Integration of Temperature Scanning System to Beamline Controls and Interface Development

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Abstract

Temperature-tunable backscattering high-energy-resolution monochromators and analyzers provide mechanically simpler alternative to angularly tunable systems. For example, multi-crystal angle-tunable monochromators lose efficiencies due to a decrease in reflectivity and demanding mechanical constraints. Through precise temperature control, the lattice parameter of a crystal can be tuned and thus the photon energy of backscattered x-rays. With adequate control, the energy resolution of this system could be <1meV at energies greater than 30 keV [1-2]. A nested PID loop heater system was implemented using the PT1000 temperature sensors and the Experimental Physicals and Industrial Control System (EPICS) software. Device Layer support of the Keithley 3706A digital multimeter and the Keithley 2330G power supply was reimplemented from previously written python code into standard EPICS database format. Thus providing a robust means of continuing hardware development.

Introduction

The goal of this project was to implement EPICS device support for the Keithley 3706A digital multimeter and Keithley 2230G multi-channel power supply so they could be used in a prototype temperature-tunable backscattering high-energy-resolution monochromator. The EPICS software has become the standard control software for synchrotron light sources and many other scientific facilities. The EPICS software has a unique layered control structure. This structure is designed such that each layer can communicate without requiring knowledge of the inner workings of other layers. The layer structure of EPICS can be seen in Figure 1.

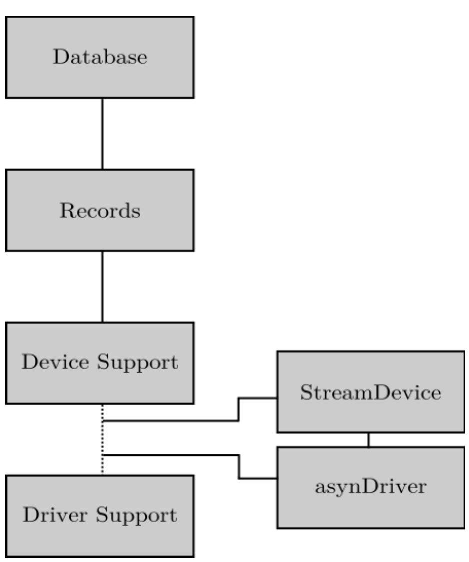

Figure 1: EPICS Layer Structure

The computer running the EPICS software stores data within a database.

This database is divided into "records" which generate a list of "process variables" that can be accessed by the user

The "Device Support" layer is the link between the instruments and the EPICS database records. The StreamDevice and asynDriver modules provide support for standard interfaces (USB, serial, GPIB, etc.).

The hardware protocols are implemented in the Driver Support layer.

Hardware Overview

Device support for the Keithley 3706A digital multimeter and the Keithley 2230G multi-channel power supply was created during this project. Both of these instruments are controlled via the EPICS software running on a host Input Output Controller (IOC). This IOC is any computer capable of running the EPICS software. The IOC can then communicate with the instruments through a variety of interfaces including serial, GPIB, TCP, and USB.

Keithley 3706A - Digital Multimeter

The Keithly 3706A digital multimeter is used to take resistance readings from temperature sensors within the prototype monochromator. A four-wire resistance measurement is used to account for resistance caused by mechanical connections and lengths of wire. In the four-wire configuration the device has 30 measurement channels.

Figure 2: Keithley 3706A Digital Multimeter

The device is controlled by sending and receiving commands in the Keithley Test Script Builder scripting language over a variety of protocols. In this application, the digital multimeter communicates over the network using Transmission Control Protocol (TCP) and has a physical ethernet connection.

Keithley 2230G - Power Supply

The Keithley 2230G multi-channel power supply is used to provide power to the resistive heating elements on, and within the heating chamber. Two channels are used. Both channels are capable of outputting 30 volts at 3 amps each. The device accepts Standard Command for Controllable Instrument (SCPI) over a USB connection to the IOC. The USB Test and Measurement Control (USBTMC) driver is used to send SCPI commands.

