CHALLENGES IN APPLYING THE J-PARC CONTROL SYSTEM TO A SMALL MUON LINAC

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Abstract

A compact muon linear accelerator (linac) is under construction at J-PARC as part of the muon g-2/EDM experiment. Unlike large-scale accelerators, this small-scale system is managed by a compact team with limited resources. To facilitate easy and fast development of its control system, we adopted the same control system framework used in the J-PARC accelerator. Development of the control system began in 2024. The implementation of the Ultra-Slow Muon (USM) section — the muon source part of the accelerator — was mostly completed by April 2025. Core functionalities of the control system has been verified during beam operation in May. This poster describes the current development status of the control system for the muon linac and discusses the advantages and challenges of adapting a large-facility control system framework to a small-scale project.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) [1, 2] E34 experiment aims to measure the muon anomalous magnetic moment (*g-2*) and the electric dipole moment (EDM) with high precision [3, 4]. As part of this program, a dedicated muon linear accelerator (muon linac) is being constructed in the H2 area of the J-PARC Materials and Life Science Experimental Facility (MLF), shown as Fig. 1. The accelerator is designed to accelerate ultra-slow muons (USMs)—produced via laser ionization of muonium atoms—up to 212 MeV [5, 6].
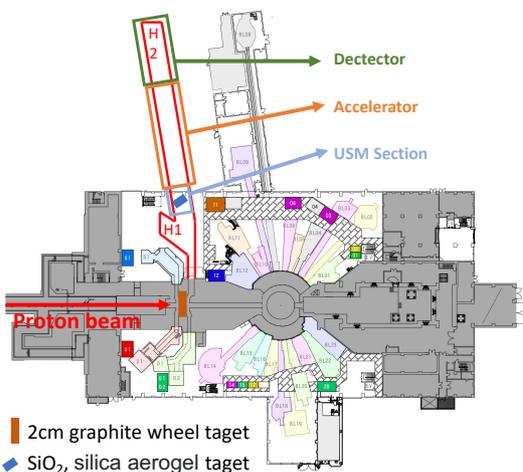

Figure 1: J-PARC MLF experimental hall. The muon linac is under construction in H2 area.

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As shown in Fig. 2, the acceleration process of muon linac consists of multiple stages: USMs are first bunched and accelerated to 0.34 MeV using a radio-frequency quadrupole linac (RFQ), followed by further acceleration through an interdigital H-mode drift tube linac (IH-DTL) and a disk-and-washer (DAW) coupled cavity linac. The final energy is reached using disk-loaded traveling wave structures (DLS) [5, 7, 8].
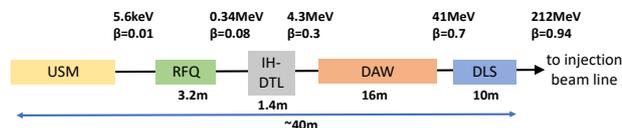

Figure 2: Structure of muon linac.

Although the accelerator is compact compared to other J-PARC facilities, it still requires integration of various subsystems, including RF, magnets, vacuum, diagnostics, and laser equipment. To ensure development efficiency and system compatibility, the control system for the muon linac adopts the same EPICS (Experimental Physics and Industrial Control System) [9, 10]-based frameworks used in the larger J-PARC accelerator complex [11]. However, applying a large-facility control system framework to a small-scale project presents unique challenges in terms of architecture scaling, resource constraints, and device diversity.

This paper describes the design and implementation of the muon linac control system, focusing on the adaptation of J-PARC control standards to a smaller system and the technical challenges encountered during this process.

CONTROL SYSTEM ARCHITECTURE

The muon linac control system is designed based on the standard architecture of the J-PARC accelerator control system. While retaining the core framework—centred on EPICS IOCs (Input Output Controllers), data archivers, and NAS-based storage—the system has been independently built to suit the scale and constraints of the muon linac project.
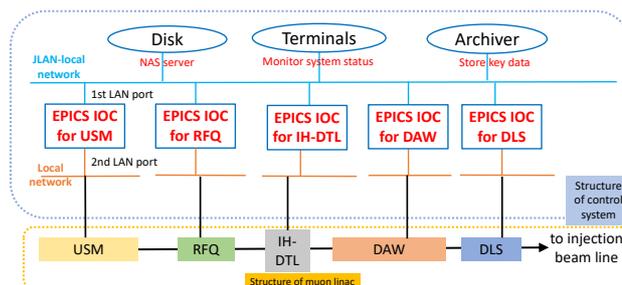

Figure 3: Overall structure of muon linac control system.

Figure 3 shows the overall structure of the muon linac control system. The system consists of:

- A disk system for centralized file storage
- Two terminals for monitoring and operational control
- An EPICS Archiver Appliance (Saba-taro) for data logging
- EPICS IOCs deployed for each subsystem (USM, RFQ, IH-DTL, etc.), responsible for device monitoring and control

All components are connected via two logically separated networks:

- A JLAN-local network (a dedicated J-PARC beam line network) for EPICS communication between servers, terminals, and IOCs
- A local network for communication between IOCs and field devices (power supplies, vacuum systems, etc.)

