Understanding Bicycle Riding Dynamics

New York State Center for Engineering Design and Industrial Innovation

Introduction

The NYS Center for Engineering Design and Industrial Innovation (NSYCEDII) at the University at Buffalo intends to develop a bicycle riding simulator to complement its driving simulator. A bicycle and rider form a complex, multiple degree-of-freedom system, which must be fully understood to build a realistic simulator. A bicycle has been instrumented in the fall 2010 semester to measure speed, pedal rpm, handlebar position, 3-D acceleration, and 3-D bicycle and rider orientation while riding. Data will be collected for the purpose of developing a dynamic model for bicycle riding to be implemented in the simulator. This poster presents the current progress on this project, as of March 2011.

Materials and Methods

Hall-effect sensors were used to measure ground speed and pedal cadence. The sensors were mounted to the bicycle frame and magnets were placed on the crankset and a wheel spoke. Steering input angle was measured with a potentiometer that was mounted on the frame and gear-driven from the steerer tube of the bicycle.

Figure I. Instrumented Bicycle

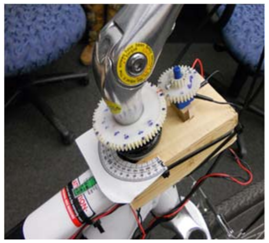

Figure II. Steering position sensor

Orientation of the rear frame was measured with an inclinometer. This allows measurement of bicycle lean and road grade. Acceleration of the bicycle is measured by a 3-axis accelerometer attached to the rear frame. The accelerometers and angle sensors were mounted in a plastic housing and attached to a rigid sheet metal bracket in-plane with the bicycle frame. A wearable sensor pack was created for the rider. This pack houses an additional inclinometer and a 3-axis accelerometer. The sensor pack is worn on the front of the rider's torso, near his center of mass and attached with an elastic strap. Data acquisition was performed with an Arduino Mega2560, an electronic prototyping platform that utilizes a 10-bit ADC [1]. The Arduino was mounted in a small bag under the seat.

A test was performed in UB's Alumni Arena in early Feb. 2011, but DAQ issues rendered the data unusable. Further testing was performed outdoors on late Feb. 2011, outside of UB's Furnas Hall. Several riding maneuvers were performed, including weaving and tight radius turning, in addition to typical riding on the roadway.

Data analysis began with the process of defining the physical parameters of the bicycle to satisfy the Whipple model of the bicycle. This model is presented in the form of linearized equations in the work of Meijaard et. al. The lean and steer equations are as follows [1]:

$$\boldsymbol{M}\ddot{\boldsymbol{q}} + v\boldsymbol{C_1}\dot{\boldsymbol{q}} + [g\boldsymbol{K_o} + v^2\boldsymbol{K_2}]\boldsymbol{q} = \boldsymbol{f}$$

$$\text{Where } \boldsymbol{q} = \begin{bmatrix}\varphi \\ \delta\end{bmatrix} \text{ and } \boldsymbol{f} = \begin{bmatrix}T_\varphi \\ T_\delta\end{bmatrix}$$

$\boldsymbol{M}, \boldsymbol{C_1}, \boldsymbol{K_o}, \boldsymbol{K_2}$ are matrix of constants obtained from the physical parameters of the bike.

The variables phi and delta correspond to the lean and steer angle of the bicycle, respectively, and have been obtained from our instrumentation. The constant matrices were populated based on measured geometry and mass of 4 idealized bicycle components. These include the rear frame, front fork/handlebar, front wheel and rear wheel.

The dynamic model was used to simulate the steer torque and lean torque (rider moment) acting on the bicycle. The first and second derivatives of the lean and steer data were obtained using a numerical differentiation technique for noisy signals. A quintic smoothing spline was applied to each data set and a 2nd order approximation of the derivative was used.

Results

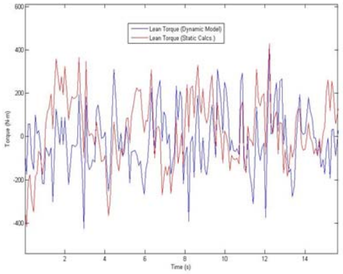

Figure III. Lean torque comparison

In figure (1), a 16 second series of weaving maneuvers was analyzed. At each lean angle data point, the lean torque was simulated using the dynamic model and calculated from a simple static analysis, as performed by He et. al. [2]. Steer angle was simulated in a similar manner. The stability of the system was analyzed as well, and is shown in figure (3). These results show the speeds at which the bicycle system is stable, based on the roots of the characteristic equation.

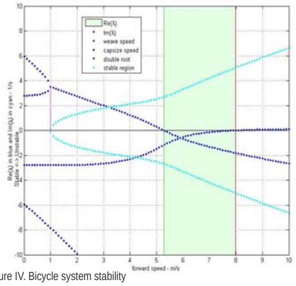

Figure IV. Bicycle system stability

Discussion

The lean angle simulation behaved as expected. At low speeds, it matched the static calculations with slight variations that corresponded to changes of the lean angle. The steer angle simulation yielded values ranging from about -10 to 10 N-m, across the range of simulation. Analysis of the entire data set from this test revealed limitations of our instrumentation. At speeds higher than approximately 5 m/s, the amount of noise present in the output signals of the accelerometers and inclinometers became problematic.

Future Work

- •Perform outdoor tests consisting of constant radius turns and weaving, with a varied group of riders
- •Refine dynamic model based on experimental results
- •Design physical platform and control of a realistic bicycle simulator, based on this work

References

[1] Andy Ruina, A. L. Schwab, 2007 "Linearized dynamics equations for the balance and steer of a bicycle: a benchmark and review," Proceedings of the Royal Society A 463:1955-1982.

[2] He, Q., Fan, X. and Ma, D.: Full Bicycle Dynamic Model for Interactive Bicycle Simulator. Journal of Computing and Information Science in Engineering Vol. 5 Issue 4, (2005) 373-380

[3] Implementation of the Interactive Bicycle Simulator with Its Functional Subsystems. Song Yin and Yuehong Yin, J. Comput. Inf. Sci. Eng. 7, 160 (2007), DOI:10.1115/1.2720885

Acknowledgements

•New York State Center for Engineering Design and Industrial Innovation (NYSCEDII)

•UB Department of Mechanical and Aerospace Engineering