Design of an Electric Bicycle Speed Controller For Bike Handling Experimentation

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Abstract

Bicycles can potentially be designed to be safer by utilizing a theoretical handling quality metric (HQM). Past efforts to experimentally validate the HQM through measuring slalom and line tracking performance can be improved through maintaining the instrumented electric bike used in the experiments at a constant speed. Our hypothesis is that a PID controller, designed using a mathematical model of an electric bike derived from first principles and controller design software, can be used to maintain the speed of the electric bike within +/- 0.1 m/s of a desired speed. The derived model of the electric bike used in the design of the PID controller was validated using a grey box system identification method by matching the mathematical model to a measured time response of the electric bike. Initial computer simulations and benchtop tests indicate the PID controller implemented on the electric bike will satisfy our requirements for further bicycle handling experimentation.

Introduction

In prior work, [1], a theoretical model of a bicycle rider control system was developed based on previous pilot modeling efforts [2]. This model includes a Handling Quality Metric (HQM) that, based on physical parameters and speed of the bike, predicts the handling quality of the bicycle. Work has been done to experimentally validate this metric [3]. Kresie et. al. designed an experimental bicycle with a cantilevered 5.11 kg mass that can be adjusted for and aft of the handlebars to alter the predicted HQM of the bike. Test riders were instructed to ride the bike as slowly as they can over a marked line. A GoPro camera was used to measure the deviation of the rear wheel from the line. The results from this experiment were limited due to the lack of precise control over the bicycle's speed.

The purpose of this work is to improve the experiment by developing a speed controller for the instrumented electric bike such that it can maintain its speed within +/- 0.1 m/s of a desired target speed. Here I present the design and preliminary implementation of a PID speed controller for the instrumented electric bike.

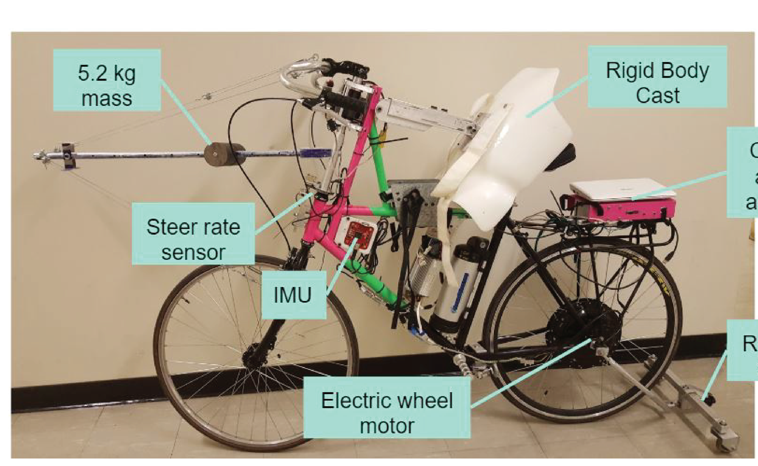

Figure 1: Instrumented bicycle used in the experiments [3].

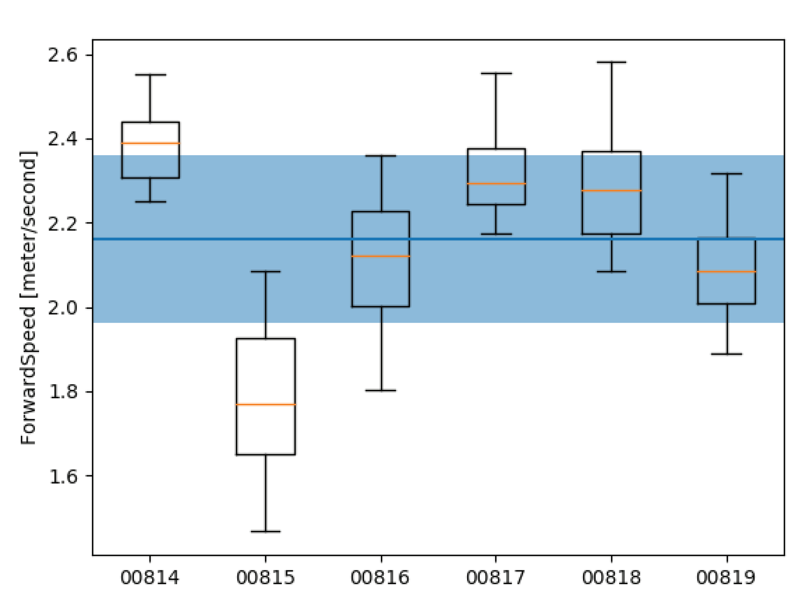

Figure 2: Speed variation during test runs.

