EasyChair Preprint

№ 13402

Bicycle Frame Load Estimation Using a Controlled Semi-Analytical Simulation of an Unconstrained Multi-Body System

Johannes Bolk, Oliver Stockemer and Burkhard Corves

May 21, 2024

The 7th International Conference on Multibody System Dynamics
June 9-13, 2024, Madison, WI, USA

Bicycle Frame Load Estimation using a Controlled Semi-Analytical Simulation of an Unconstrained Multi-Body System

Johannes Bolk, Oliver Stockemer, Burkhard Corves

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

Abstract

In the design of bicycles, the operating loads acting on the various bicycle components are of particular interest. Simple test bench tests, such as those established in the bicycle industry today, are not sufficient to accurately describe the complex operating loads [4]. Therefore, in other industries multi-body simulations (MBS) are used to realistically model the loads acting on the components. In this way, a proper representation of the complex stress conditions in a component can prevent the failure of the component and enable an efficient design.

However, choosing a classic fully analytical simulation approach for bicycle development presents two significant drawbacks when compared to other industries, such as the automotive industry. To utilize this approach, all environmental influences must be modeled in addition to the actual model. However, modeling the test track presents significant complexity and variability, particularly in the mountain bike sector, requiring the creation of dozens of track profiles to model all areas of use of a mountain bike. The rider, on the other hand, has a significantly greater influence on the system compared to the driver of a car. Consequently, creating realistic rider models is crucial in fully analytical simulation approaches to precisely represent the loads acting on the bike [2].

A semi-analytical approach (SAA) is therefore chosen in this work, where only the bicycle model to be tested is modeled. Environmental models are replaced by stimulating the model with measurement data at its interfaces to the environment [3, 6]. As a result, the modeling effort is significantly reduced, as it eliminates the need to create complex rider models, as well as model the track and tire models. The utilization of the SAA proves particularly advantageous and convenient in the simulation of bicycle loads, given that the system's internal inertial forces are negligible when compared to the impact of external forces [1].

However, the use of an SAA results in the simulation of an unconstrained system, as all constraints found in a fully analytical simulation are replaced with excitation forces. Due to this model there are imbalances in the applied forces throughout the system, resulting in a total force that causes the model to drift. This is due to measurement inaccuracies and noise, the sampling rate of the system, geometric inaccuracies in modeling, and numerical errors in integrating the equations of motion [5].

To avoid model drift, artificial constraints can be used as shown in [1, 5]. However, another promising approach evaluated in this paper is a control structure that balances resulting forces, thereby avoiding excessive forces at points where artificial constraints are used and enabling a realistic force and stress curve. A simple control loop with a PD or PI controller is used. Systems with PD controllers can be found in the literature [3, 6]. These systems have the advantage of being able to follow the trajectory of the reference measurement to account for some inertial forces that may occur. However, according to paper [1], inertial forces can be neglected due to the high ratio of driver and bicycle weight in the case of a bicycle simulation. The PI controller offers the advantage of being especially suitable for reducing unwanted velocity-dependent forces.

Furthermore, the use of control forces instead of artificial constraints favors the implementation of elastic body properties used in an elastic MBS (eMBS). To distribute the required control force over the system an algorithm is presented that distributes the forces and torques required to compensate for the model drift in the form of single forces acting at designated points on the bicycle structure. It is ensured that no additional motions are introduced into the system by the divided force components. The level of force distribution also varies, ranging from three control points to nine.

A basic test ride in the form of a fully analytical simulation is performed while also measuring acting forces, which are then used as input variables for a semi-analytical simulation (see Fig. 1). To verify the results, the force curves at different points on the bicycle frame are compared between the fully analytical simulation and the semi-analytical simulation with the objective of achieving a high level of conformity

between the force curves.

This paper demonstrates that the control of the system concerning an eMBS yields better results. The distribution of the control forces over several frame points results in a better reproduction of the acting forces within the system compared to a control at only one control point. Furthermore, it is significantly better in performing an eMBS. A comparison of control systems shows that the PI controller system outperforms the PD controller.

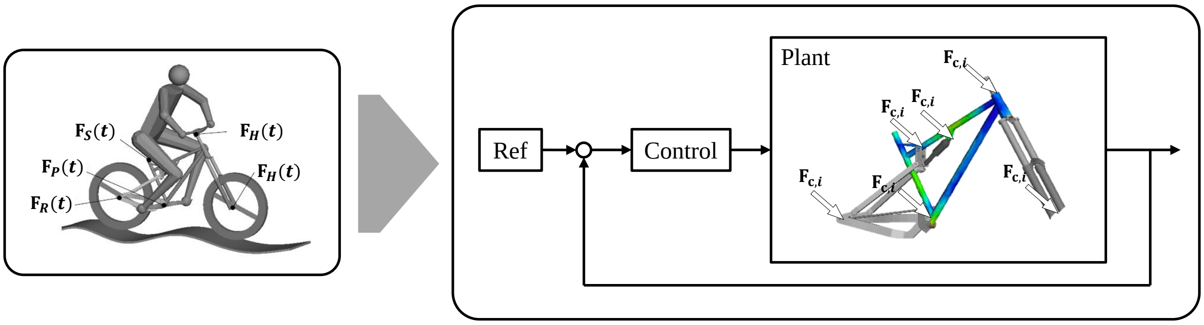

Figure 1: Fully analytical Simulation with measurements of the forces at the interfaces to the environment (left). Exemplary SAA simulation with six control forces equally distributed on the system (right).

References

[1] Bolk, J. & Corves, B. (2023). Bicycle frame load estimation using semi-analytical multi-bodysimulation methods. In: The Evolving Scholar - BMD 2023, 5th Edition. https://doi.org/10.59490/64f9af50bbdaed7fd1703229

[2] Bruni, S.; Meijaard, J. P.; Rill, G.; Schwab, A. L.: State-of-the-art and challenges of railway and road vehicle dynamics with mutli-body dynamics approaches. In: mutli-body System Dynamics, 49, 1-32, 2020. https://doi.org/10.1007/s11044-020-09735-z

[3] Joubert, N.; Boisvert, M.; Blanchette, C.; St-Amant, Y.; Desrochers, A.; Rancourt, D.: Frame loads accuracy assessment of semianalytical mutli-body dynamic simulation methods of a recreational vehicle. In: mutli-body system dynamics, 50, 189–209, 2020. https://doi.org/10.1007/s11044-020-09756-8

[4] Köhler, M., Jenne, S., Pötter, K., and Zenner, H.: Zählverfahren und Lastannahme in der Betriebsfestigkeit In: Springer, Berlin and Heidelberg, 2012. https://doi.org/10.1007/978-3-642-13164-6

[5] Mack, W.; Edelmann, J.; Falkner, A.: Drift-Effekte in der nabenkrafterregten Kraftfahrzeugsimulation In: Elektrotechnik und Informationstechnik, 132 (2015) 8, S. 462–468. https://doi.org/10.1007/s00502-015-0370-x

[6] Tebbe, J. C.; Chidambaram, V.; Kline, J. T.; Scime, S.; Shah, M. P.: Chassis loads prediction using measurements as input to an unconstrained multi-body dynamics model. In: SAE 2006 World Congress and Exhibition. Detroit: SAE International, 2006. https://doi.org/10.4271/2006-01-0992