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STRATEGY FOR MODERNIZING A 40-YEAR-OLD ACCELATOR CONTROL SYSTEM*

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Abstract

Modernizing the Fermilab accelerator control system is essential to future operations of the laboratory's accelerator complex. The existing control system has evolved over four decades and uses hardware that is no longer available and software that uses obsolete frameworks. The Accelerator Controls Operations Research Network (ACORN) Project will modernize the control system and replace end-of-life power supplies to enable future accelerator complex operations with megawatt particle beams. The project team is evaluating three design concepts, and the future deployment of artificial intelligence capabilities for accelerator operations is an important consideration. An overview of the ACORN Project will be presented, including R&D used for evaluating the conceptual designs in the context of requirements for future accelerator operations.

ACORN

Accelerator Controls Operations Research Network (ACORN) will modernize the accelerator control system and replace end-of-life accelerator power supplies to enable future operations of the Fermilab Accelerator Complex with megawatt particle beams. ACORN is a DOE 0413.3B project with an estimated project cost from $100M to $140M and a lifetime of 8 to 10 years. As an upgrade of the accelerator complex, the ACORN team is analyzing risk associated with current accelerator operations and is developing requirements for modernization.

THE CURRENT CONTROL SYSTEM

Fermilab's accelerator control system has enabled major scientific discoveries such as the top quark, Tevatron collider program, g-2 anomalous muon magnetic moment measurement, etc., all without taking beam down for major upgrades. All upgrades have been incremental without interrupting the beam delivery program.

ACORN is Fermilab's first opportunity to take a large-scale and deliberate approach to modernizing the control system by "standing on the shoulders of giants": building on the success of the current system, upgrading to modern architectures, hardware, user interfaces, software, development processes, documentation, and integrating with modern toolkits like EPICS.

ACORN is taking a requirements-centric approach, first by gathering functional requirements of the current system from interviews with the division; we're making sure we don't lose functionality when we upgrade.

Using requirements as a guide, ACORN is building an aggressive R&D plan to inform our conceptual and technical design process. We will work with AD experts to investigate and prototype ambitious new systems that take advantage of cutting-edge technology, with a focus on standardization and compatibility across the entire division (including with PIP-II).

Requirements and R&D will enable exotic new uses of the control system, such as applied robotics and AI/ML.

We're working with Idaho National Lab (INL) with their human factors team to develop a set of user interface and user experience design standards and frameworks to improve accessibility.

REQUIREMENTS AND RISKS

ACORN in coordination with the accelerator division is performing risk analysis for accelerator operations risks. As a part of that risk analysis, the risks will be categorized based on criticality and cost. Those categories will be used to rank the risks as a priority list to be addressed by the project.

Using the risk ranking, ACORN will define project scope in conjunction with operational and other project risks that may be discovered.

We know that we have more work than our funding can support. The risk ranking allows us to prioritize and include the most important work in the project scope.

For the systems that need modernization, we will develop functional requirements for the existing accelerator control system to help ensure there's no loss of functionality in the modernization process.

In addition to functional requirements of the existing system, we will identify new requirements needed to implement new capabilities.

RESEARCH AND DEVELOPMENT

ACORN is beginning the R&D process to establish knowledge required to define our conceptual design.

Some topics we know we will investigate include:

- Explore new data acquisition capabilities
- Support for AI/ML for accelerator operations
- Evaluation of 5G technology
- Support for robotics
- Evaluation of Experimental Physics and Industrial Control System (EPICS)

Data Acquisition

Our requirements strongly suggest a centralized architecture and we have begun exploring the implications of that choice. In Figure 1 you can see a preliminary block diagram of key components.

We think that a Data Lake structure for our centralized storage will allow us the flexibility to add storage systems as we implement new tools. Key features of the Data Lake we need to test include:

- Measure expected data flows from different types of front-ends

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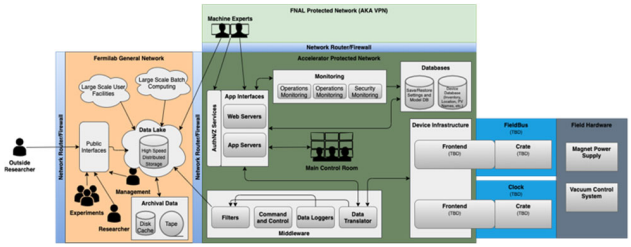

Figure 1: Centralized architecture.

- Create a testbed Data Lake
  - Measure total data volumes
  - Test filters to select and store relevant and interesting data
  - Measure commit latencies for writing data
  - Measure latencies for reading data
- Determine if a Data Lake satisfies accelerator control system requirements

Support for AI/ML for Accelerator Operations

The Accelerator Division mission for AI/ML is to enable safe and reliable improvements to accelerator operations by applying modern artificial intelligence and machine learning (AI/ML) techniques.

- Investigate machine learning operations (MLOps) frameworks to develop, deploy, and monitor AI/ML applications for accelerator operations.
- Design MLOps processes to ensure verification, validation, assurance, and trust for data collection and model building, deployment, and monitoring

Evaluation of 5G technology

The Department of Energy (DOE) tasked the ACORN project with evaluating the uses of 5G wireless technologies in the operator of the accelerator systems.

We are considering the complexities of our use cases and we are planning R&D for the following topics:

- Multiple bands on a single radiating coax antenna
- Silicon equipment lifetime in a radiation environment
- Interference with accelerator equipment
- Signal propagation in accelerator tunnels

Support for Robotics

Development and proliferation of robotics at Fermilab will bring novel technical challenges to the future accelerator control system. Technical challenges include the following:

- Low-latency feedback and control between robot and operator to minimize errors.
- High-resolution and frame-rate video streaming for navigation feedback and reconnaissance.
- Transmitting and logging data from a diverse array of sensors such as temperature, humidity, photography, thermal imaging, and radiation mapping.
- Data storage and computation for training robots to autonomously navigate and manipulate tooling for maintenance and installation tasks.

Human Factors Design Principals

The ACORN team has been working with INL Human Factors team on interviewing operators and developing a guide for intuitive user interfaces.

We plan to build our framework around this guide to give a sane set of defaults to our software developers.

CONCLUSION

ACORN is taking a diligent approach to project management using risk analysis and requirements gathering that will enable us to fulfill the requirements of the accelerator control system users effectively and efficiently.

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APPENDIX A
THE ACORN TEAM†

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