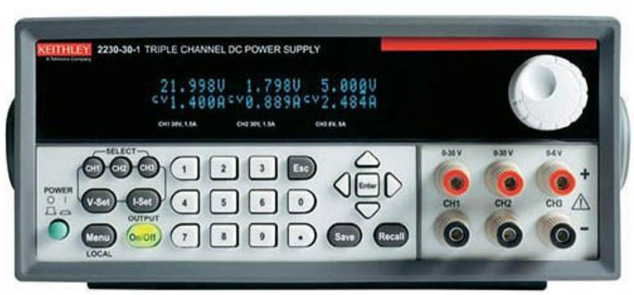

Figure 3: Keithley 2230G Power Supply

Monochromator Chamber

The monochromator chamber consists of a metal box and lid, resistive heating elements, PT1000 temperature sensors, and crystal holder. The chamber also contains inlets and ports for sensors, gas lines, and power. The device has three resistive heating elements. Two on the outside of the chamber and one on the crystal holder. Three PT1000 temperature sensors are soldered to corresponding 4-pin Lemo connectors with enameled, copper wire. While only three sensors are currently used, software support for up to six sensors is implemented. PT1000 sensors of this type where chosen for their high resolution and convenient form factor.

The crystal is held in place with metal strips acting as springs, and is thermally linked to the crystal holder with silicone thermal grease. When operational, a steady stream of Helium gas is pumped through the chamber. This provides a constant and more rapid rate of heat dispersion within the system in order to increase responsiveness of temperature control.

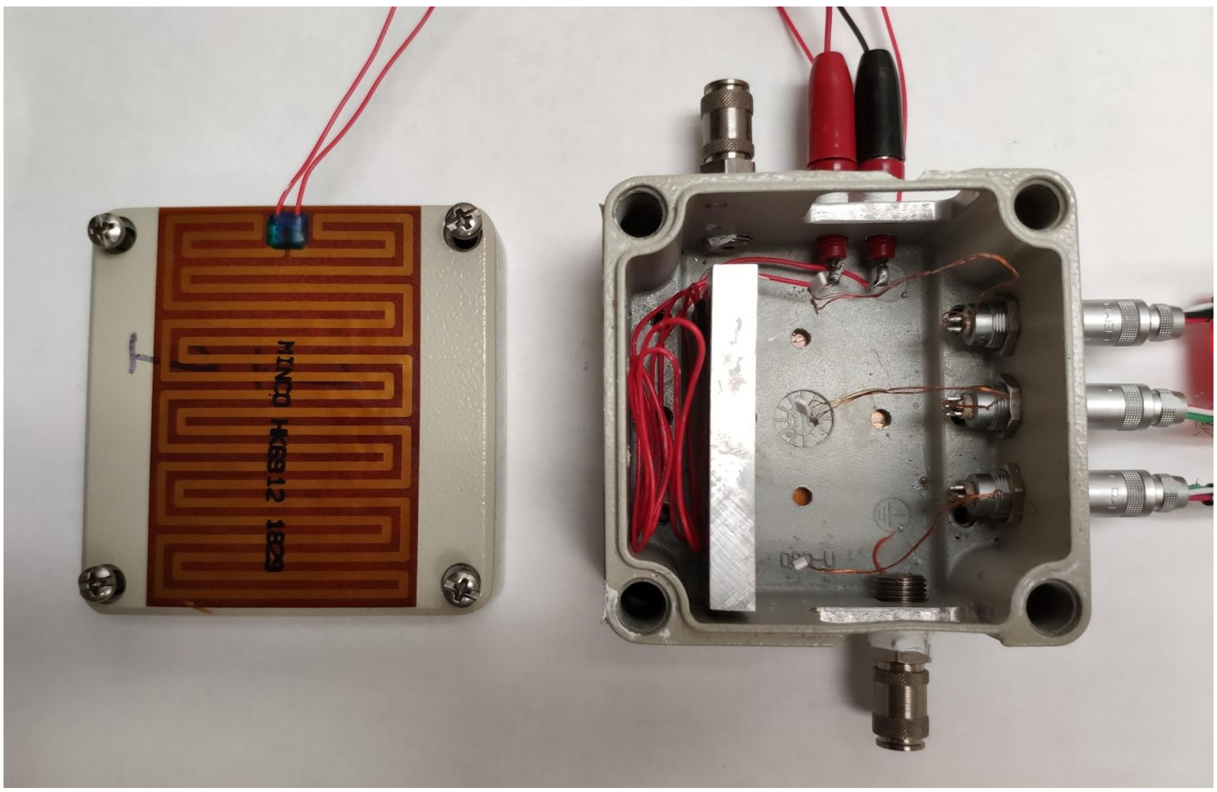

Figure 4: Monochromator Chamber

Software Overview

EPICS Program Flow

The EPICS IOC created in this project is designed to regulate the temperature within the chamber through use of nested PID-controlled heaters. All of the calculations and conversions necessary to implement these control loops were completed by a series of interconnected EPICS records (process variables). Figure 5 illustrates a simplified program flow.

