Bicycle and Motorcycle Dynamics 2010
Symposium on the Dynamics and Control of Single Track Vehicles,
20–22 October 2010, Delft, The Netherlands

Modeling Manually Controlled Bicycle Maneuvers

Ronald Hess, Jason K. Moore, Mont Hubbard and Dale L. Peterson
Mechanical and Aerospace Engineering
University of California, Davis
One Shields Avenue, Davis, CA 95616, USA
e-mail: rahess@ucdavis.edu, jkmoor@ucdavis.edu, mhubbard@ucdavis.edu,
dlpeterson@ucdavis.edu

Abstract

An ability to predict the handling qualities of bicycles with different physical characteristics remains an important research issue in the study of manual control of single-track vehicles. Numerous factors affect bicycle handling qualities as perceived by the rider, e.g. the dynamics of the bicycle itself, the dynamics of the rider, the control characteristics of the rider, and the manner in which the rider quantifies his/her opinion of the bicycle's handling qualities. The work to be described follows in the footsteps of [6] and [7], and utilizes a human operator model discussed in [2] as applied to piloted aircraft control.

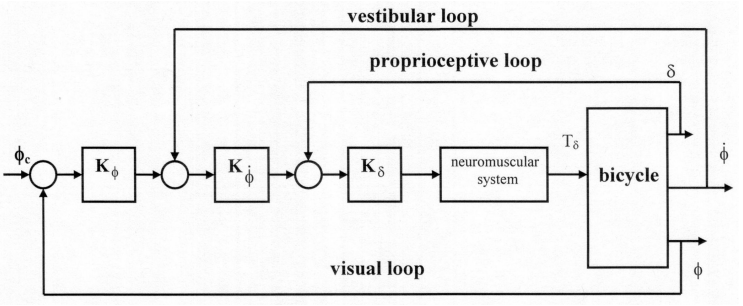
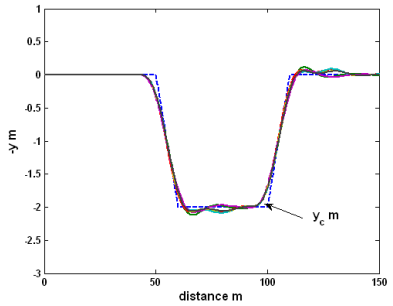
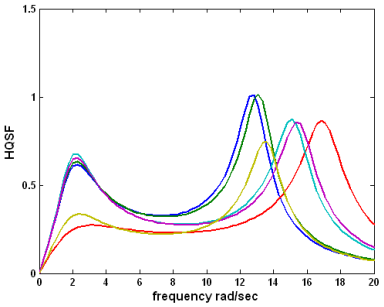


Figure 1: Block Diagram of Rider/Bicycle System

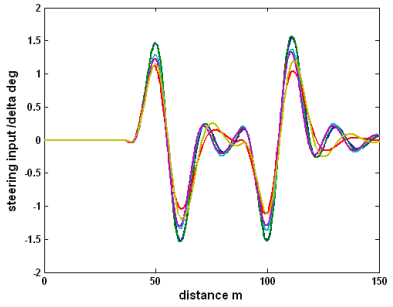
Figure 1 is a block diagram representation of the rider model for roll control of a bicycle, with appropriate sensory modalities noted. As presented in Fig. 1, only three gains and a simple neuromuscular system model parameterize the rider. By way of exposition in this brief abstract, six bicycle models were chosen, five from existing bicycles as parameterized by the second author in [5], and the sixth being the "benchmark" bicycle from [4]. All models are linear and valid for a forward velocity of 5 m/sec. A simple two meter lane change and lane return maneuver was selected as a simple task. Figure 2a shows the maneuver paths of the six rider/bicycles, where the bicycle coordinate shown is associated with the rear wheel contact point. The complete rider model includes two additional outer-loop closures not shown in Fig. 1 (heading and lateral deviation). In addition, a simple model of rider preview is included [1]. Figure 2c shows the rider steering inputs for the task. Figure 2b shows the "Handling Qualities Sensitivity Functions" (HQSFs) for each vehicle. The magnitude of each of these functions has been shown to correlate well with handling qualities ratings for aircraft flight control [2]. As an example here, the two functions with the lowest magnitudes in the frequency range of importance for manual control ($0 < \omega < 10$ rad/sec) are associated with the two bicycle models that are either stable or marginally unstable (one root just into the right-half plane). Finally, Fig. 2d shows Bode diagrams for the rider/bicycle open-loop transfer function for each application, showing that the rider model follows the dictates of the well-known "crossover model" of the human operator [3], appropriate for the dynamics of the bicycles in question. The final paper will include nine bicycle models and maneuvers and a thorough discussion of applying the HQSF to the prediction of bicycle handling qualities.



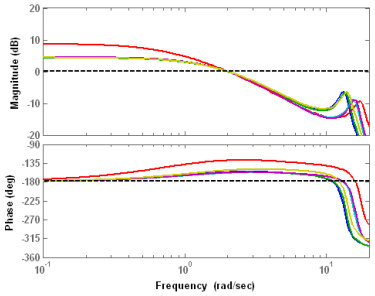
(a) Lane Change Performance



(b) Handling Qualities Sensitivity Functions



(c) Rider Steering Inputs



(d) Bode Diagrams of Rider/Bicycle Open-Loop Transfer Functions

Figure 2: Linear simulation results and comparative metrics for six bicycles.

References

[1] HESS, R. A. *Principles of Aviation Psychology: Human Factors in Transportation*. CRC Press, New York, 2003, ch. 8: Pilot Control, pp. 265–310.

[2] HESS, R. A. Simplified Approach for Modelling Pilot Pursuit Control Behaviour in Multi-Loop Flight Control Tasks. In *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering* (2006), vol. 220, pp. 85–102.

[3] MCRUER, D. T., AND KRENDEL, E. S. Mathematical models of human pilot behavior. Technical Report STI-P-146, Systems Technology, Inc., Hawthorne, CA, USA, 1974. AGARD AG 188.

[4] MEIJAARD, J. P., PAPADOPOULOS, J. M., RUINA, A., AND SCHWAB, A. L. Linearized dynamics equations for the balance and steer of a bicycle: A benchmark and review. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 463*, 2084 (August 2007), 1955–1982.

[5] MOORE, J. K., HUBBARD, M., PETERSON, D. L., SCHWAB, A. L., AND KOOIJMAN, J. D. G. An accurate method of measuring and comparing a bicycle's physical parameters. In *Bicycle and Motorcycle Dynamics: Symposium on the Dynamics and Control of Single Track Vehicles* (Delft, Netherlands, October 2010). Awaiting acception for the same conference.

[6] VAN LUNTEREN, A., AND STASSEN, H. G. Investigations on the bicycle simulator. Chapter III of Annual Report 1969 of the Man-Machine Systems Group WTHD21, Delft University of Technology, Laboratory for Measurement and Control, 1970.

[7] WEIR, D. H. *Motorcycle Handling Dynamics and Rider Control and the Effect of Design Configuration on Response and Performance*. PhD Dissertation, University of California Los Angeles, Los Angeles, CA, 1972.