A bicycle simulator for the evaluation of traffic control strategies in urban environments

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Abstract *– Urban environments often involve the interaction of numerous vulnerable road users both with each other and with motorized road users. Many factors influence the ability of pedestrians and cyclists to efficiently move through such environments, and in order to study these, we use a bicycle simulator to conduct studies with test subjects, evaluating novel traffic control strategies on existing transport infrastructure depicted in Virtual Reality (VR) environments. Two studies are conducted and their quantitative (trajectories of the test subjects) and qualitative (questionnaire responses) results are analyzed. We discuss the first insights into and usefulness of conducting bicycle simulator studies, both with and without simulated road users, particularly as it relates to the approval and planning phases of infrastructure elements and traffic control strategies.*

Keywords: *bicycle simulator, microscopic traffic flow simulation, traffic efficiency, traffic control, bicycle infrastructure.*

Introduction

Since the early 2000s, bicycle simulators representing Virtual Reality (VR) environments on displays have been a topic of research [Kwo01]. Numerous applications focus on different aspects of cycling that are measurable using test subjects, such as the recorded perception of lane markings [Sch18], reactions to parked vehicles [Aba19], and the experience of microscopic traffic flow simulations [Kat19].

Bicycle Simulator Setup

We focus on the latter of these topics and extend the idea to measuring interactions between test subjects. For this, we use a bicycle simulator for interacting with other simulated road users in a VR environment. Since cyclists lack light signals for indicating maneuvers to other road users, communication via gestures is important, together with head movements, especially during turning maneuvers. Therefore, we record the body movements of test subjects cycling on a bicycle simulator with at least one depth camera installed above and in front of the cyclist. The setup of the bicycle simulator system is depicted in Figure 1. An IR sensor attached to a smart trainer collects a signal of the speed and a magnetic rotary encoder in a rotary plate the steering angle. Both signals are transmitted to a microcontroller, which in turn provides the processed information to the simulation software.

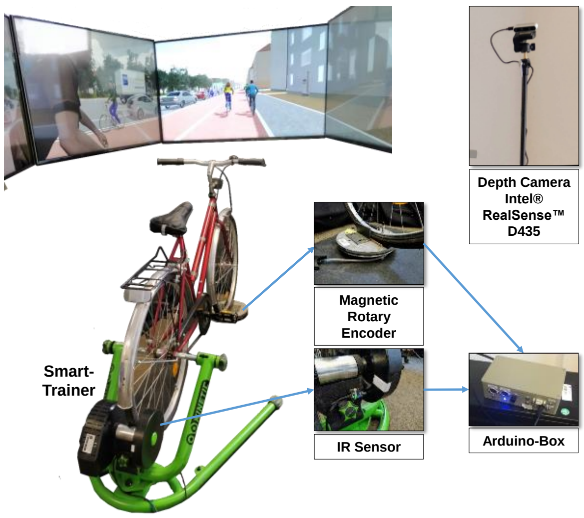

Figure 1. Setup of the bicycle simulator system

Hard- and Software Components

The hard- and software components of our system are pictured in Figure 2. DYNA4 is used to simulate and visualize the ego bicycle according to the sensor inputs. A co-simulation setup with the traffic simulator SUMO enables the simulation of a large number of road users including their interactions among each other and with the ego bicycle. The position of the test subject is calculated from the speed and a steering angle sensor measurements and then projected into the ongoing microscopic traffic flow simulation, which allows the test subject to interact with the simulated traffic participants visualized within the VR environment.