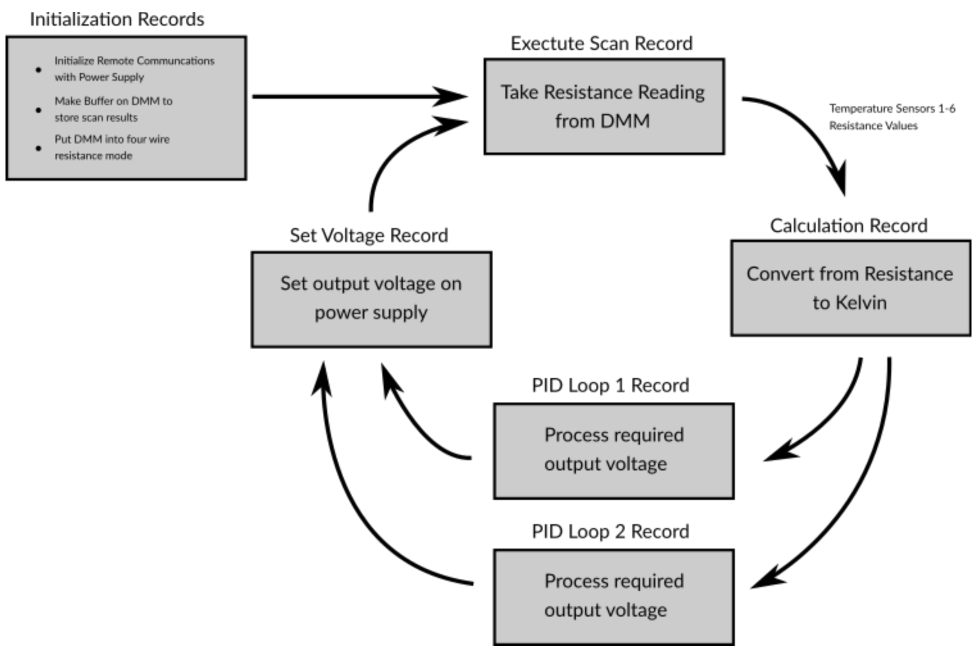

Figure 5: PID Loop Program Flow

- During IOC start-up the digital multimeter and power supply go through an initialization process.
    - The digital multimeter is sent TSP commands to allocate memory in its buffer to store six resistance readings.
    - The multimeter is configured for the specific scan range on which to take periodic measurements and measurement in "fourwire" mode.
    - The power supply is sent SCPI commands to configure it to accept further remote commands over it's USBTMC interface.
- Every second the digital multimeter takes six resistance measurements from the PT1000 temperature sensors. These readings are fed into an EPICS calculation record which performs resistance to temperature conversion.
- Two of these values fed into corresponding PID loop records which calculate output voltage necessary to maintain the setpoint temperature
- The process then begins again with new temperature readings

Below is a more detailed view of the communication flow that occurs when the EPICS IOC and physical device communicate via the StreamDevice and AsynDriver.

