# Design of an Electric Bicycle Speed Controller

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MECHANICAL AND AEROSPACE ENGINEERING

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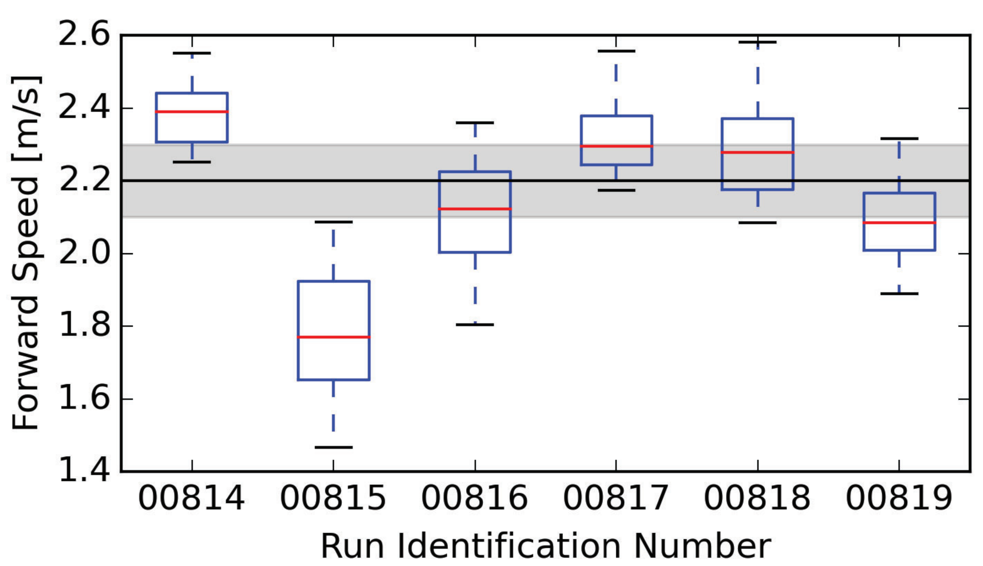
## Introduction

Speed control is not a prevalent feature found in electric bicycles. Many electric bicycles implement a pseudo speed controller that does not include feedback based on sensing speed. As with automobiles, speed control can be desirable for driver comfort and safety. Additionally, accurate speed control is also very helpful when validating dynamic models of single-track vehicles, which is our motivation. This poster describes a low cost feedback speed controller for an electric bicycle.

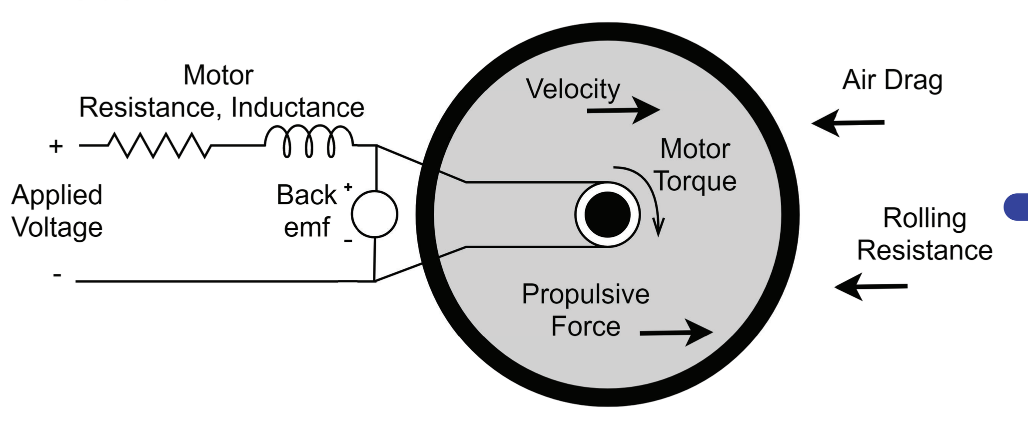
In prior work [1], attempts at maintaining 2.2 m/s with a factory electric bicycle pseudo speed controller resulted in scattered results too poor for model validation purposes. The purpose of this work is to design and implement a speed controller on an electric bicycle such that the inter-quartile range of speeds fall within a ±0.1 m/s of the desired setpoint speed.




Electric bicycle speed variation in prior work [1]. The average root mean square error of each run is 0.21 m/s and the average standard deviation about the mean is 0.12 m/s.

