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MOTION CONTROLS FOR ORNL NEUTRON SCIENCE EXPERIMENTAL BEAMLINES*

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Abstract

This paper presents a comprehensive overview of the motion control systems employed within the neutron science user facilities at Oak Ridge National Laboratory (ORNL). The Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR) at ORNL have a total of 35 neutron beam lines with numerous motors for motion control. The motion systems vary in complexity from a linear sample positioning stage to multi-axis end stations. To enhance the capabilities of these motion systems, a concerted effort has been made to establish standardized hardware and flexible software that improve performance, increase reliability and provide the capability for automated experiments. The report discusses the various motion controllers used, the EPICS-based IOCs (Input Output Controllers), high-level motion software, and plans for ongoing upgrades and new projects.

INTRODUCTION

The Neutron Sciences Directorate at Oak Ridge National Laboratory (ORNL) maintains two independent experimental facilities providing neutron beams for user experiments: the Spallation Neutron Source (SNS), and the High-Flux Isotope Reactor (HFIR). Both facilities have multiple beamlines (19, 16) offering diverse beam properties and detector capabilities. Within each beamline experimental samples are exposed to neutron beams while measuring and recording the interactions. To expedite user time, it is desirable to automate the data acquisition process to the extent possible. Of concern here is the control and automation of sample position, orientation, and exposure within the neutron beam, to which we refer to concisely as *motion control*.

Although the experimental beamlines are quite different in configuration, sample motion control has many consistencies throughout both facilitates. Our team is attempting a uniform approach to all motion control. This approach was initiated by migrating both the SNS and HFIR experimental beamlines to the Experimental Physics and Industrial Control System (EPICS) control system [1]. This effort began formally in 2012 [2, 3]. Since then, all SNS beamlines and half the HFIR beamlines have adopted EPICS systems, most utilizing the Control System Studio (CS-Studio or “CSS”) user interface [4].

MOTION CONTROL SYSTEMS

Motion systems are used for diverse functions within SNS and HFIR beamlines. The following are typical applications:

- Linear and rotary sample positioning stages
- Slits sizing - both beams and detectors
- Neutron guides
- Detector positioning
- Attenuators
- Hexapods
- Shutters

However, within all systems the fundamental components are stepper and servo motors along with their associated hardware (e.g., controllers, encoders, limit switches, etc.) and software support (drivers, sequencers, user interface, etc.).

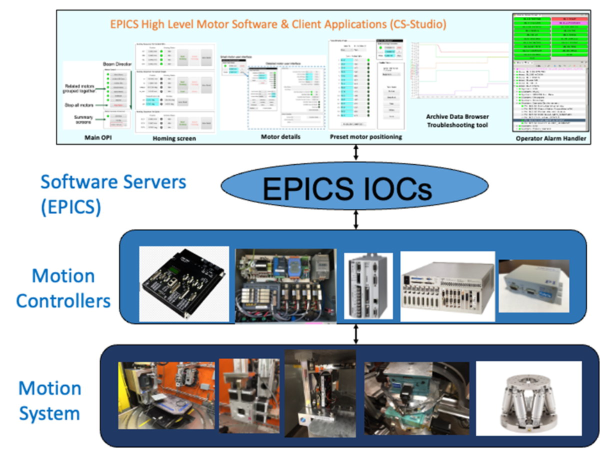

Figure 1: Control System Architecture.

Overview

Figure 1 is a hierarchical representation of a typical motion control system used at ORNL. At the base of the diagram is the motion system itself, examples of which are listed above. (Note that the motors are embedded within these systems.) The next level shows the hardware controllers required by the motors, covered in detail below. The middle layer between hardware and user interface is the EPICS IOCs through ethernet or serial-ethernet connection. Here EPICS motor records provide driver compatibility with the motor controllers. The final layer in Fig. 1 represents the motion control software. This includes software supporting basic control signal access to high-level client applications potentially automating experimental processes over the Channel Access (CA) protocol.