Part of the components are same hardware used in the J-PARC control system, an intel NUC for terminal [12, 13] and a commercial microserver "Saba-taro" for IOC [12, 14]. Operating system is AlmaLinux 9 for both. While for a disk system and an archiver, a QNAP NAS and a "Saba-taro" are selected, since J-PARC's ones are too large.

This architecture ensures modularity, scalability, and compatibility with existing J-PARC infrastructure, while being lightweight enough for small-scale application.

USM SECTION CONTROL SYSTEM IMPLEMENTATION

Based on the overall control system architecture described in the previous section, development began with the USM section as the first target for implementation.

USM Section Control System

The structure of the control system for USM section is shown in Fig. 4. The USM section includes multiple accelerator devices:

- Vacuum system: vacuum gauge, turbomolecular pumps (TMPs), gate valves, and back pumps
- Power supplies used for deflectors and field cancellation coils
- High-voltage power supplies used for Soa lens
- High-voltage power supplies used for diagnostic line

To manage signals of USM devices, following interfaces are selected:

- A PLC for vacuum, managing the interlock logic of pumps and valves
- A PLC for Soa lens, interfacing with Matsusada power supplies for Soa lens operation
- A PLC for diagnostic line, managing multiple Matsusada and Max-Elec power supplies
- A MOXA serial-to-LAN converter, used to connect a vacuum controller (e.g., Anelva gauge controller)
- Each of the power supplies for deflectors and field cancellation coils has a direct network connection
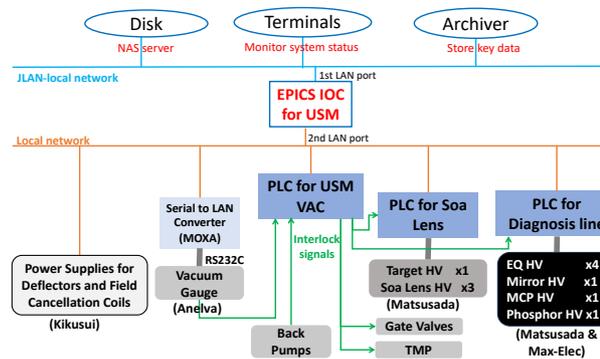

Figure 4: Control system structure for USM section.

Since PLC [15] and MOXA [16] are also used at J-PARC accelerator, driver-level EPICS software is available.

As shown in Fig. 4, interlock signals are fed into the PLC for USM VAC, where safety logic over the vacuum system will run. Development of the safety logic will be done before next beam time in November 2025.

All these interfaces are connected to a dedicated EPICS IOC for the USM section, which aggregates signal processing, device control, and real-time status updates.

System Implementation and Deployment

The physical implementation of the control system followed the architecture described earlier.

- Disk system (QNAP NAS): installed in the H2 area, connected to JLAN-local network. It hosts IOC boot files, database configurations, and display panels.
- Terminals (Intel NUCs): one of the terminals is placed in the H2 area for local monitoring and operator access. The other one is placed at J-PARC Central Control Room (CCR) for remote monitoring.
- EPICS IOC for USM (Saba-taro): installed in the H2 area. It manages communication with PLCs, network-based power supplies (e.g., Kikusui), and a serial-to-LAN converter for a vacuum controller (Anelva vaccum gauge).
- An archiver, EPICS Archiver Appliance [17], is configured on a Saba-taro. It is placed at the CCR for easier maintenance, connecting real-time data (e.g,. vacuum pressure). We can retrieve logged data from a web interface or an application "Control System Studio (CSS, see below)."

Figure 5 shows the disk system, terminal, and the JLAN-local network hub in the H2 area. The EPICS IOC, MOXA server, local network hub, PLCs, and controlled USM devices are shown in Fig. 6.

EPICS CSS is a collection of tools and applications to monitor and operate control systems [18, 19]. The CSS GUI has been developed to monitor and control the USM devices remotely. It is shown in Fig. 7.

Figure 5: The on-site outlook of a QNAP disk system, one of the terminals, and JLAN-local hub in the MLF H2 area.
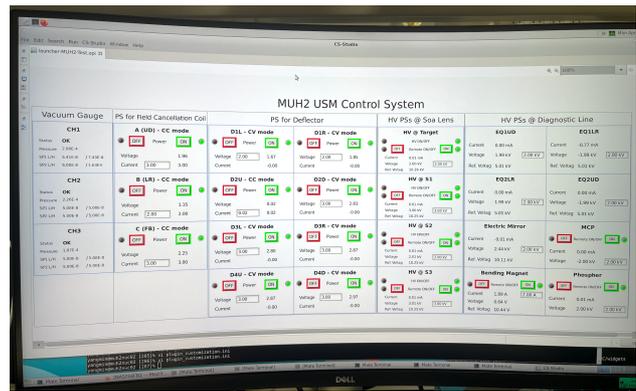

Figure 6: The implementation of the EPICS IOC, MOXA server, local network hub, PLCs, and the controlled devices in the MLF H2 area.