## Plant Model Derivation

A second order plant model is derived from a point mass model of a bicycle coupled with an electric powertrain modeled by a simple DC motor.




Point mass model and electrical schematic of an electric bicycle powertrain.

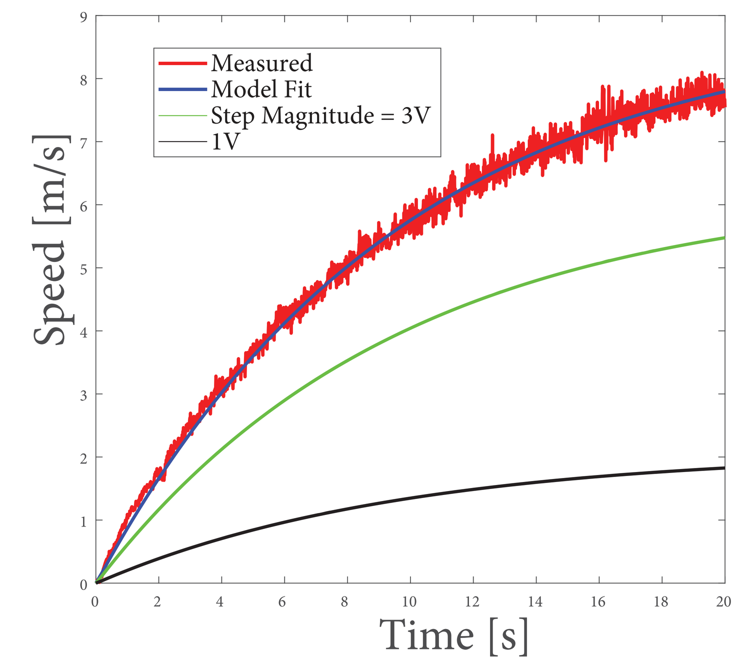
$$\frac{v(s)}{V(s)} = \frac{d}{as^2 + bs + c}$$

General form of the derived plant model

## Plant Model Identification & Controller Tuning

Unknown parameters in the derived plant model are identified using a grey box system identification procedure. Based on the plant, a PID controller is tuned and analyzed for robustness.

### Plant Model Identification




Identified plant model plotted against identification data

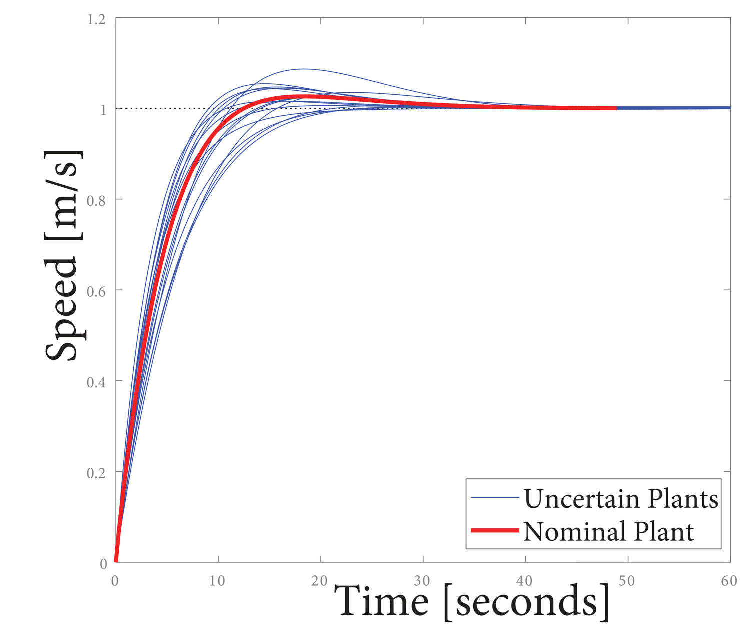
$$\frac{v(s)}{V(s)} = \frac{15.32}{s^2 + 70.81s + 7.34}$$

