

## EXPERIMENT AUTOMATION USING EPICS

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### Abstract

Beam time at accelerator facilities around the world is very expensive and scarce, prompting the need for experiments to be performed as efficiently as possible. Efficiency of an accelerator facility is measured as a ratio of experiment time to beam optimization time. At RBI we have four ion sources, two accelerators, ten experimental end stations. We can obtain around 50 different ion species, each requiring a different set of parameters for optimal operation.

Automating repetitive procedures can increase efficiency of an experiment and beam setup time. Currently, operators manually fine tune the parameters to optimize the beam current. This process can be very long and requires many iterations. Automatic optimization of parameters can save valuable accelerator time. Based on a successful implementation of EPICS [1], the system was expanded to automate reoccurring procedures. To achieve this, a PLC was integrated into EPICS and our acquisition system was modified to communicate with devices through EPICS. This allowed us to use tools available in EPICS to do beam optimization much faster than a human operator can, and therefore significantly increased the efficiency of our facility.

### INTRODUCTION

Some experiments performed have a standardized procedure which must be repeated on many samples sequentially. In the Laboratory for Ion Beam Interaction at the Ruđer Bošković Institute these experiments are for material analysis purposes and are performed on a dedicated beam line specifically designed for such studies. Materials are studied by applying Rutherford Backscattering (RBS) and Particle Induced X-Ray Emission (PIXE) ion beam analysis techniques. Using these quantitative analysis methods, a precise elemental composition ( $N_Z$ ) of the target samples can be calculated. Typically, the elemental concentrations of an unknown sample are determined by measuring a standard with a known concentration of an element and comparing it to the sample of interest, using the following formula [2].

$$N_Z = N_A \frac{I_Z m_Z \sigma_Z^x \text{eff}_A Q_A}{I_A m_A \sigma_A^x \text{eff}_Z Q_Z} \quad (1)$$

where  $N_Z$  is the concentration ( $\text{g}/\text{cm}^2$ ) of the element in the sample,  $N_A$  is the concentration in the standard,  $I_Z$  and  $I_A$  refer to the integral of the peak in the accumulated spectrum,  $m$  is the mass,  $\sigma$  is the cross-section,  $\text{eff}$  is the

efficiency of the detectors, and  $Q$  is the integrated projectile charge. The experimental chamber on this beam line consists of two particle detectors and two x-ray detectors that are connected to a custom data acquisition system [3]. The integral of the peak ( $I$ ) is calculated by constructing a histogram from the data acquired from the detectors. The total charge ( $Q$ ) is collected by measuring the current from the target if it is a thick sample, or a Faraday cup located behind the sample, if it is thin. This current is measured by an Electrometer and integrated over the time of the experiment to get the total projectile charge on the target.

The measurement procedure consists of the following steps:

1. Setting the target in the beam position.
2. Setting the acquisition system to start recording.
3. Resetting the charge counter.
4. Opening the chamber valve so the ion beam can enter the chamber and hit the target.
5. Waiting for enough statistics to be collected for a well-defined histogram, which typically requires about  $1 \mu\text{C}$  of charge.
6. Closing the valve to the chamber.
7. Stopping the acquisition system.
8. Reading the total charge from the electrometer.
9. Logging the results.

These 9 steps must be repeated for each sample being measured which in one day could be as many as 30 times. Due to this highly repetitive process, errors can occur where the electrometer is not reset, the positioning of the sample is not correct or simply the steps are preformed out of order. Such mistakes result in having to repeat measurements, decreasing beam time utilization efficiency.

Many of these steps can be automated if the various hardware and software components could be controlled remotely. EPICS was used to interconnect all the elements because it creates a common communication framework through which repetitive processes can be automated.

