HyperRail: Modular, 3D Printed, 1-100 meter, Programmable, and Low-cost Linear Motion System for Imaging and Sensor Suites

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Abstract

Reliable, accurate, and affordable linear motion systems for agricultural applications are currently not easily accessible due to their elevated cost. Most systems available to the public have price tags in the thousands and their dimensions cannot be easily customized. Current systems have a max length of about ten meters and for a typical greenhouse application, the length may not be sufficient. The price of the system increases with an increase in length and with a base price in the thousands it becomes almost impractical to buy a system for such application. The HyperRail is a modular linear motion system with a repeatability of 2mm and current top speed of 100mm/s. An advantage this system has is its ability to increase or decrease the length of system with minimum effort and nominal increase in price. The HyperRail can be mounted on a set of tripods or directly on the structure of a building such as a greenhouse. The base price for a three-meter system, on tripods, is US$240 and an additional US$45 for each additional one-and-a-half meter. The HyperRail was designed for the use of hyperspectral imaging but can be adapted for other sensor systems. We report on a nine-meter study over pine seedlings infected with a virus. A push-broom hyperspectral camera (Headwall Nano) was mounted on the carriage of the system imaging the seedlings. The rail is currently being adapted to an environmental sensor suite that will monitor CO2, luminosity, humidity, temperature, and the concentration of dust. The HyperRail also includes bidirectional-wireless communication between the drive and the carriage; this means that the sensor suite can operate autonomously and communicate to the HyperRail drive to move to a specific location and take measurements. This system includes a graphical user interface for users who are unfamiliar with programming but could also be used through a command line interface for individuals that want to work the code and see the effects of the changes immediately. This system was developed at Oregon State University's OPEnS Lab, here is a link to the project page for more detailed information. URL for project page: http://www.open-sensing.org/hyper-rail/

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Abstract: Linear Motion Systems for Environmental Sensing

Reliable, accurate, and affordable linear motion systems for agricultural applications are currently not easily accessible due to their elevated cost. Most systems available to the public have price tags in the thousands and their dimensions cannot be easily customized. Current systems have a max length of about ten meters and for a typical greenhouse application the length may not be sufficient. The price of the system increases with an increase in length and with a base price in the thousands it becomes almost impractical to buy a system for such application. The HyperRail is a modular linear motion system with a repeatability of 2mm and current top speed of 100mm/s. This is possible through a stepper motor driver that allows for 1/16th microstepping giving an average of 6180 steps per revolution. An advantage this system has is its ability to increase or decrease the length of system with minimum effort and nominal increase in price. The HyperRail can be mounted on a set of tripods or directly on the structure of a building such as a greenhouse. The base price for a three-meter system, on tripods, is US$240 and an additional US$45 for each additional 1.5 meters.

Purpose: Modular Sensing

The initial HyperRail design was for a study over pine seedlings infected with a virus, but is now a general purpose linear motion system for any adaptable sensor. The first design mounted a push-broom hyperspectral camera (Headwall Nano) to image the seedlings. The rail is currently being adapted to an environmental sensor suite that will monitor CO_2 luminosity, humidity, temperature, and the concentration of dust. It also includes bidirectional-wireless communication between the drive and the carriage; this means that the sensor suite can operate autonomously and communicate to the HyperRail drive to move to a specific location and take measurements. This system includes a graphical user interface for users who are unfamiliar with programming but could also be used through a command line interface for individuals that want to work the code and see the effects of the changes immediately.

Electronics

The electronics of the HyperRail consist of:

- FeatherM0 microcontroller
- BigEasyDriver stepper motor driver
- 12VDC power supply
- 400 steps/rev stepper motor.

The microcontroller processes all of the user input and sends the appropriate command signals out to the stepper motor driver. The driver processes the signals coming from the microcontroller and delivers the appropriate current to the motor. The only other piece of equipment that would be added to this setup is the RF breakout board that is used for data transmission.

