Hadron Monitor Calibration System for NuMI

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Background

Abstract:
NuMI (Neutrinos at Main Injector) beamline at Fermi National Accelerator Laboratory provides neutrinos to various neutrino experiments. The hadron monitor consisting of a 5 by 5 array of ionization chambers is part of the diagnostics for the beamline. In order to calibrate the hadron monitor, a gamma source is needed. We present the status and progress of the development of the calibration system for the hadron monitor. The system based on Raspberry Pi controlled CNC, computer numerical control, system, gamma source, motors, and position sensors would allow us to place the precisely to calibrate the signal gain of individual pixels. The ultimate outcome of the study is a prototype of the calibration system.

NuMI System:
NuMI is a neutrino beam facility at Fermi National Accelerator Laboratory. It is a conventional horn focused neutrino beam designed to accept a 120 GeV proton beam from the Fermilab Main Injector Accelerator.

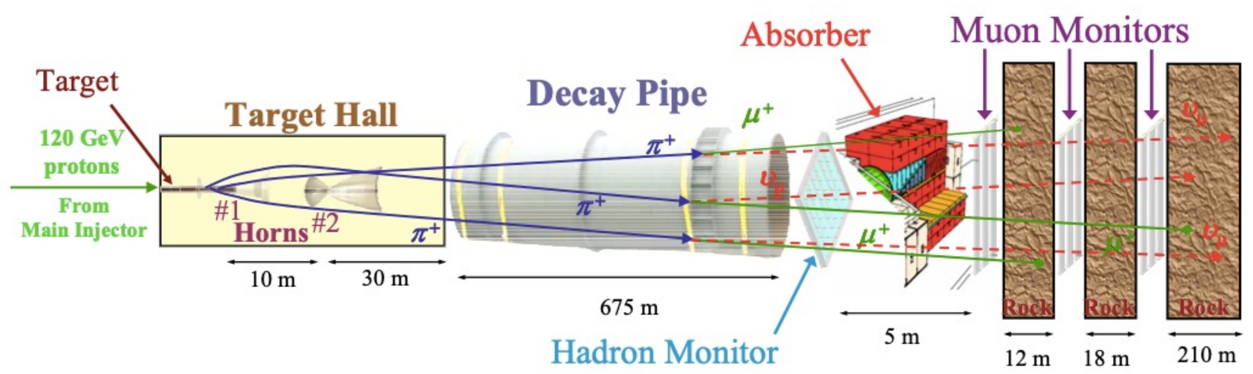

Fig 1: The major components of NuMI. The Fermilab Main Injector delivers proton to a carbon target producing pions, which are then focused into the decay pipe. The hadron monitor measures the spatial distribution of any protons and pions left after decay. These are then absorbed by the hadron absorber.

