

Design of an Electric Bicycle Speed Controller

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Abstract

Bicycles can potentially be designed to be more safe by utilizing a theoretical handling quality metric (HQM) derived from previous aircraft pilot modeling work [1]. We are working to experimentally validate this metric, but previous experimental results [2] were limited due to the lack of precise control over the instrumented electric bicycle's speed during slalom and line tracking maneuvers. The purpose of this work is to improve the instrumented electric bicycle such that it can maintain its speed within +/- 0.1 m/s of a desired target speed. Here we present the design and preliminary implementation of a PID speed controller for an electric bicycle.

In order to design the controller, a plant model representing the longitudinal, rotational, and electrical dynamics of the bicycle was first derived from first principles. The electric bicycle powertrain consists of a standard conversion kit motor controller and a brushless, three-phase, direct drive induction motor mounted inside the rear hub of the bicycle. Figure 1a shows a simplified model of the motor circuit and rotational wheel dynamics representing the powertrain.

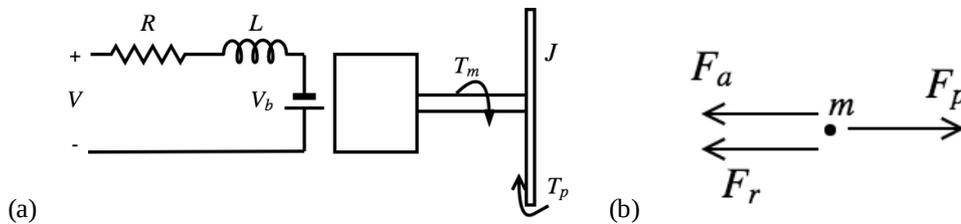


Figure 1: (a) Diagram of the electric bicycle powertrain circuits and rotational dynamics where T_m is the torque produced by the motor, T_p is the torque applied on the wheel by the ground, J is the rotational inertia of the wheel and R , L , V and V_b are the internal resistance, inductance, applied voltage and back emf of the simplified electric motor, respectively. (b) Simple particle model of a bicycle where m is the combined mass of the bike and rider and F_a , F_r and F_p are the aerodynamic drag, rolling resistance, and propulsive forces respectively.

Coupled with the governing equation for the powertrain was a simplified equation of motion for the bicycle defined by the free body diagram in Figure 1b [3]. Together, the powertrain and bicycle longitudinal dynamics were combined to form a simple, second order plant model that takes the form of a transfer function mapping input motor voltage V to output bicycle speed v .

$$\frac{v(s)}{V(s)} = \frac{d}{as^2+bs+c} \quad (1)$$

The plant model coefficients a , b , c , and d are constants that are functions of parameters such as the motor internal resistance and inductance, wheel radii, rolling resistance coefficient of the tires, and drag coefficient. We found it difficult to estimate some of the specific parameters in the plant model, such as motor inductance, so we used a grey box system identification method to identify the plant model based on actual speed data collected with a constant voltage input. A

nonlinear least-squares solver was used to find the optimal coefficients $a = 1.00$, $b = 70.82$, $c = 7.54$ and $d = 8.31$ in the transfer function to fit the measured open loop voltage and speed data (Figure 2a).

A basic tuned PID speed feedback control architecture was employed with the identified plant model. The PID controller ($k_p = 68.5$, $k_i = 106$, $k_d = 1.44$) was tuned using MATLAB's Control System Toolbox (Mathworks, Natick, USA) with closed loop goals of zero steady state error and underdamped transient behavior. The resulting closed loop system step response has zero steady state error, a settling time of 1.56 s and an overshoot percentage of 10.45%.

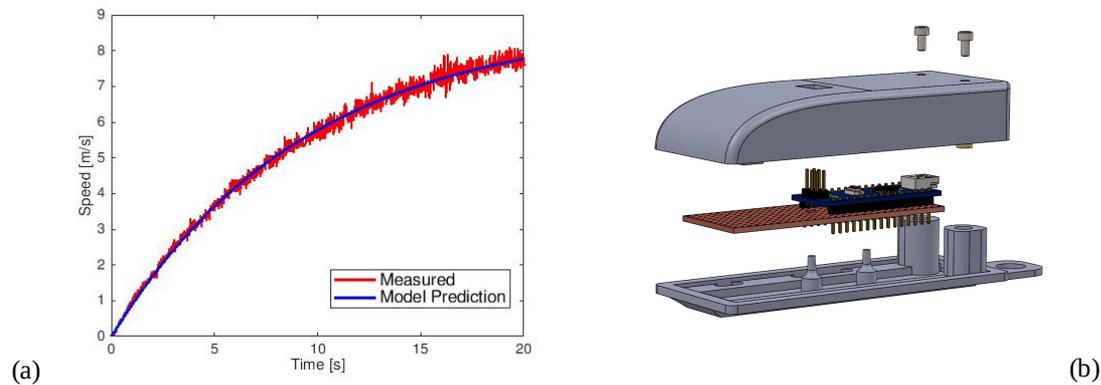


Figure 2: (a) System identification result showing the model predicted (blue) and measured speed (red). (b) CAD model of the 3D printed housing for the Arduino Nano microcontroller.

The controller is implemented on an Arduino Nano microcontroller (Arduino, Ivrea, Italy) with a handlebar mounted user interface for precisely selecting target speeds and enabling/disabling the speed control. Figure 3b shows the 3D printed microcontroller housing design. The conference paper will report on the performance, cost, safety, and reliability of the tested controller.

References

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