Methods

Electric Bike Plant Model Derived From First Principles

2nd Order Transfer Function From Applied Motor Voltage (V) to Speed of the Bike (v) with generic constants a, b, c & d.

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

Grey Box System Identification in MATLAB

The constants, a, b, c, and d in the plant model were optimized to fit the model to a measured speed time response from the ebike, resulting in the following model.

$$\frac{v(s)}{V(s)} = \frac{8.31}{s^2 + 70.82s + 7.543}$$

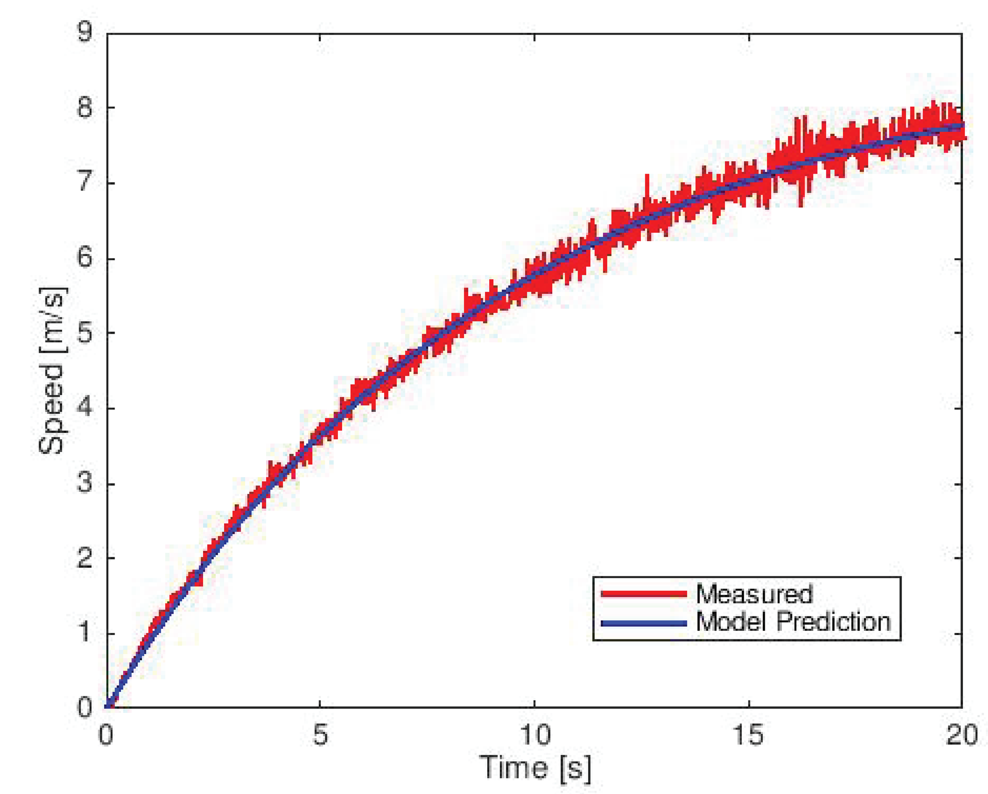

Figure 3: Model fit to measured data.

Controller Design in MATLAB

Results

Constant	Magnitude
Proportional	68.5
Integral	106
Derivative	1.44

Steady State Error	0
Overshoot Percentage	10.45%
Settling Time	1.56s

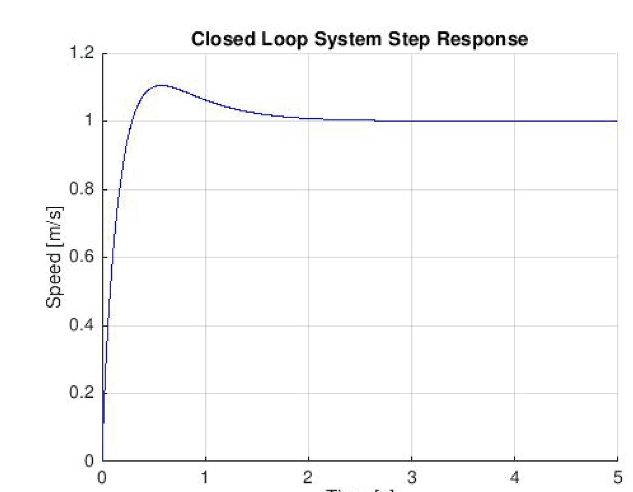

Figure 4: Closed loop system step response.