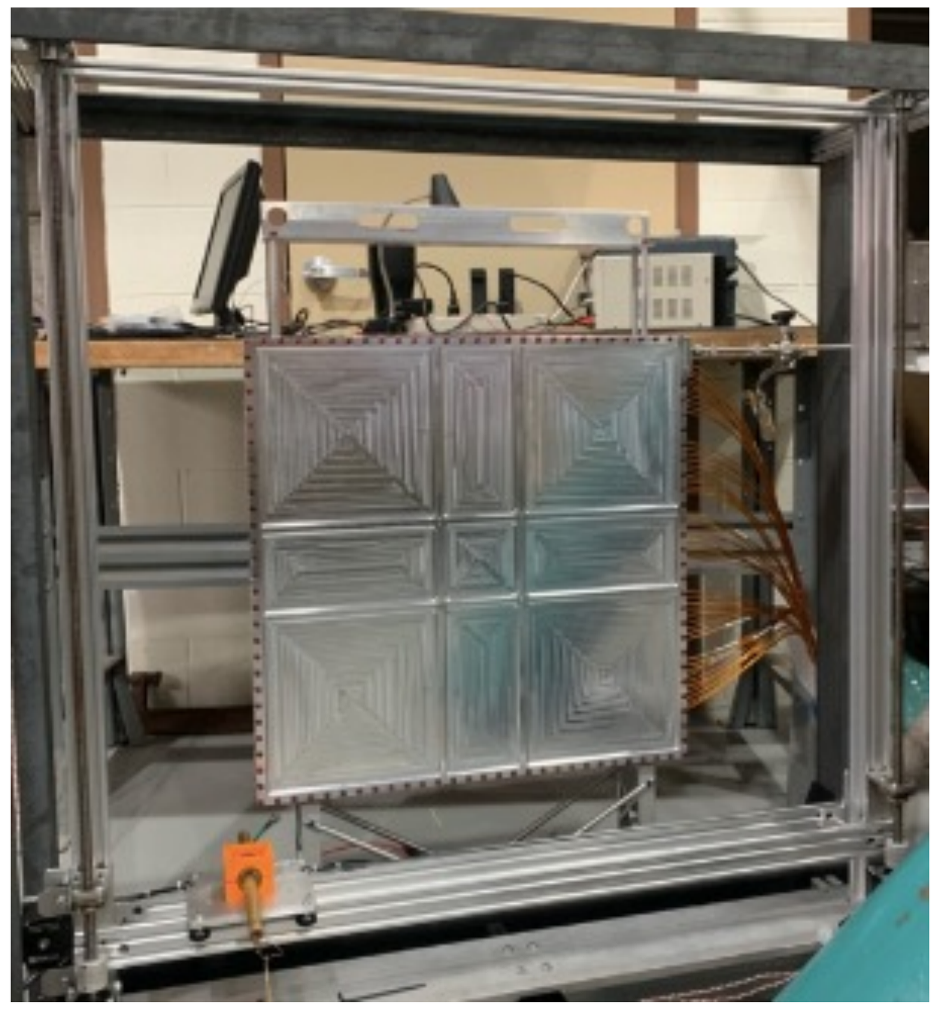

Fig 2: The hadron monitor set up for calibration

Experimental Setup

The prototype is based on a four-sided frame composed of aluminum T-slotted beams attached at the four corners using L-brackets. Track rollers are attached perpendicularly to a T-slotted framing beam, cross beam, at both ends and rolled in parallel onto the frame. One roller is place on the outside of both sides of the frame, while a third roller is added to the inside of the frame on the opposite side of the beam but parallel with one of the outside rollers. The two rollers on the same beam are held together with a square bracket. This configuration allows the cross beam to move back with minimal friction. The configuration to the outside of the frame reduces unwanted lateral motion in the system and allows the cross beam to be pushed rigidly at a singular point.