### IMPLEMENTATION

As we are still in the preliminary phase of upgrading our accelerator control system to an industrial standard such as EPICS, it was crucial that all implementation for this work were made to work in parallel with our existing system and could easily be disconnected. The existing system utilized

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a local Ethernet control network which communicates with all the instrumentation in the facility through a PLC, serial routers or directly TCP protocols. All instrument control is performed from a single computer running LabView software which sets and reads variables through this control Ethernet network. An EPICS server was connected

to this existing Ethernet control network and two soft Input Output Controllers (IOCs) were programmed to scan parameters from instruments on the network without writing to them, leaving the current LabView based control system to run without interference.

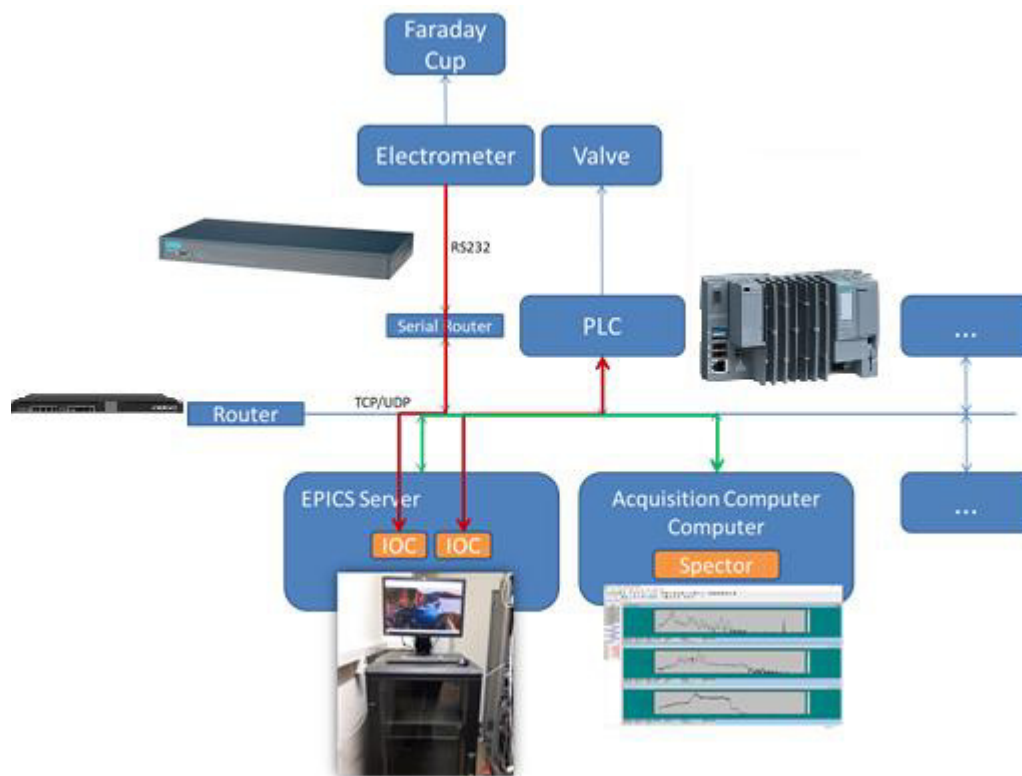


Figure 1: System Implementation.

Illustrated in Figure 1, the EPICS server was connected to the Ethernet control network and connected to the Faraday cup located on the beam line, the pneumatic valve before the chamber and the acquisition software running on the acquisition computer using the EPICS framework. A dedicated IOC was created to communicate with the Keithley 6514 System Electrometer through a virtual COM port provided by an Advantech EKI-1526 serial router. The IOC records were configured to abstract three commands to the network. The first command initializes the instrument, changes the operation mode to charge measurement and then sends zero set and zero correct instructions to the instrument. The second command reads the current charge reading from the instrument while the third command estimates the ion beam current by monitoring the charge change over a constant period of time. A second IOC was created to control the valve which is connected to a SIEMENS SIMATIC ET 200SP PLC. This IOC contains two commands. One to get the current valve position and a second that sets the valve position. The IOC reads and writes to the variable database inside the PLC to control the valve.