System Operation

Development of the basic control system for USM section has been completed. The system was operated successfully during the beam operation in May 2025.

Aside from the interlock system, everything worked without any major problems during beam operation.

Figure 7: CSS GUI for USM control system.

BENEFITS AND CHANLLENGES OF APPLING THE J-PARC CONTROL SYSTEM TO A SMALL LINAC

The application of the J-PARC accelerator control framework to the compact muon linac project demonstrated both technical advantages and inherent challenges. While using the same framework, the implementation represents an entirely new and independent control system tailored for a compact beamline application.

Advantages

- **Rapid System Setup Leveraging J-PARC Know-How:** We reused standard components from the J-PARC control system as much as possible, such as pre-configured AlmaLinux images and existing EPICS IOC templates. System design elements—including naming conventions and network structure with IP addressing—were slightly modified to fit the requirements of the target control system. This approach significantly accelerated the initial setup, enabling system operation within one year.

- **Consistency and Reliability Through Proven Architecture:** Some of the power supplies and controllers used in the project were new to us and required the development of low-level software. The EPICS-based modular design allowed quick integration of these devices into the control layers. This architectural consistency simplifies future scalability and maintenance.

- **Access to Spare Devices and Operational Resources:** Since the muon linac control system uses the same hardware components as the J-PARC control system, spare parts (e.g., PLC modules, network switches, Saba-taro microservers) were readily available for replacement and testing. This helped reduce downtime and procurement delays.
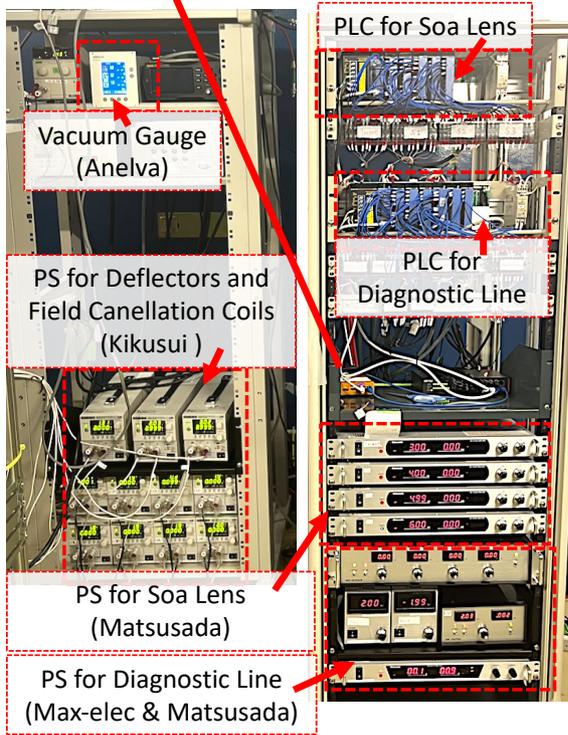
Challenges

- **System Reconfiguration for a Compact Accelerator:** Although we followed the J-PARC control framework, several components had to be

reconfiguration to suit a smaller, standalone accelerator. Examples include: (a) configuring local file management for the disk system, (b) setting up a local LDAP server for user account management, and (c) installing and tuning the archiver server environment. These tasks required a deep understanding of both infrastructure design and operational constraints.

- **Device-Specific Driver Development and Integration:** Many devices used in the USM section—such as Matsusada high-voltage supplies, Kikusui power supplies, and Anelva vacuum gauges—are not commonly used in the main J-PARC accelerator. As a result, we had to first familiarize ourselves with their operation and then develop dedicated EPICS drivers using PLCs or RS232C (MOXA) interfaces, increasing development and testing complexity.

- **Limited Manpower for Full-System Development:** In contrast to large accelerator control teams, the muon linac control system was developed by a compact group with overlapping responsibilities. This posed challenges for parallel task execution and required efficient project planning and careful prioritization.

CONCLUSION

We successfully applied the J-PARC accelerator control system framework to the newly constructed muon linac—a compact accelerator developed under resource constrained conditions.

Starting with the USM section, we implemented a complete EPICS-based control system including disk system, operator terminals, archiving, EPICS IOC, and PLC interfaces.

By leveraging J-PARC's existing control system architecture and operational experience, the team was able to achieve a rapid system startup and stable operation within one year. At the same time, several challenges—such as adapting infrastructure for a standalone setup and integrating commercial devices lacking existing EPICS support—highlighted the practical limitations of directly applying large-scale frameworks to smaller, independent systems.

The results demonstrate the feasibility and effectiveness of applying a proven accelerator control infrastructure to a compact beamline, providing valuable insight for similar future projects.

ACKNOWLEDGEMENTS

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