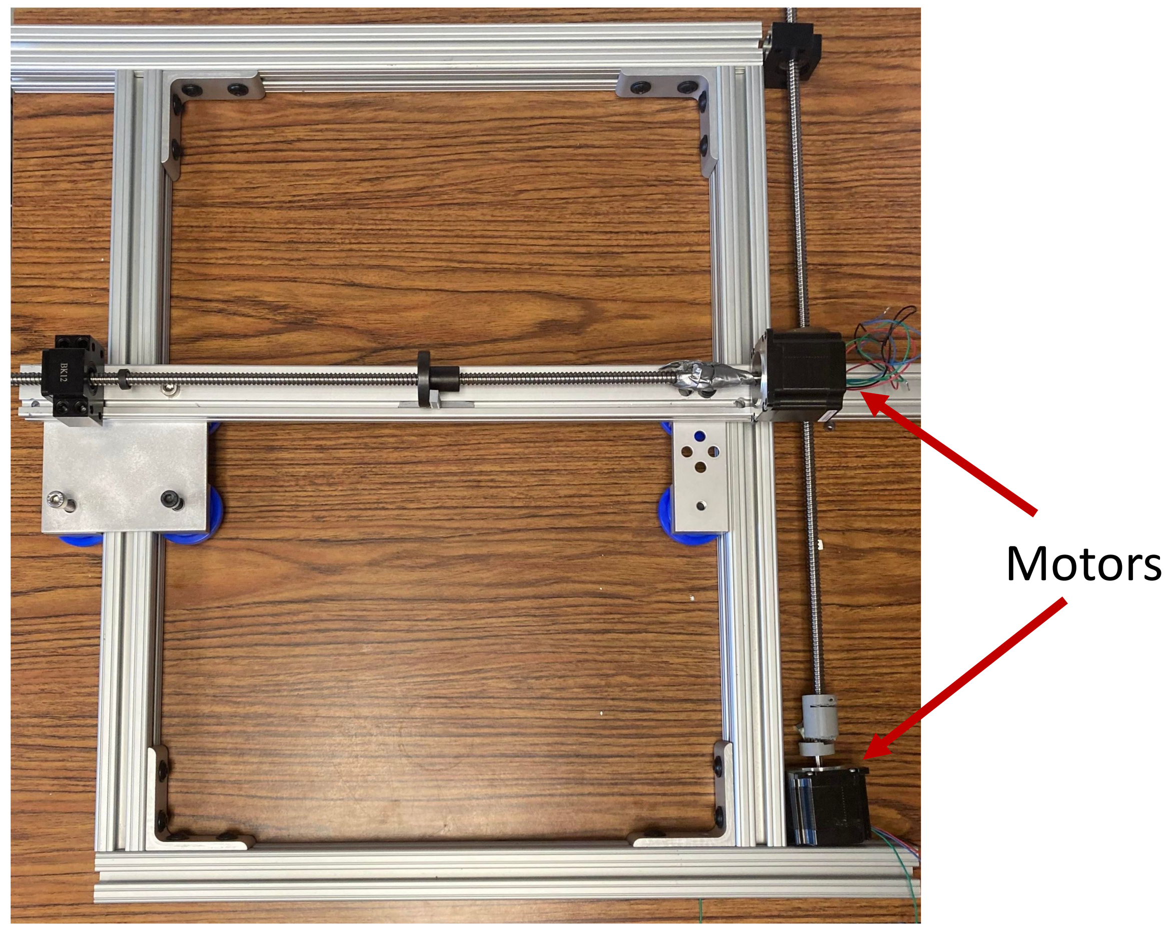

Fig 3: The experimental set up including the frame, crossbeam, location of the two motors is noted above

This set up also involves two stepper motors. The first motor is used to push and pull the cross beam along the frame. This motor is connected to a ball screw via a 3D printed shaft coupler. A circular flange is attached to the ball screw and a custom fit bracket, shown in Fig. 5

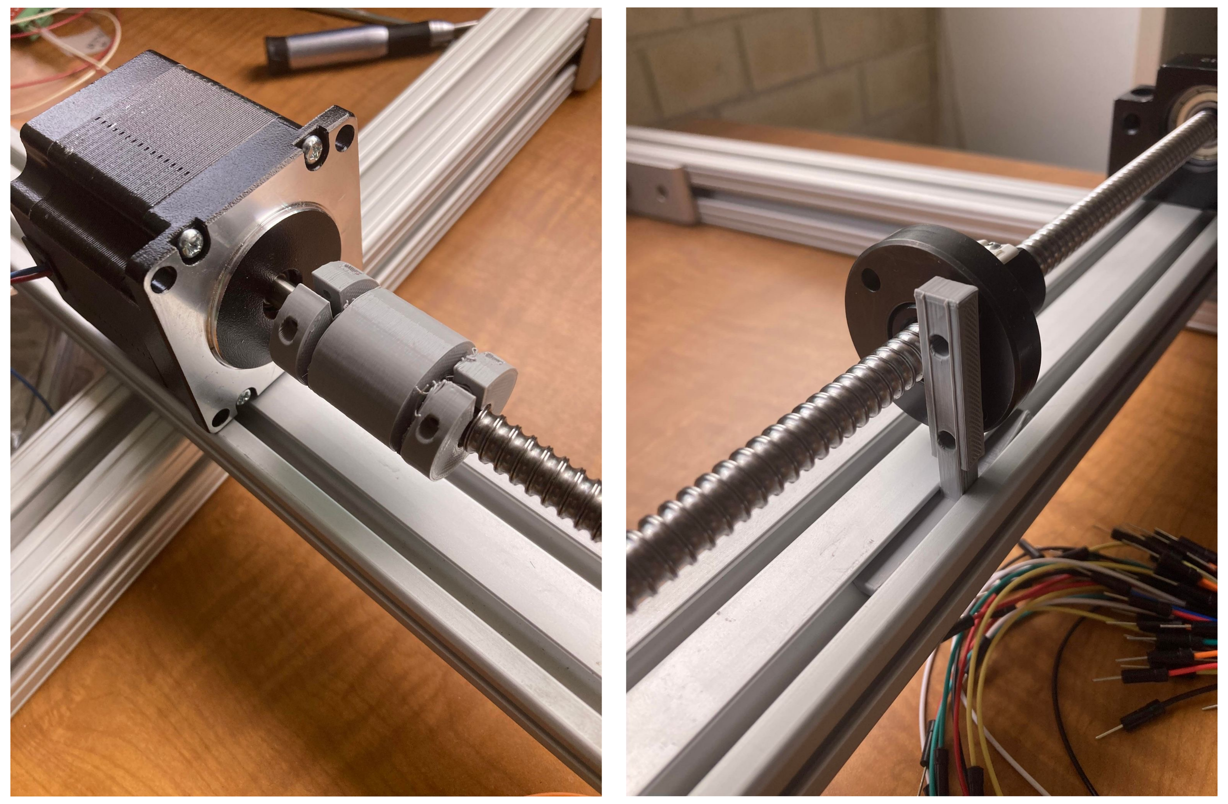

Fig 4: (left) The 3D printed coupler fitted to the motor and ball screw and (right) the stabilizer attached to the flange