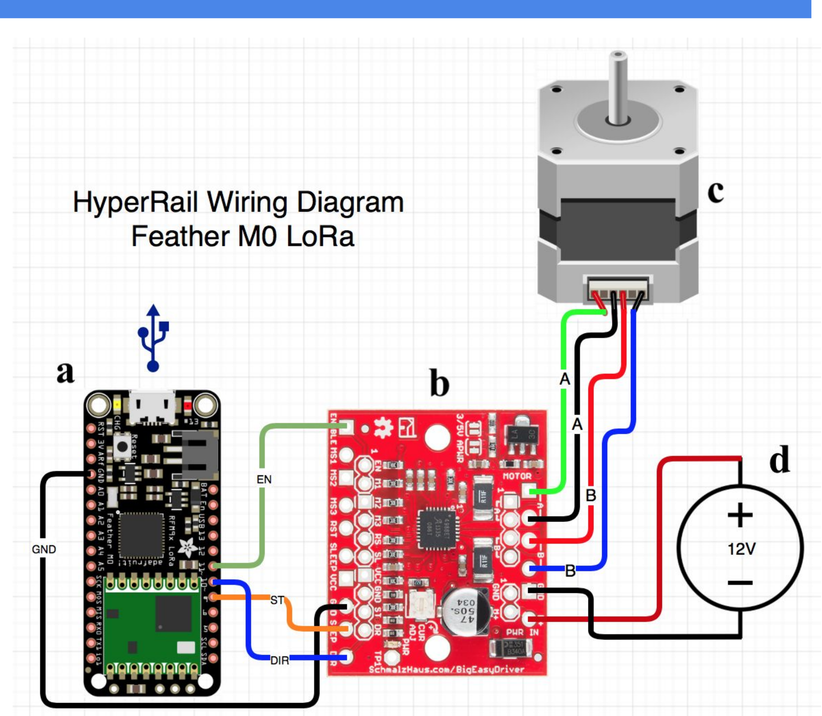


Figure 1. Wiring diagram of the electronics used in the HyperRail. The system makes use of microcontroller(a),stepper motor driver(b), stepper motor(c), and power supply(d) for the basic setup of the HyperRail.

Scan QR code to go to the HyperRail website

Scan QR code to go the OPEnS Lab website to see more projects.

