Software Architecture and Hardware Organization in Mu2e Solenoid Field Mapping System

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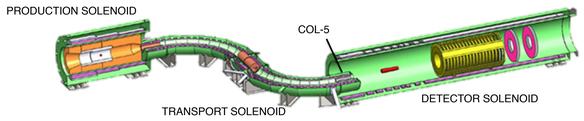
Mu2e Experiment

The Muon-to-Electron Conversion Experiment (Mu2e) is under construction at Fermilab. This experiment will probe for the indication of physics beyond the Standard Model by searching for evidence of charged lepton flavor violation through the direct conversion of muons into electrons.

The magnetic field in the large superconducting Detector Solenoid (DS) and the field in the Transport Solenoid collimator (COL-5) aperture need to be accurately mapped prior to the start of the experiment. The magnitude of measured magnetic field value needs 0.01% accuracy, and the direction error of the B field vector accuracy should be less than 0.1 mrad.



The Mu2e apparatus includes the Detector, Transport, and Production solenoids.

Field Mapping

Mu2e field mapper

The large volume of the DS necessitated the development of a self-propelled mapper device equipped with 3D Hall probes and an NMR probe. The mapper traverses the full length of the DS magnet on tracks. At each longitudinal position, several readouts are performed, each at a different angular position of the mapper's rotating arms. The positions of the arms are precisely determined by a laser tracker, which allows for calculating and precisely determining Hall probe positions.

The field mapping process is completely automated. Each measurement includes readouts of all Hall and NMR sensors, Hall sensor temperatures, the positions of retroreflectors on the mapper arms and the current in the magnet. The measurement space is divided into multiple measurement regions, each with a different granularity of field mapping positions.

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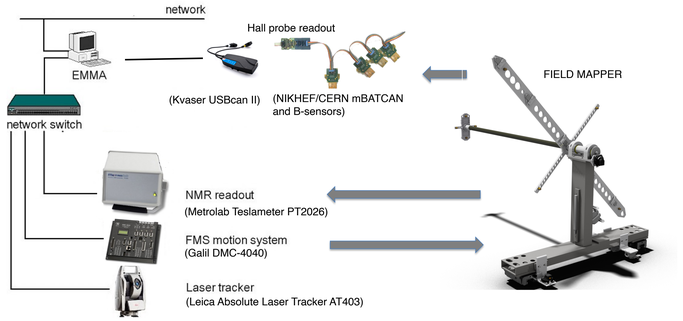
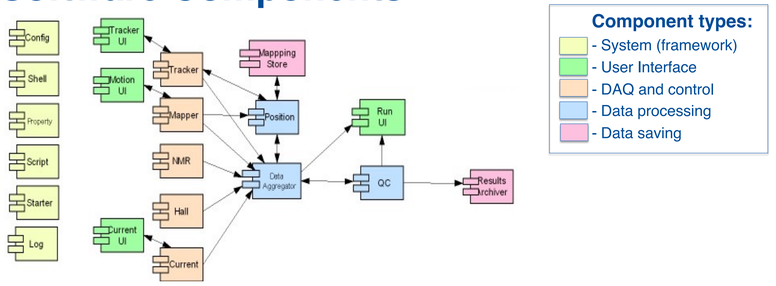
Hardware Organization



Software Framework

The Mu2e Field Mapping System (FMS) is based on the EMMA framework, where applications are constructed via assembly of software components. An EMMA component is designed following the classical object model, where objects are separate entities with states and defined behavior and communicate via messages. The message-oriented middleware is implemented as a publish-subscribe software bus.

Software Components



The Hall, NMR and Current data acquisition components acquire data in response to commands from Script. The Position component coordinates laser tracker operations interacting with the Tracker component, which provides information about the precise location of the field mapper. The Mapper component is responsible for controlling motion of the field mapper. All acquired data are combined by the Data Aggregator component and verified by the QC component. The Run UI provides visualization of the data and monitoring of the progress of the mapping process. The data is saved in files by the Archiver component.

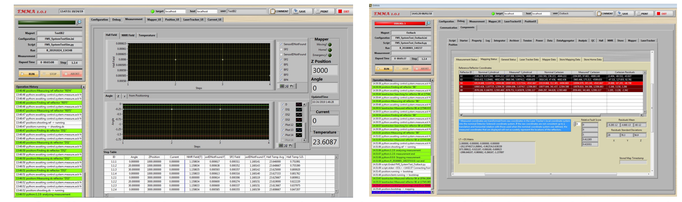
Laser Tracker Operations

The Tracker component implements access to the Leica Absolute Laser Tracker AT403 connected to the Mu2e FMS via Ethernet. This tracker has been selected because of its proven ability to work in a high magnetic field (AT403 operates up to 200 Gauss with full functionality and accuracy).

The Tracker component obtains the list of optical targets (retroreflectors) to measure from the Position component, which is also responsible for mapping between different coordinate systems. There are two groups of targets: a) the reference group, including targets mounted on the Mu2e solenoids and possibly on the walls, and b) the measurement group, including targets mounted on the arms of the field mapper device.

The measurement starts with the Tracker component initializing the laser tracker and measuring the targets from the reference and measurement groups with the mapper in the home position. After each move of the mapper, the Position component calculates the predicted positions of all non-stationary targets and checks, using a model of the mapper, if any target is hidden behind the mapper's column. All visible targets are measured.

User Interface



Shell with plugin components (operation views – left, debug views - right)

The user interface is implemented using a flexible component (Shell), which allows embedding of the front panels of other components to create a consolidated system monitor. The plug-in components can show either their standard operation view or a debug view that permits inspection of the internal state of the component.

Summary

A flexible measurement system has been developed to map the field in the Mu2e detector solenoid. Its software is configurable from components, which are integrated via a message-based middleware. The components implement: magnetic field measurements with Hall and NMR probes, motion control of the mapper, and position monitoring with the laser tracker. Field mapping is automated via a parameterized script, with parameters specifying measurement positions.