Identified plant model

### Controller Tuning & Analysis

$$K_p = 1.03 \quad K_i = 0.145 \quad K_i = 0.05$$

Tuned Controller Parameters

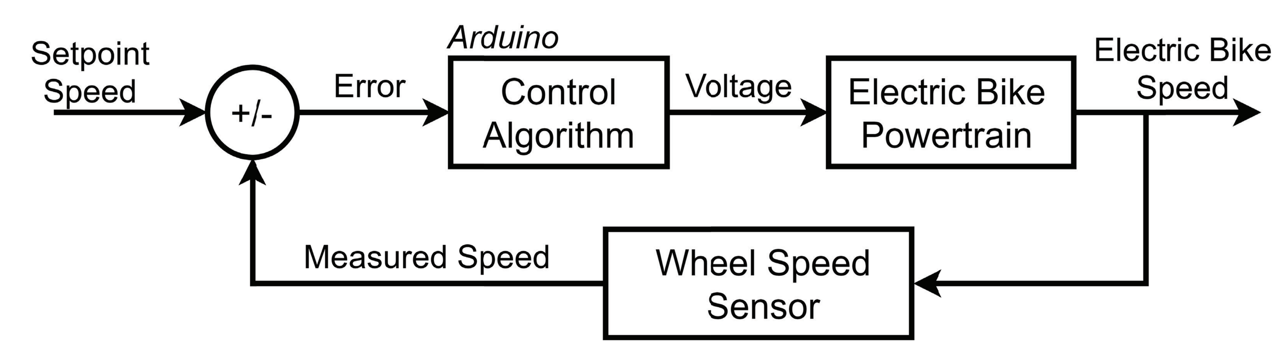



Plot of 15 uncertain plant model samples to gauge controller robustness

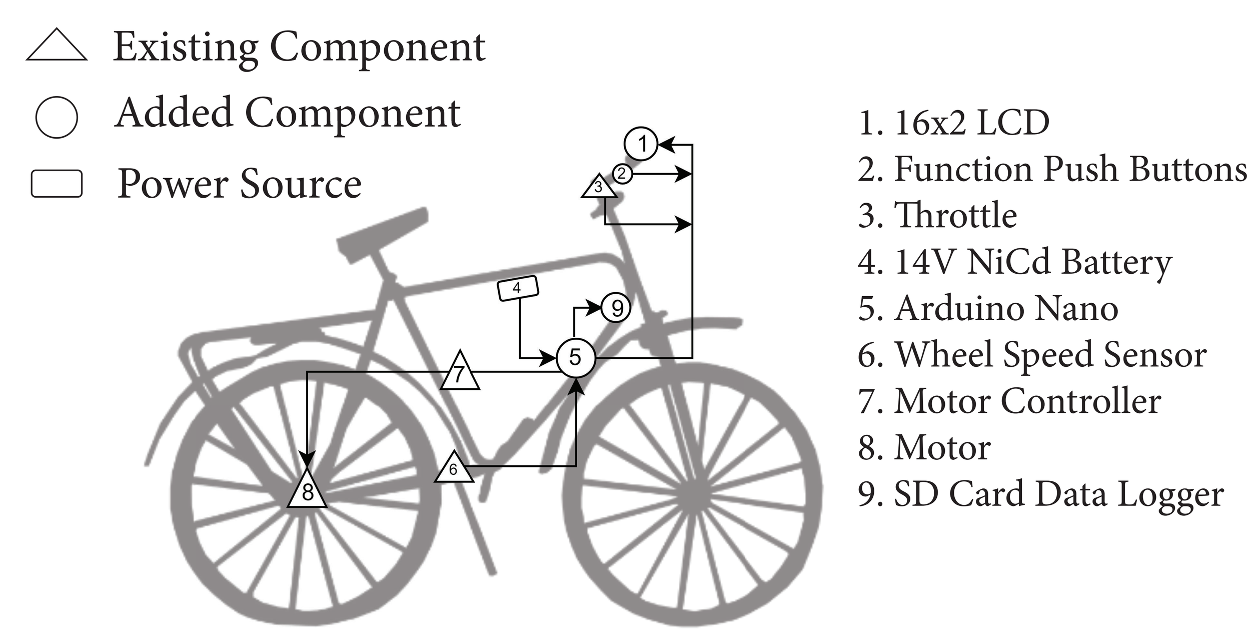
## Controller Implementation

The controller is implemented on an Arduino Nano microcontroller integrated into the powertrain of the electric bicycle.