HyperRail Implementations

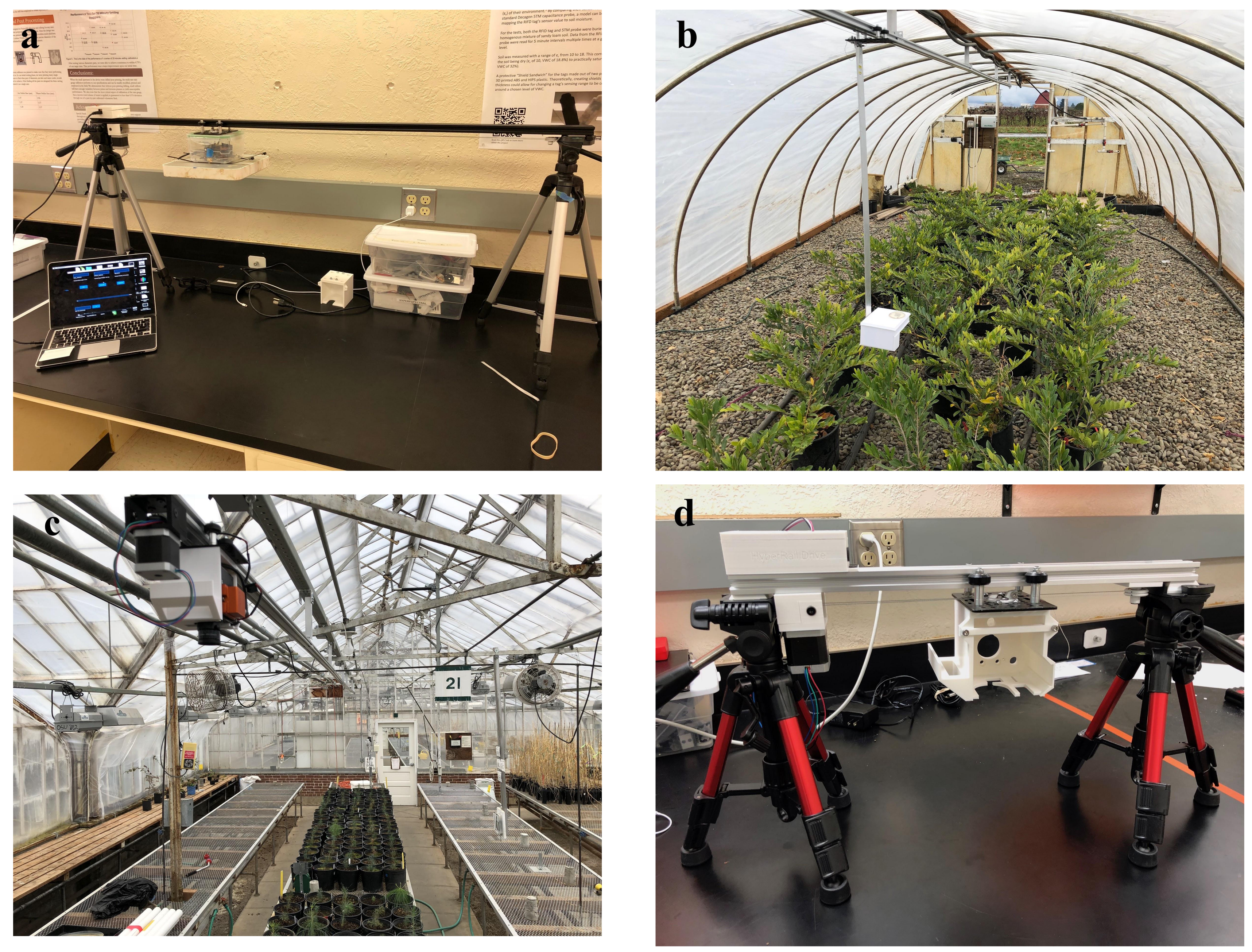


Figure 2. (a) An implementation of the HyperRail that demonstrates its use in soil moisture sensing. The white box attached to the HyperRail is the antenna that is used to receive data from the moisture sensors. (b)This implementation of the HyperRail is used for monitoring of humidity, temperature, luminosity, CO_2, and small particles in a 25.5m greenhouse. (c) This implementation is used for Hyperspectral imaging of over 100 pine seedlings over a nine meter span.(d) This implementation, was used for imaging of leaves.

Graphical User Interface

The system can be controlled using a custom software application or just a command line interface from Arduino IDE. The application is geared towards people who either do not have a background in programming or just want a plug-and-play solution. The interface permits the user to easily change the length and speed. It also allows for relative movement or going to a specific location along the length of the rail. The command line interface gives your more control of the HyperRail as it allows to quickly compile source code and see the immediate effects.

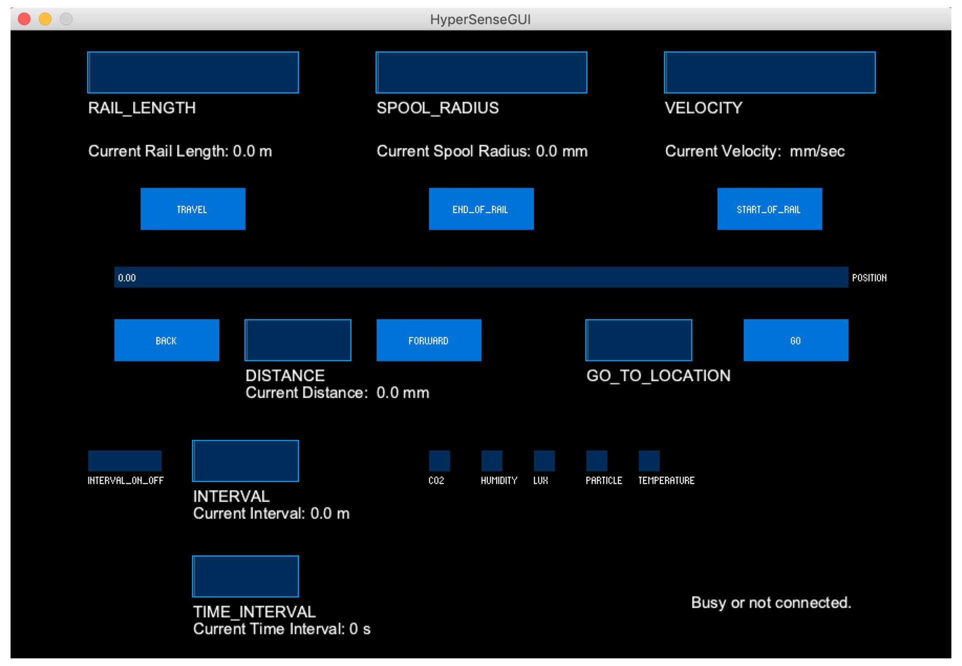
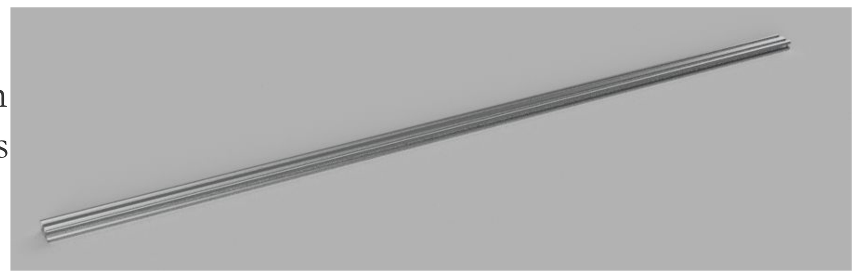


Figure 3 . Custom graphical user interface created for the HyperRail. This iteration of the interface allows for quick configuration of the sensors that will be used on the HyperRail.