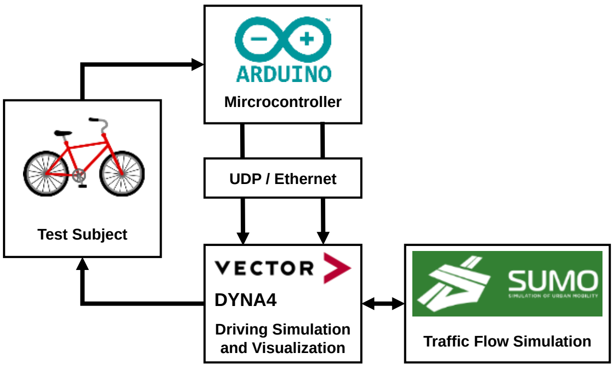

Figure 2. Hard- and software components of the TUM-VT bicycle simulator

Methodological Approach and Conducted Studies

Depending on the investigation areas, we calibrate our simulation networks with a combination of real traffic observations, freely available geodata (from OpenStreetMap), and official traffic signal plans for selected traffic lights as available. In order to ensure consistency between simulations, spatial and ego-speed-based triggers are implemented to control the behavior of the simulated road users. In the absence of such triggers, a higher number of test subjects is required in order to account for this inter-simulation variability. The questionnaires for the studies consist of questions regarding general cycling behaviour, evaluation of specific situations, and the simulator perception in general.

The intention of the conducted studies is to prove the usefulness of a bicycle simulator for evaluating bicycle infrastructure in the planning phase. Therefore, bicyclist behavior data is gathered from bicycle simulator rides with simulated traffic on a network derived from real conditions in urban investigation areas.

In the RASCH project on urban bicycle highways, the evaluation consisted of different infrastructural designs of urban bicycle highways in Munich with variations in traffic control strategies, always in comparison with the modelled existing conditions, based on traffic count and traffic control information.

In the project RadOnTime, the evaluation consisted of different designs of countdown timer displays for cyclists, which depict either the remaining red or remaining green time, based on the test subjects' stated preferences and the displays' impact on cyclist red-light violations.

Results and Discussion

Regarding traffic control, the results show that the introduction of a Green Wave for cyclists can expand the cycling capacity and has a positive impact on the flow of cycling. Cyclists would be more motivated to use bicycle highways with such green waves thanks to this improvement in flow. By comparing the widened one- and two-directional bicycle highway segments (3.0 m width per direction) with existing conditions (1.6 to 2.0 m), we found that there is an increase in average speeds of test subjects of 0.37 to 0.62 m/s. More available space results in riskier observed cycling behavior at intersections, however, though we found that the number of encounter locations with other road users within a 1 m distance decreased.

Countdown timer displays, for remaining red and remaining green time information, caused a reduction in the proportion of red light violations, with green countdown timers achieving a greater and more statistically significant improvement.

The value of the conducted studies comes from the ability to quantify the perception of test subjects in response to different traffic conditions, transport infrastructure, or traffic signal control programs. Real implementations may integrate the public at an early state of the planning phases. In addition to providing perceptional evaluation of proposals, such studies provide quantitative estimates for their impacts on traffic efficiency and safety for the various types of road users through the direct analysis of collected trajectory data.

References

Abadi M. G., Hurwitz D. S., Sheth M., McCormack E. and Goodchild A. **Factors impacting bicyclist lateral position and velocity in proximity to commercial vehicle loading zones: Application of a bicycling simulator** *Accident Analysis & Prevention*, 2019, 125, pp. 29-39.

Kaths H., Keler A., Kaths J. and Busch F. **Analyzing the behavior of bicyclists using a bicycle simulator with a coupled SUMO and DYNA4 simulated environment** *EPiC Series in Computing*, 2019, 62, pp. 199-205.

Kwon, D.-S., Yang G.-H., Lee C.-W., Shin J.-C., Park Y., Jung B., Lee D. Y., Lee K., Han S.-H. and Yoo B.-H. **KAIST interactive bicycle simulator** *Proceedings 2001 ICRA, IEEE International Conference on Robotics and Automation*, 2001, South Korea, pp. 2313-2318.

Schramka, F., Arisona S., Joos M. and Erath A. **Development of a Virtual Reality Cycling Simulator** *Journal of Computers*, 2018, 13, pp. 603-616.