Effect of electrification of bicycles on dynamic riding behavior

Johannes Bolk, Burkhard Corves

Institute of Mechanism Theory, Machine Dynamics and Robotics,
RWTH Aachen University, Eilfschornsteinstrasse 18, 52062 Aachen, Germany,
Bolk@igmr.rwth-aachen.de
Corves@igmr.rwth-aachen.de

Abstract
Bicycles with electric drive assistance lead to a change in the driving characteristics compared to conventional bicycles due to the additionally attached masses of motor and battery. In order to describe the resulting interaction of the electric drive components on the driving dynamics, this paper examines simulations of the driving behavior of bicycles with different positions of battery and motor in open- and closed-loop tests. The results are analyzed using characteristic values that describe the system behavior in a suitable way. The extension of the multi-body simulation with control loops for the representation of the human driving behavior, shown in Figure 1, enables the analysis of the driving characteristics and steering effort under more realistic driving situations.

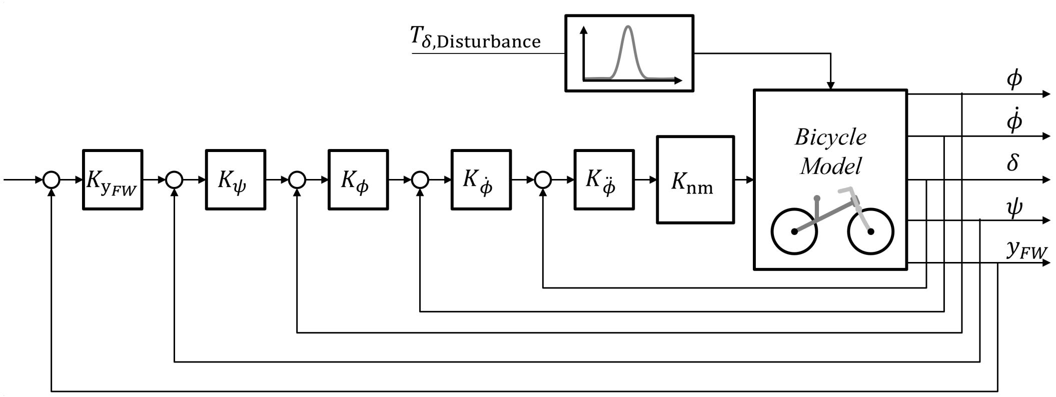

Figure 1: Closed-loop multibody simulation setup [5, 6].

Worldwide sales figures for bicycles show that the popularity of e-bikes has been increasing for years and will likely continue to do so in the future [1]. In the mountain sports sector in particular, both beginners and professionals are increasingly using the motorized alternative to the classic mountain bike. Here, arguments such as the facilitation of uphill rides or the enabling of longer riding distances clearly speak for the choice of an e-bike. Currently a large number of variants can be found on the market, in which the additional masses of motor and battery are arranged differently. The main reasons for this diversity include factors such as design, ergonomics or cost. However, the influence of the additional weight on the driving characteristics is hardly evaluated during the development, although the answer to this question plays a crucial part regarding e.g. the use of bicycles in sports or the mobilization of physically limited persons. In this paper, the effects of different arrangements of the additional masses on the driving behavior are presented, taking into account open-loop and closed-loop tests. For this purpose, the designs for the most common positions of motor and battery are investigated and compared with respect to their driving dynamic properties for different speed ranges. The focus here is in particular on the evaluation of the driving stability with the aid of various characteristic values. To simulate the driving maneuvers, a numerical multibody system using the Carvallo-Whipple bicycle model is employed [2, 3, 4]. The center of gravity, mass and inertia properties of the driver are combined with those of the bicycle frame into a single rigid body as described in [5]. The motor and battery are added similarly to the existing model elements of the Carvallo-Whipple bicycle model. In the driving maneuvers, disturbances are imposed on the system in the form of a steering torque impulse for a range of different driving speeds and bicycle setups in order to subsequently analyze the system behavior [5]. Besides the passive driver represented by open-loop tests, the system behavior with an active driver is additionally investigated in closed-loop simulations. In this way, it can be shown whether and how fast the bikes can be stabilized by control operations. The control system used in the simulation corresponds to the control system developed by Moore. It replicates human behavior through technical control loops using the cross-over approach [6, 7]. In addition to the already established consideration of eigenvalues and the resulting inherently stable speed ranges [8], further characteristic values are added to evaluate the driving stability in open-loop tests. The driving dynamics evaluation of the closed-loop tests is carried out by considering various system variables such as the course of the angular rolling acceleration or the steering effort applied. From this, characteristic values are derived with which the controlled system behavior can be described and interpreted in a simple and unambiguous manner. Based on the results, conclusions can be drawn about the influence of individual components on the overall vehicle dynamics. This enables the development of e-bike designs with handling characteristics similar to conventional bicycles or on the other hand with improved handling characteristics for certain speed ranges.

References

[1] Inkwood Research: Projections for the global electric bike market between 2018 and 2028. Avalible at: https://inkwoodresearch.com/reports/e-bike-market/ [Accessed 26th Jan 2022], 2021.

[2] Whipple, F: The stability of the motion of a bicycle. In: Quart. J. Pure Appl. Math, Vol. 30, pp. 312–348, 1899.

[3] Meijaard, J.P.; Papadopoulous, J.M.; Ruina, A.; Schwab, A.L.:Linearized dynamics equations for the balance and steer of a bicycle: a benchmark and review. In: Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science. pp. 1995–1982, 2007.

[4] Kooijman, J.D.G.; Schwab, A.L.; Meijaard, J.P.: Experimental validation of a model of an uncontrolled bicycle. In: Multibody System Dynamics, Vol. 19, pp. 115–132, 2008.

[5] Ingenlath, P.; Archut J.; van der Beek J.; Corves, B: Simulation eines vollgefederten Mountainbikes unter Berücksichtigung des Fahrerverhaltens. In: Tagung Mechatronik 2017, Dresden, 2017.

[6] Moore, J.K.: Human Control of a Bicycle. UC Davis Doctoral Dissertation, 2012.

[7] Hess, R. A.; Moore, J. K.; Hubbard, M:Modeling the Manually Controlled Bicycle. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, Vol. 42 No. 3, pp. 545–557, 2012.

[8] Dieltiens, S.; Debrouwere, F.; Juwet, M.; Demeester, E.:Practical Application of the Whipple and Carvallo Stability Model on Modern Bicycles with Pedal Assistance. In: applied sciences, Vol. 10, No. 16, pp. 5672, 2020.