Motion Control Hardware

The stepper motors require specialized hardware interfaces called motion controllers. These devices direct the motor action according to predetermined software inputs.

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As seen in Table 1, there are 129 motion controllers deployed across the SNS and HFIR facilities.

Table 1: Axes at SNS and HFIR

Facility	Controllers**	Axes
SNS*	98	462
HFIR	31	162
Total	129	624

*NSE beam line and some shutters are not included.

**Parker: 95, Galil: 24, Others: 10

Motion Controllers Commonly used motion controllers are listed below.

Parker 6K / Parker GT6K:

The Parker 6K controller was the SNS standard until 2019. It does not have an internal driver. It controls Parker E-AC or E-DC drives. In contrast, the Parker GT6K is a single-axis controller with an internal drive; it is particularly well-suited for driving sample environment sticks and stages. The GT6K is configurable and can be moved to different beam lines. Both controllers' interface with the network via a Moxa RS232-Ethernet converter.

Galil DMC-40x0, DMC-3x01x:

The Galil DMC-40x0 has become the preferred and standard motion controller. It has a more modern design and offers more features than the Parker 6K, providing "user-friendly" functionality. A variety of Servo Amplifiers and Stepper Drivers can be integrated into the controller.

DMC-3x01x is single-axis motion controller, which is designed to work with both servo and stepper type motors. Recently, the DMC-30016 has been integrated into the cryostat system where it controls needle valves adjusting helium flow for magnet cooling.

Newport XPS:

The XPS is an extremely high-performance controller with built in amplifiers for up to 8 axes. Notable for its flexibility and precision, the XPS provides outstanding trajectory accuracy.

Finally, some servo motors and hexapods stands are supported by the PI servo controller and PI C-887 Hexapod Controller.

Motion Control Software

The motion control software is distributed within the EPICS control system and also separate host platforms supporting high-level motor control and client applications. This is the case for the scan application shown in Fig. 2. We consider software systems for several other motion applications.

EPICS IOC Motion Application Basic motion control is implemented as an EPICS IOC application, as shown in Fig. 2. Typically, an EPICS asyn motor record, in conjunction with updated Model 3 Galil motor software driver, provides the primary interface. Motor home and slit modules are developed to meet specific instrument requirements. More complex system runs a State Notation Language (SNL) program on the IOCs managing interlock signals and motor movements.

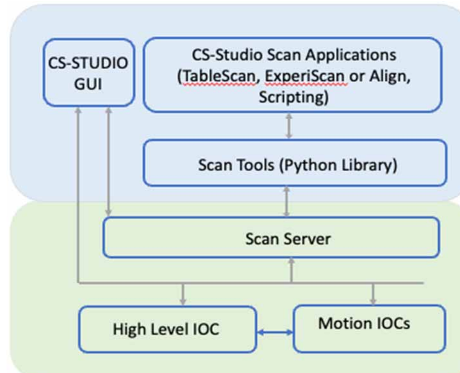

Figure 2: Data Acquisition Software Architecture.

Slit Software Slits are used for adjusting neutron beam sizes. There are four stepper motors controlling four slit blades. The blade movements are based upon demand positions, rather than relative changes given by readback positions. Therefore, special algorithms were developed for coordinating slit blade positions. Specifically, two virtual motors are created to manage the gap width and gap center; these motors are assigned to "left/negative" and "right/positive" actions. When the real blades are moved both virtual motors positions are considered. This configuration avoids gap center and width drifts, which is an issue for small gap sizes.

Homing Sequence The client software provides a user-friendly interface for homing multiple motors. Users can either home motors concurrently or in a specific sequence. For instance, consider the possible homing sequence: 1) Home motor A, 2) Shift motor A to 100 mm post-homing, 3) Simultaneously home motors B & C, 4) Reset motor A to initial position (0 mm).

The software provides adjustable motor speeds, from fast to slow while approaching limit switch positions.

