Chances and challenges in using bike simulators as a tool for studying cycling behavior

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INTRODUCTION

Bicycle simulators are used as a tool to investigate cyclists' behavior since they allow the precise reproduction of specific conditions in a controlled environment as well as the collection of data for further research. However, to obtain reliable data, a simulator must provide a realistic cycling sensation to the riders. For this purpose, an appropriate technical design of the simulator, fitting to the intended purpose has to be chosen. Furthermore, the hardware control and software components have to be parametrized in order to reach the required degree of realism for allowing the rider to show a realistic riding behavior. To find the right parameter set is often an iterative process. The final set-up has to be validated with real world data which is often difficult to obtain.

In recent years, there is a rising interest in bicycle-simulator-based research. A basic prerequisite is the evaluation of the accuracy and realism of these systems. E.g. Dialynas et al (2019) and Shoman and Imime (2020) explored objective criteria for accurate and realistic models of the physics and dynamics of cycling and report on their development of bicycle simulator hardware and software. Subjective criteria such as simulator sickness (Matviienko et al., 2022; Mittelstädt et al., 2018), the sense of presence (Grassini et al., 2021; Gyoung & Biocca, 2018) or acceptance (Martinez Garcia, 2021) serve as metrics for the usefulness of a certain simulator set-up and/or study design.

METHOD

The bicycle simulator at the DLR – Institute of Transportation Systems (Fischer et al., 2022) has been built and improved in an iterative process (Martinez Garcia, 2021, 2022, 2023). The hardware set-up is shown in Figure 1.

Figure 1. Bicycle simulator at the MoSAIC-VRU-Lab

The latest improvements are

- the introduction of a whipple-model for the calculation and presentation of more realistic bicycle physics, especially regarding lateral force feedback.
- the introduction of a position control of the motion pitch in order to allow for a realistic leaning behavior of the test subjects
- the usage of an incremental encoder for acceleration and disc brake measurement and control in order to reduce latencies
- a dynamic and velocity-dependent headwind control

An evaluation study took place in order to assess the latest set-up (Martinez, 2023), to portray a realistic experience, reduce simulator sickness and increase acceptance. To evaluate the human perception of the simulator, several criteria were analysed. Simulation sickness was measured by the Simulator Sickness Questionnaire SSQ (Kennedy et al., 1993) and the misery scale MISC (Bos et al., 2005; Reuten et al., 2021), acceptance was evaluated with the Acceptance Scale (Van Der Laan et al., 1997) and presence was measured by the Presence Questionnaire PQ vs. 3.0 (Witmer & Michael, 1998). To evaluate realism, a series of self-developed questions and statements were presented after

each trial. The main objective criteria used for the objective evaluation of the test subjects driving behaviour are the leaning angle of the bicycle, the steering angle and the driving velocity.

Currently, a validation study is in preparation which shall deliver insights in real world cycling behavior for typical cycling maneuvers and deviations of observable riding behavior in reality and with the bicycle simulator.

RESULTS

Evaluation criteria, both objective and subjective, showed that the longitudinal cycling behaviour is already in a good condition and was widely accepted. Whereas the situation regarding lateral accelerations and steering controllability is more ambiguous. Subjective ratings did not show a clear preference of the current set-up and overall realism regarding lateral aspects were rated quite low. However, objective metrics such as leaning angle and steering angle distributions seem to be more realistic and the set-up allows for a more controlled driving than earlier versions.

CHANCES & CHALLENGES

A main challenge that has been faced during the development process is the reproduction of the leaning behavior of the bicycle. The relation between steering and leaning behavior is very dependent on several factors, i.e. the physical characteristics of the rider, the physical characteristics of the bicycle and the cyclists driving behavior and driving style. Another challenge is the derivation of mathematical models and standardization of the results. Furthermore, the 2 DoF platform that controls the leaning of the bicycle simulator has limitations in both software and hardware. This complicates the development process and restricts the realism that can be experienced. Due to technical restrictions of VR-glasses and the simulation software, it is difficult to portray a realistic riding velocity while completely avoiding simulator sickness. Another challenge is the development of realistic motion cueing algorithms and how to consider perception effects in the presentation of the motion signals. Finally, the validity of a simulator according to its usability in the context of a certain research question or cycling task has to be proven. These challenges have to be solved in order to obtain valid research results when utilizing bike simulators.

However big the challenges might seem, the chances a bicycle simulator offers are worth the effort. First of all, such a simulator enables the study of cycling in critical situations without endangering the test subject. Furthermore, all situations and conditions are repeatable, so that the obtained data provides a profound base for analysis. After a successful parametrization and validation of the simulatior set-up, realistic riding behavior can be observed and used for studying a huge number of different research areas, e.g.:

- Evaluation of intersection measures for cyclists (e.g. protected intersections) to investigate the influence of complementary infrastructure elements for bicycle safety.
- Perform simulator studies to investigate operating ranges for AVFs with a focus on VRU interaction
- Obtain insight in cyclist behavior in different situations for understanding trigger actions, motivation aspects and other influencing factors on cycling behavior for the development of cyclist simulation models
- Support design and evaluation of new communication concepts between automatic vehicles and other road users
- Assessment of cooperation between road users in complex scenarios with multiple interaction partners

Continuous work on improving and validating bicycle simulator facilities will lead to raised importance of the usage of this kind of research tools in future activities towards improving cyclist road safety.

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