately limit the achievable scanning speed for some systems.

Another issue arises if the motors rely on a closed feedback loop to reach the necessary accuracy. For step scans it can be tolerated that the position deviates while moving, as long as the position after the motion has stopped is accurate. But in continuous scans the closed loop must ensure that the motion closely tracks the target position during the entire motion. Careful tuning of the loop parameters can improve this. Lowering the scanning speed is also benefinial.

Best results are obtained for systems that were designed with continuous scans in mind. This means that vibrations are minimized, and the mechanical accuracy is high, to reduce the amount of corrections needed by the feedback loop.

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OUTLOOK

Performing continuous scans provides the obvious benefit that scans can be done considerably faster. This allows much more efficient use of the X-ray beam at storage ring facilities, where it often is the case that the signal level is strong enough to perform high quality measurements with short exposure times.

The increased speed leads to the added benefit that the sample is exposed to a much smaller radiation dose for for each scan. This is an important factor for for example biological samples that are often sensitive and easily damaged by exposure during scans.

The continous scans can be implemented for many types of measurements. Here we used it to scan the energy of a monochromator. A follow up project is planned to include the motion of the insertion device, also using the parametric trajectory mode of the IcePAP. This will allow scans over a larger energy range.

ACKNOWLEDGEMENTS

The authors thank the staff at the MAX IV FlexPES beamline for performing the measurements.

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