Railing

The HyperRail uses 40x20 mm V-slot aluminum for the railing. This is a very light weight material that can be cut or linked together to make the rail as long or as short as needed. Their standard sizes are 1500, 1000, 500, and 250 mm in length.



Results: Linear Motion Performance

The accuracy of the displacement was first validated using a laser distance measure; it gave an accuracy of 2mm over a one meter span. We then validate the average-speed accuracy by measuring time, through software, from the beginning of motion to when it stopped. The following graphs display the data collected from the trials.

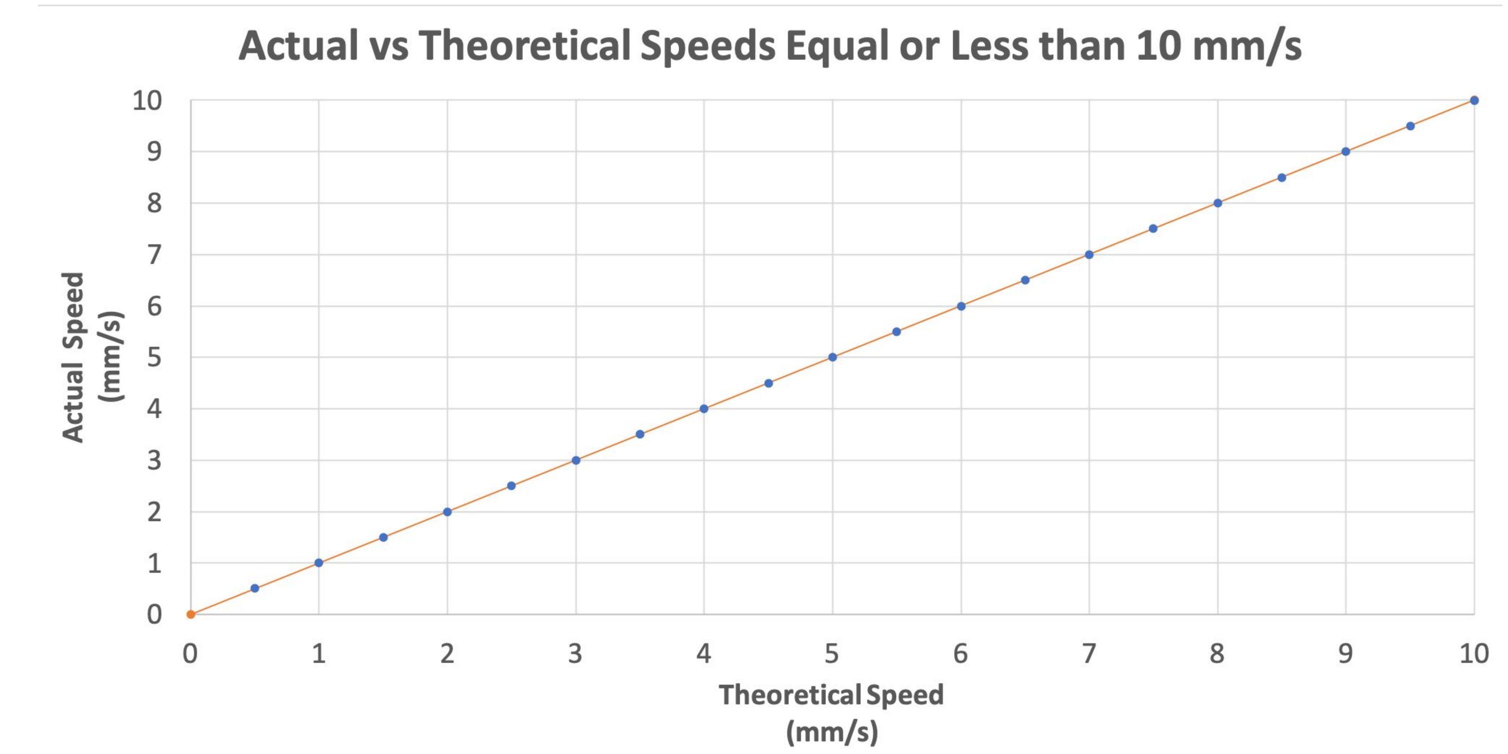


Figure 5. Data of the performance of the HyperRail for speeds less than or equal to 10 mm/s.

A second-order-linear compensation was used in order to be able to reach the target speed.It can be observed from the performance validation data that the HyperRail's speeds are accurate to within 0.1% from the target speed.