Controller Robustness Analysis in MATLAB

The robustness of the controller is analyzed by introducing uncertainty in the plant model constants. The resulting closed loop system is then simulated.

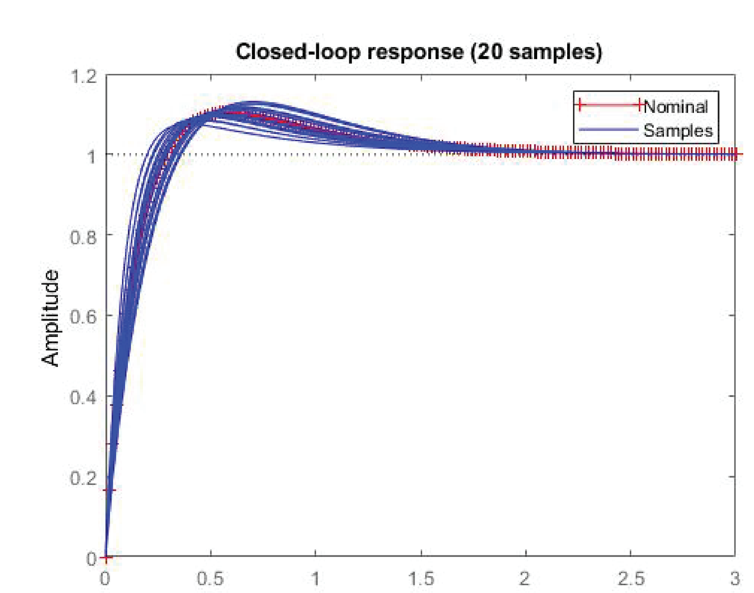

Figure 5: Closed loop step responses of 20 random uncertain plant models.

Initial Prototyping and Implementation

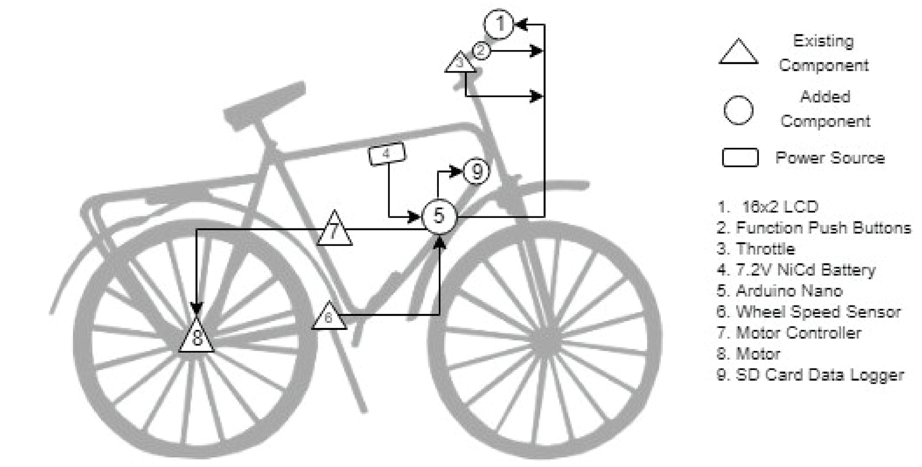

Figure 6: Implementation of the control architecture.

The tuned PID controller is implemented digitally on an Arduino Nano integrated into the electric bike's powertrain. When the cruise control is active, the Arduino modulates the throttle to maintain the bike at a constant speed.

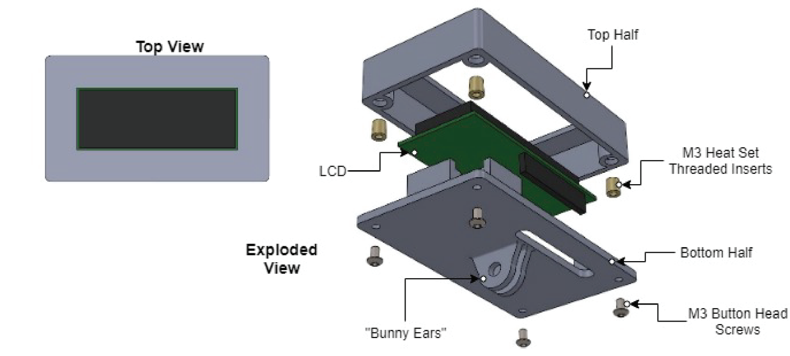

Figure 7: LCD display for user feedback.