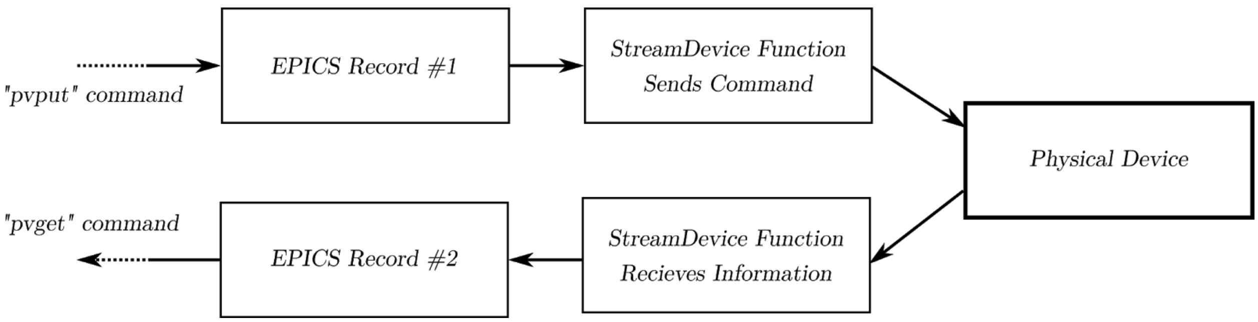

Figure 6: EPICS Communication Flow

- A "Process Variable Put" (pvput) command is received by the IOC over the network
    - This could originate from a command line tool or some sort of other interface.
- The data received over the network in the "pvput" put command is stored in an EPICS Record #1.
    - This data could be a temperature setpoint for example.
- The EPICS Record #1 requests that StreamDevice send a command to the physical device. StreamDevice and asynDriver handle this request at the driver support level. StreamDevice and asynDriver support serial, GPIB, TCP, and USBTMC communication protocols.
- The physical device then sends back information (if it has been requested) and StreamDevice will put that information into EPICS Record #2. This information can then be retrieved by a "Process Variable Get" (pvget) command.

<u>MEDM Interface</u>

Additionally, an interface using the Motif Editor and Display Manager (MEDM) was created in order to provide real time operator feedback for a variety of system characteristics.

Information displayed on the interface includes:

- Setpoint of each heater loop in Kelvin
- Proportional, Integral and Derivative weights
- NPLC (Measurement Integration Rate)
- Applied Voltages
- Sensor readouts

This information is presented in both tabular and graphical formats on the interface. Data logging can be achieved via the EPICS Archiver tool or a local Bash-Shell script.

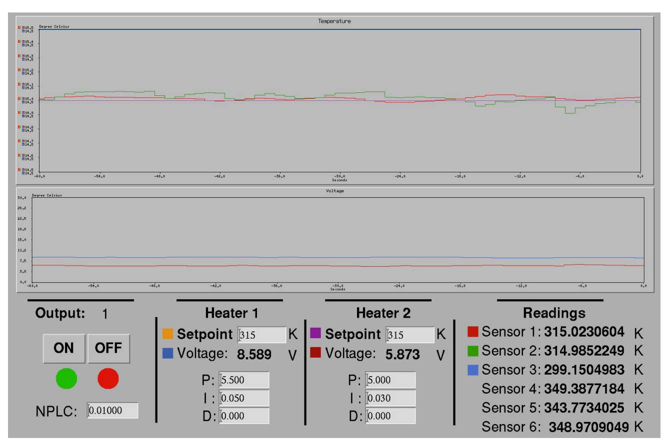

Figure 7: MEDM Interface for Prototype Monochromator

Summary

By the end of this project device level support for the Keithley 3706A digital multimeter and Keithley 2230G multi-channel power supply was implemented in the EPICS software.

Interfacing with these devices originally required a Python 2 wrapper script that would interface with the digital multimeter and power supply over a serial to GPIB converter. This solution was non-standard, required additional hardware, and would have been unlikely to achieve the goal of beamline integration. Both devices now use modern interface methods and protocols. The Keithley 2230G power supply now uses a USB connection to the IOC with the standard USB Test and Measurement Control driver. The Keithley 3706A digital multimeter has now been assigned a static IP address and can be interfaced with from anywhere on the network via TCP. These protocols will continue to grow in popularity and support.

These advancements will allow for further development of the temperature-tunable backscattering high-energy-resolution monochromator. With standardized control software and graphical interface, the challenge of tuning and integration of the device into the beamline has been greatly reduced. This software is portable and can be implemented with relative ease on most computers and embedded beamline system.

The combination of precise software control and hardware measurements should allow the device to achieve a precision of 1-2mK. However further refinement is necessary before such levels of precision can be achieved.

Acknowledgments

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References

[1] P. Alexeev, et al., Hyperfine Interact. 237:2016
[2] Y-W Tsai, et al. Optics Express 24, 30360, 2016