Both motors are connected to a CNC board on the Raspberry Pi, which allow the motors to move in defined steps. Two distance sensors are employed to ensure accuracy of the distance from the motors. The next sections will discuss the software system and the distance sensor calibrations

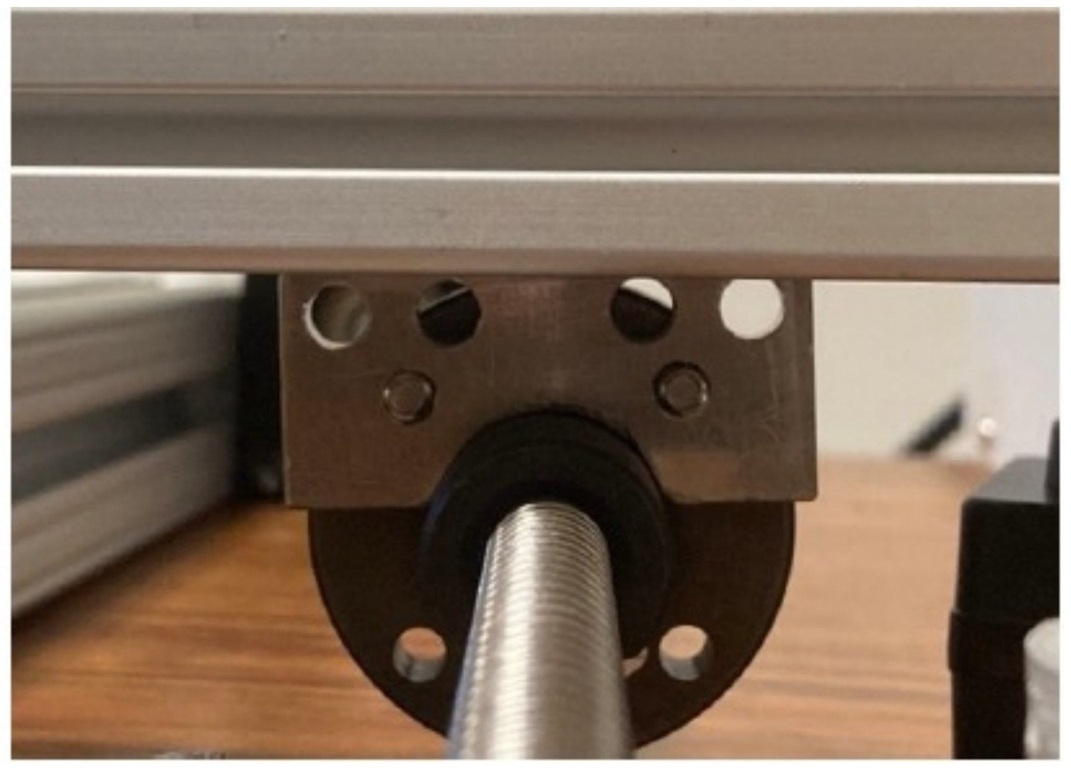

Fig 5: The machined bracket to fit the flange and rail

Hadron Monitor:
The hadron monitor is used to measure the spatial distribution of the uninteracted and undecayed pions produced by the main injector beam interacting with the carbon target. The design of the Hadron monitor is comprised of a grid of 1mm ionization chambers in a transverse orientation to the beam contained in an aluminum box. The calibration of the Hadron monitor involves a radioactive source moved in front of the monitor by a motor driven motion table to find the highest sensitivity position and observe the spatial sensitivity of the individual pixel. The focus of this project is to create a system to control and display to the user the position of a radioactive source.

Software System

bCNC Software:
The motors can be controlled using the software bCNC, a cross-platform program written in python to ensure communication between the hardware and an open-source GRBL CNC software. To operate, the controllers must be connected to the physical channels. An RPI-CNC board is attached to the raspberry pi. For control, the bCNC software must translate the motor step sizes into physical distances. To calibrate, the motor is attached to a ball screw and flange. The flange is marked at a starting distance and then moved a specified number of steps. The distance traveled is noted and this can be used to determine the step size, in mm, and then can be input into the bCNC software. With both motors connected, the x-y position of the sample can be adjusted via the graphical user interface in which the user inputs the position on each plane in mm.

