Diagnostics and Restoration of Electronics for Imaging the Duomo of Florence

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Background

The Dome of Santa Maria Del Fiore

The dome atop the Cathedral of Santa Maria Del Fiore in Florence, Italy is one of the city's most famous landmarks. Designed by Brunelleschi in the early 15th century, its architectural plans remain a mystery to current-day scholars. In 2017, researchers at Los Alamos National Laboratory proposed a way of imaging the internal structure of the Dome, in order to determine if the Dome is reinforced with iron bars or chains in its masonry.

Cosmic-ray muons

Cosmic-ray muons are produced in the atmosphere in large amounts through the interaction of cosmic rays with atoms. Due to their large mass, they are capable of penetrating large amounts of material. Muons are charged, and thus undergo Coulomb scattering when they pass through matter.

Multiple scattering muon radiography (MSMR)

The angular distributions of muons that undergo multiple Coulomb scattering is dependent on the atomic number and density of the material it passed through. Thus, by measuring the distribution of the scattering angles, it is possible to reconstruct images of the matter that they passed through. This can be done by measuring muon tracks before and after they pass through a material.

Charged Particle Tracking Detector

The detector consists of a pair of drift tube trackers to detect muons, which are then connected to the data acquisition (DAQ) system that processes the signals into data.

The trackers consist of groups of carbon fiber drift tubes which are filled with a mixture of Ar, CF4 and ethane gas, with a high voltage wire running through the middle. When a muon passes through the tube, it ionizes the gas and produces free electrons that are attracted to the anode wire, producing a signal.

The data taking system consists of multiple chips: First the ASDBLR chip, which shapes the incoming signal, and then the DTMROC chip which measures the drift time, and lastly a trigger and data board with a SoC that issues triggers, reads out the timing data, and sends it over ethernet to a central computer.

Fig 1. Image of the Cathedral of Santa Maria Del Fiore. Cole, M. My Modern Met. https://mymodernmet.com/florence-cathedral/.

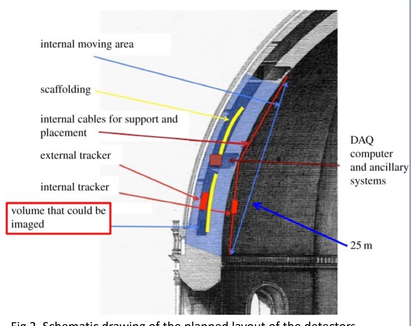

Fig 2. Schematic drawing of the planned layout of the detectors, electronic components, and scaffolding on the inner wall of the Cupola of the Duomo. (Guardincerri et al. 2018)

Objective

- The goal of the overall project is to identify and image the internal structure of the Dome, in order to determine the placement of iron elements in the masonry. This is done by designing a cosmic-ray muon detector and placing it on both sides of the inner dome, and producing an image through multiple scattering muon radiography.
- The role of the University of Pennsylvania's involvement in the project is to design and manufacture custom electronic boards for data acquisition, specifically re-purposing the DTMROC and the ASDBLR chips used in the ATLAS experiment to custom-made circuit boards.
- For the summer of 2021, our preliminary goal is to test the previously designed electronic boards, namely the digital boards with DTMROC chips and the analog boards with ASDBLR chips, and to evaluate and document their readout behavior

Materials & Methods

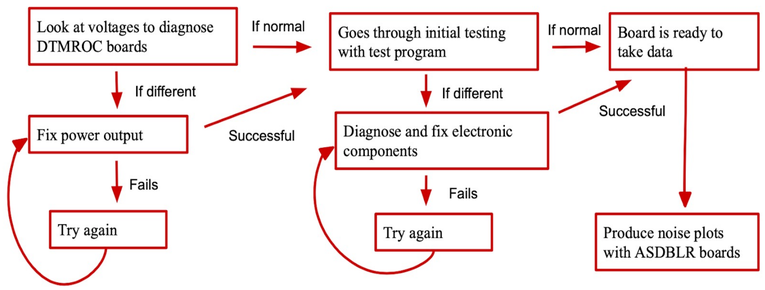

Fig 3. Flow diagram of the steps taken in evaluating and repairing the data acquisition circuit boards. Circuit boards and chips first manufactured in 2018 were first inspected for physical errors in the circuit, and then passed through a testing program to ensure the integrity of the memory and signal lines. Noise plots of the functional circuit boards were then produced.

Acknowledgements

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Results & Summary

- A full inventory of the available DTMROC and ASDBLR boards was made, along with the electronic components necessary in order to complete the remaining unfinished boards.
- A test program for the DTMROC boards was created and used to determine if the signal lines on the board and the relevant registers in the chips were functional.
- Noise plots of working ASDBLR boards were produced, as shown below.

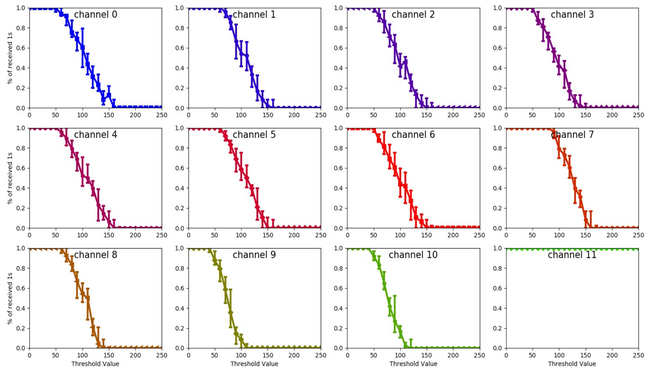

Fig 4. Example noise plot from the first 12 channels of ASDBLR board #32. The x-axis is the threshold value, and the y-axis for each graph is the percentage of time that noise is recorded. Error bars indicate 1 standard deviation. As shown, the amount of noise recorded decrease as the threshold value goes from 50 to 150, and no noise is recorded for any channel at a threshold value above 170. Furthermore, channel 11 is dead, indicating a possible fault in the electronics.

Future Directions:

- Finish repairing the currently malfunctioning boards and ensure their integrity.
- Test methods to reduce the substantial amount of background signal as shown in the noise plots, and calibrate each board to its corresponding noise level.
- Assemble the complete data acquisition system, including drift tubes, and determine its performance on tracking cosmic ray muons.

References

Guardincerri E, Bacon JD, Barros N, et al. Imaging the dome of Santa Maria del Fiore using cosmic rays. Philos Trans A Math Phys Eng Sci. 2018;377(2137):20180136. Published 2018 Dec 10. doi:10.1098/rsta.2018.0136

Ouellette, J. Italy's famous dome IS cracking, and cosmic rays could help save it. Ars Technica. https://arstechnica.com/science/2018/08/cosmic-rays-could-help-unlock-the-secrets-of-brunelleschis-dome/.