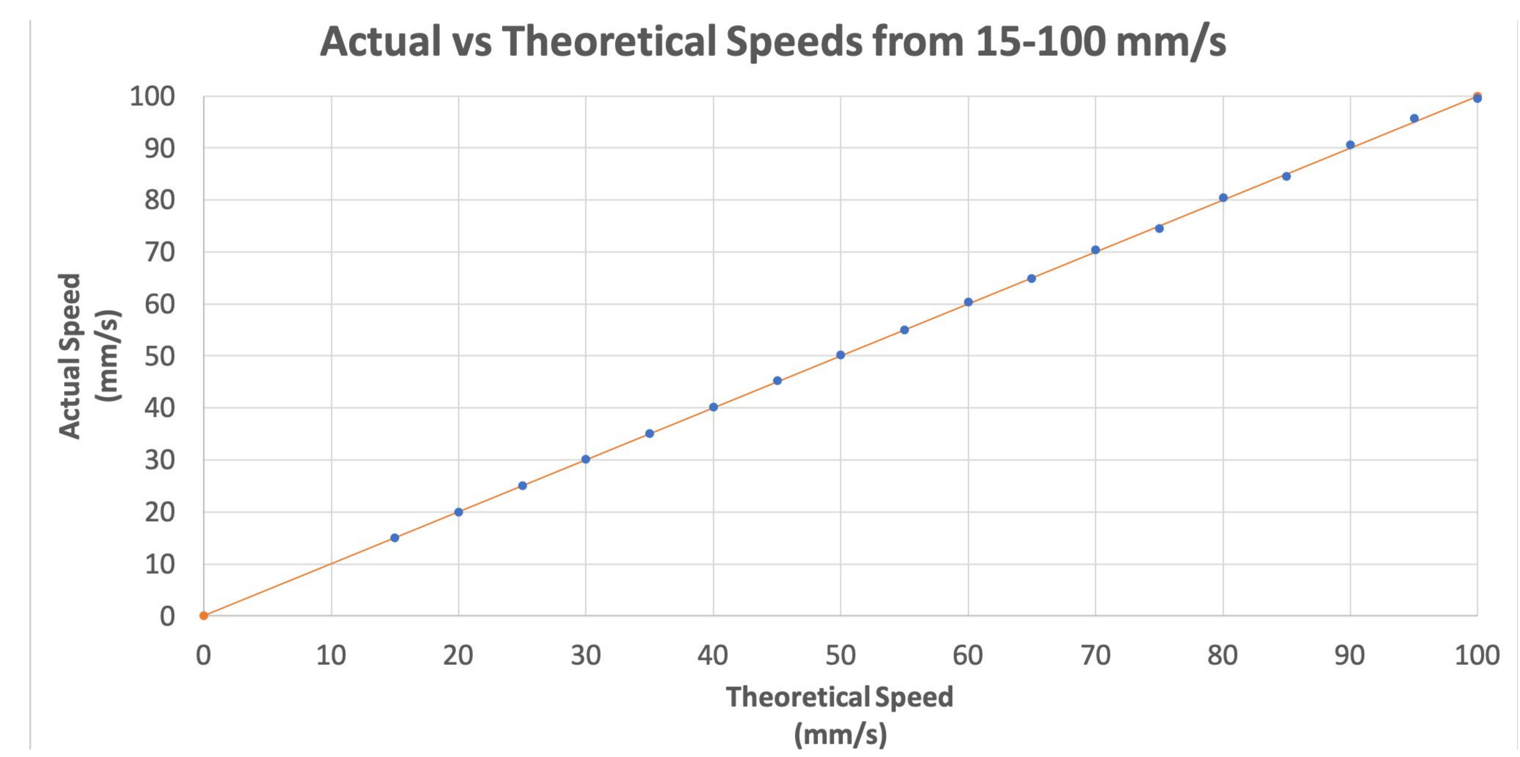


Figure 6. This is the data of the performance of the HyperRail for speeds 15-100 mm/s.

This section of the speeds also used a second-order-linear compensation to reach the target speed. It can be observed from the performance validation data that the HyperRail's speeds are accurate to within 0.75% from the target speed.

Conclusions

This system is versatile in its implementation and utility. It can be used for a variety of sensors such as C02, temperature, soil moisture, humidity, or practically any sensor. It can also be used to just move an object very slowly and at a precise speed. The system has an easy setup if used on tripods and a more involved setup if doing a building deployment. Using the custom user interface will allow for plug-and-play solution, but if additional functionality needs to be added, the command line interface will allow for easy debugging and implementation of the new code.

Acknowledgments

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