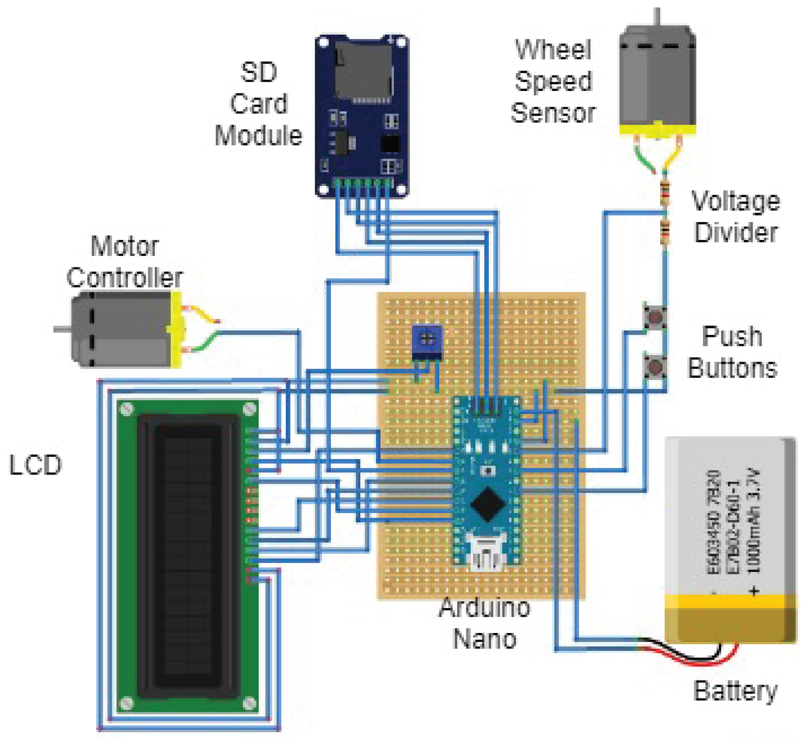

Figure 8: Implementation wiring diagram.

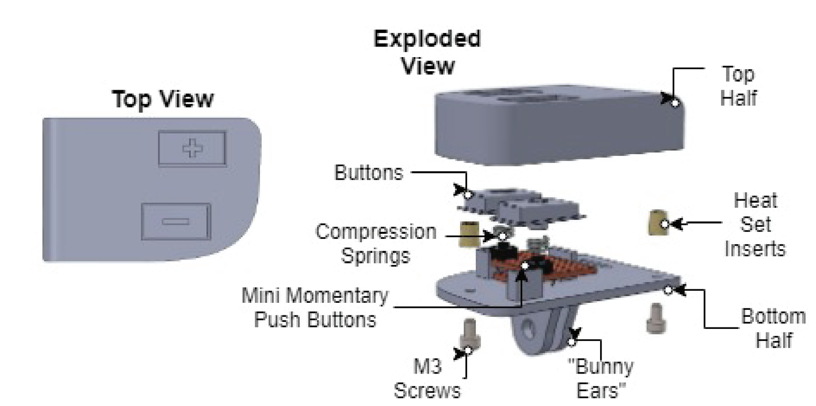

Figure 9: User interface buttons.

Conclusions

- A plant model of an electric bike was derived and validated experimentally.
- A robust PID controller was tuned to achieve the desired steady state outcome.
- Initial implementation shows the speed controller having a good probability of satisfying our requirements for further bicycle handling experiments.

Acknowledgments

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References

[1] R. Hess, J. K. Moore and M. Hubbard, "Modeling the Manually Controlled Bicycle," IEEE Transactions on Systems, Man, and Cybernetics, vol. 42, no. 3, pp. 545-557, 2012.

[2] Hess, Ronald A., Moore, Jason K., Hubbard, Mont. Modeling the manually controlled bicycle. IEEE Transactions on Systems, Man, Cybernetics - Part A: Systems and Humans. 42(3):545–557, May 2012.

[3] 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.