Instead of using a EPICS sequencer [4], communication with the abstracted EPICS commands was implemented into the acquisition control system used on the beam line. The data acquisition software SPECTOR is written in C/C++ and handles all communication with the data acquisition hardware and instrumentation on the beam line. This software starts the experimental measurement and handles data visualization and storage. EPICS commands provided by the EPICS server were integrated into the acquisition flow of SPECTOR in the following sequence:

1. Researcher presses the “Start” button
2. Initialize electrometer
3. Start charge measurement
4. Start data acquisition from detectors
5. Open chamber valve
6. Current and charge values are read with detector data and displayed to the user
7. Chamber valve is automatically closed when a user preset charge value is reached
8. Final data from detectors and electrometer is read into the program

## 9. Data with the total charge is saved with the histogram spectrum

Figure 2 depicts how the SPECTOR user interface was modified to display the information from the electrometer. The whole implementation does not change the acquisition process for the researcher and can be enabled or disabled by selecting a menu option.

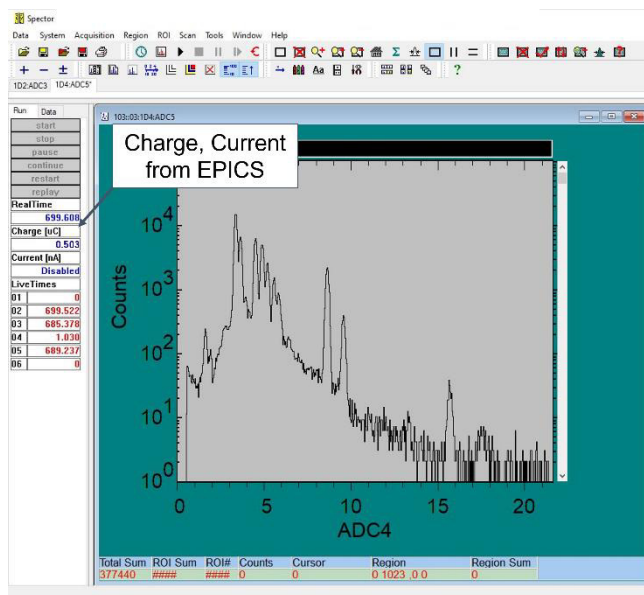


Figure 2: SPECTOR Integration.

## RESULTS AND DISCUSSION

The implementation was very quickly accepted by researchers due to minimal changes introduced to the measurement procedure. It increased the number of samples that could be analyzed per beam time and proved to be more reliable when compared to the manual setup. An added benefit was that it stimulated researchers to suggest further automation on other beam lines which will further streamline the operating procedure in the laboratory. However, complications and challenges are also experienced during the implementation of the system. Communication delays and indeterministic response times from the IOCs running on the EPICS server created problem during the integration into SPECTOR as data was not always available when requested. This delay along with the mechanical delay of the pneumatic valve required modifications and redundancies to be added into the program flow of SPECTOR. SPECTOR was developed in cooperation with the IAEA [5] in 2002 and it mostly written in C with basic WIN32 libraries make it very difficult to modify due to unstructured code.

Further automation can be achieved by integrating the sample positioner located in the experimental chamber into EPICS. This would allow the system to automatically measure all the loaded samples with minimal supervision resulting in a further increase in laboratory efficiency. However, this would require precise sample position information in a feedback loop to confirm that the sample is located in the beam spot as not all samples are of standard shape and size. The integration of the acquisition system into EPICS would decrease the development time required to introduce further automation into the laboratory.

## CONCLUSION

Expanding on the feasibility study/preliminary implementation of EPICS [1] at the Ruđer Bošković Institute Laboratory for Ion Beam Interactions, the advantages of such a control system were successfully demonstrated by adding automation to beam line measurements, and with it increased beam time utilization. The implementation of this simple system demonstrated the benefits of EPICS to the research staff and opened the doors to future automation.

This work implements only a small portion of the EPICS framework and future work is planned to incorporate other EPICS modules to expand the system. At the moment, the backward compatibility with the existing control system is limiting the implementation. Switching to an EPICS only control system will allow for further automation to both the accelerator and experimental systems.

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