Calibration Results

In order to ensure accuracy in motion from the motors, SHARP analog infrared distance sensors are employed. The given sensors are accurate to ± 2mm for objects between 10 - 80 cm from the sensor [2]. These distance sensors produce a voltage output corresponding to some distance between the sensor and a target. For calibration, the sensor is fixed in a location and a target is moved fixed distances away. The average voltage output was used to develop a calibration curve.

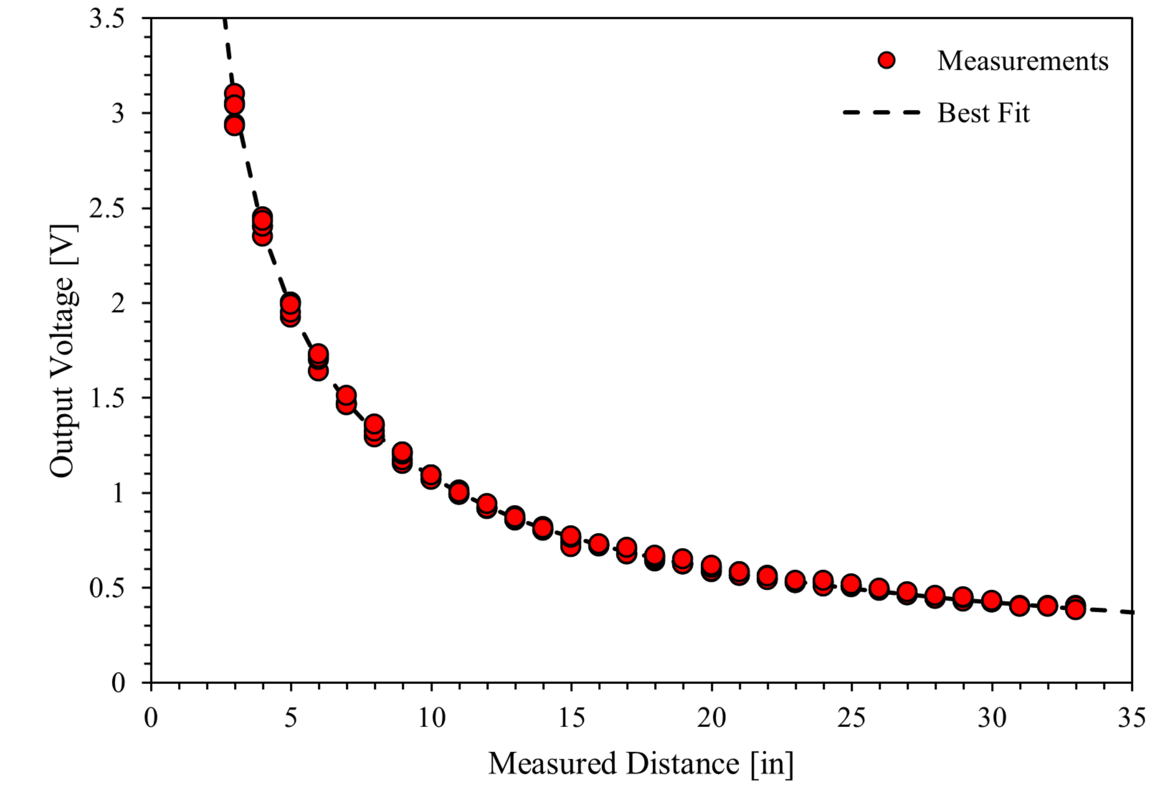

Fig 6: Data acquired from distance tests and calibration curve

Conclusion

In summary this paper presents the design, construction and fabrication of a prototype for the calibration system for the hadron monitor of the NuMI beamline. This project was designed to introduce a system of checking the location of the radioactive source, which is moved by a series of motors, used in the calibration of the monitor. This was accomplished by introducing and calibrating two infrared sensors to measure the distance of the stabilizers moved by the motors. In the future, further testing of the scaled system will be performed and a similar system can be implemented to monitor the hadron monitor of the NuMI beamline.

References

[1] R.Zwaska, "Accelerator Systems and Instrumentation for the NuMI Neutrino Beam", Ph.D. thesis, Phys. Dept., The University of Texas at Austin, 2005
[2] *Sharp GP2Y0A21YK0F Data Sheet*, Sharp, Dec. 2006; https://www.pololu.com/file/0J85/gp2y0a21yk0f.pdf

Acknowledgements

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