Control architecture as implemented on the electric bicycle



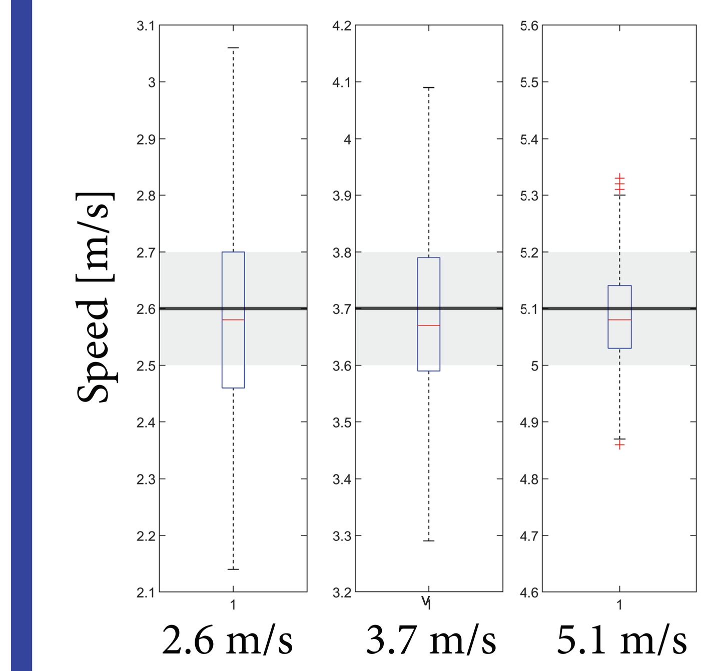

Physical layout of the cruise control implementation on the electric bicycle




## Controller Testing

### Straight-Line Test

This test involves using the cruise control while riding in a straight-line out and back along a reasonably flat bicycle path.

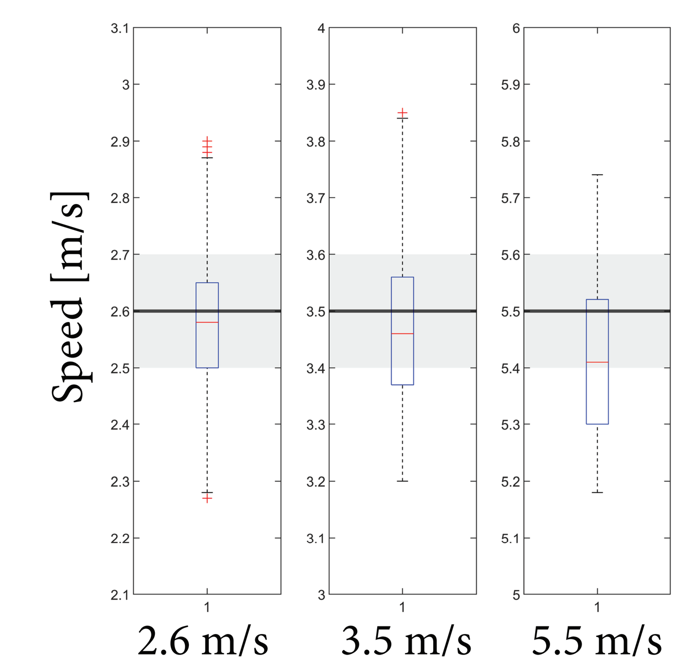



| Trial Number | Mean Error [m/s] | Precision Error [m/s] |
|---|---|---|
| 1 | -0.0111 | 0.1658 |
| 2 | -0.0041 | 0.1506 |
| 3 | -0.0041 | 0.1057 |

Boxplots of three trials of the straight line test with tabulated mean and precision errors

### Slalom Test

This test involves riding the bicycle on a reasonably flat path in a slalom maneuver through gates 0.76m wide spaced 7.3m apart.




| Trial Number | Mean Error [m/s] | Precision Error [m/s] |
|---|---|---|
| 1 | -0.0113 | 0.1473 |
| 2 | -0.0086 | 0.1532 |
| 3 | -0.0738 | 0.1456 |

Boxplots of three trials of the slalom test with tabulated mean and precision errors

## Conclusions

- A PID controller for the control of the speed of an electric bicycle was designed and implemented
- On average, the controller was able to maintain the interquartile range of steady state speeds within ±0.1m/s of a desired setpoint speed.

## Acknowledgments

We would like to acknowledge the help of Scott Kresie in the design of the slalom course. We would also like to acknowledge the help of Sejin Han with testing the speed controller.

## References

[1] S. W. Kresie, J. K. Moore, M. Hubbard, and R. A. Hess, "Experimental Validation of Bicycle Handling Prediction," in Proceedings of the 6th Annual International Cycling Safety Conference, Davis, CA, USA, 2017.