The homing protocol for individual motors can be easily customized via a Graphic User Interface (GUI). It allows for various settings such as pre-home move position, post-home absolute position.

Scan Applications Most beamlines provide sample scanning, which is implemented by Scan Server and Scan Tools [5] shown in Fig. 2. These applications can integrate and coordinate all motor movements. The "table scan" is a very common procedure for moving motors sequentially, or concurrently, according to a table prescription. Note that samples can also be aligned through a scanning process. This can be done manually; however, some beamlines provide automatic alignment capability.

Sample Changer Pre-set Positioning Some user experiments require multiple samples which must be swapped dynamically using sample changers.

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Configurable pre-set sample changer positions enable users to easily move to predetermined positions.

Experiments involving multiple samples with different sizes and heights require pre-sets for multi-slot sample changers. In this case groups of motors move concurrently and must be synchronized for proper pre-set alignment.

Sample Environment Rotation Stage Configuration There are a total of 34 sample stages across all beamlines. Configuration details for the stages are stored in text files while Python scripts manage stage settings and restart IOCs. The scripts are used by Sample Environment and instruments to setup stages.

Software Management

A central Wiki platform has been established for instrument control documentation and documentation of the instrument control system in general [6]. Additionally, there are Wiki pages providing guidance specific to each beamline; they contain detailed motion control information such as IP addresses, control variables names, axes numbers, limit switch and home positions, etc.

UPCOMING PROJECTS AND UPGRADES

SNS-NSE Motion Control System

A significant transition is ongoing for the Neutron Spin Echo Spectrum (NSE) beamline. The original TACO and SIEMENS control system developed by the Research Center Jülich, is scheduled to be converted to an EPICS/CSS-based system. This move is expected to bring the SNS-NSE instrument in line with the other equipment at SNS.

PPS Shutter System

Neutron shutters are integrated with the Personnel Protection System (PPS) to prevent excessive radiation exposure to personnel during routine access to the beamline sample or detector cave. The newly designed motion system for the shutter operation uses a Galil DMC-30017 controller operating an external drive and an existing servo motor. A Moxa ioLogik E1212 provides the digital input and outputs monitoring the PPS status and motion cabinet signals, and to reset the amplifier. This will be the standard shutter motion control system at SNS.

Motion System Standardization

After a decade since post-commissioning, many Parker 6K controllers are due for replacement. A campaign is underway to replace them with the Galil DMC-40x0 to standardize motion systems across the HFIR and SNS beamlines. This upgrade is motivated by hardware reliability, adaptability, ease of use and maintenance.

The upgrade process for adding and commissioning a new motor consists of several steps:

1. collecting information on motor and encoder parameters, limit and home switches, home settings,
2. determining the motor requirements by application, recommend speed and acceleration, etc.,
3. preparing the EPICS environment, such as IOC drivers, build and/or modify the IOC application and GUI, and
4. configure the motion controller, specifically the axis, motor and encoder, homing logic, limit switches, etc.

LabVIEW-Based Control System Conversion

The control system for HFIR is the Spectrometer Instrument Control Environment (SpICE); it was built in-house primarily with custom code. Instrument device control applications were written in LabVIEW. Although five beam lines have been migrated to an EPICS/CSS-based control system, there remain seven beamlines running the legacy SpICE system. An ongoing upgrade continues for these remaining beamlines. Recently, an EPICS migration for the HB3 Triple-Axis ((TAx) Spectrometer instrument beam line was planned. Because of the short reactor outage period, the instrument will potentially run on a hybrid platform supported by both EPICS and SpICE control systems.

SUMMARY

The motion control systems for the SNS and HFIR experimental beamlines were described in general, while highlighting specific cases of our current activities. Our objective is to standardize these systems to the extent possible in addition to optimizing performance. This objective provides the foundation for further automation and technological advancements of the experimental systems. Standardization and automation ultimately benefit the facility users by streamlining the experiment process.

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