A Virtual Reality Electric Cargo Bicycle Simulator for Experiencing Realistic Traffic Scenarios

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Abstract - *The transformation towards sustainable urban traffic strongly includes bicycle traffic. Besides conventional bicycles, (electric) cargo bicycles are discovered to have a great potential both for private and commercial usage in transportation. Despite many similarities to conventional bicycles, cargo bicycles differ especially in weight, size, and load configuration. Driving simulators for many road user groups such as cars and even conventional bicycles are intensively applied in urban planning and transportation research. Cargo bicycle riders are often omitted as traffic participants in these considerations. In this paper, we describe the setup of an electric cargo bicycle simulator with all hard- and software components used. Additionally, we give insights into first results.*

Keywords: *Cargo bicycle simulator; Virtual Reality; Driving simulation; Microscopic traffic flow simulation*

Motivation

Countries such as the Netherlands and Denmark show impressively that cycling is not only a short-term trend but that it also contributes to a sustainable urban transportation system. During the last years, cargo bikes are discovered to have a great potential both for private and commercial usage in transportation. The integration of an electric drive system further expands the range of potential applications. Compared to motorized individual transport, a cargo bike combines many advantages, such as low operating costs, locally emission-free transport, and higher driving flexibility. Despite many similarities to conventional bicycles, cargo bicycles differ especially in weight, size, and load configuration. The existing bicycle infrastructure is usually not designed for this novel vehicle type and moreover, the interaction with other road users is barely investigated. Therefore, (electric) cargo bikes should be included to both simulations and experimental simulators. Simulators already cover and represent a wide range of traffic participants such as cars, trucks, or pedestrians. Also, bicycle simulators exist (Keler, et al., 2018; Ullmann, et al., 2020), but to the best of our knowledge, the development of an electric cargo bicycle simulator has not yet been described in the literature. We aim at equally including and considering cargo bicycle riders to traffic planning.

Hard- and Software Components

The simulator hardware consists of the cargo trike, sensors connected to a microcontroller, a virtual reality (VR) headset with tracking base stations, and a computer (Fig. 1). This trike has two degrees of freedom while turning axes against the frame: the steering angle and the angle between the frame and the cargo box. Since test subjects cannot start without any movements, the simulator needs to be fixed for low speeds. A future challenge is to release the fixation at higher speeds. We put the bicycle frame into a holder consisting of four threaded rods and a rotatable U-bracket, see Fig. 1. In order to control a digital vehicle model, the cargo bicycle is equipped with sensors. They measure the parameters *speed* and *steering angle*. The speed is recorded by an infrared sensor mounted on one of the roller trainers that counts the number of rotations of a metal cylinder. The front wheel stands on a rotating plate equipped with a magnetic rotary encoder, to measure the steering angle. In Fig. 1, this plate is covered by a blanket to avoid noise from friction between the metal rotary plate and the rubber wheel. The sensor values are read via a microcontroller and sent to a communication port of the simulation computer. This sensor setup is based on simulator concepts for conventional bicycle simulators (Keler, et al., 2018; Ullmann, et al., 2020).

A particular challenge while designing a cargo bike simulator is that wheel and load arrangements as well as tilt and steering behavior vary greatly from one model to another. Thus, the simulator must be well adjusted to individual cargo bicycle models. For a realistic impression of the size of cargo bicycle, we use a VR headset for the visualization. To reliable track position and rotation of the headset, two base stations are installed in the corners of the tracking space.

To achieve a high-performance simulation, effective software solutions are needed. The game engine Unity 3D is used as the main software component for rendering and vehicle control. The 3D environment – a replication of the Munich inner city – is modeled with Esri City Engine and then exported to Unity (Fig. 2). The driving behavior of the virtual cargo bike is modeled using Unity's physics engine. Real mass can be assigned to geometry objects, which can be moved by forces and torques. This physical approach

Figure 1: Cargo bicycle simulator (left: simulator setup, right: virtual model in Unity 3D)

allows an intuitive and realistic modeling of different weight, load configurations, and vehicle movement. The cargo bike is created with responsive wheels and suspension to react in a realistic manner to the driveway. It can be controlled by rotating the handle bar and applying a drive and a brake torque to the rear wheels according to the sensor input. The cargo bike's loading area width can be adjusted and a load with a certain mass can be applied. For further studies, which include several virtual traffic participants, a bridge to a traffic simulation software can be integrated, as described in (Keler, et al., 2018).

Figure 2: Ego perspective from the cargo bicycle in the virtual environment

Proof-of-Concept Study and First Results

In order to test and further develop the cargo bicycle simulator, a proof-of-concept study with 18 test subjects and one simulation run each was performed. During a simulation run, the test subjects should follow a predefined route. Some obstacles and gates are placed along, and instructions to perform an emergency brake appear. The focus of the study was a qualitative evaluation and assessment of the simulator control and the applicability of VR technology for the cargo bike simulator. The following main outcomes were found during the study:

- Calibration with real world trajectory data for steering and pedaling behavior is required, in order to make the simulator control intuitive and realistic.
- The electric drive forces the test subject to ride at high speeds but indeed, this is not necessary depending on the microsimulation environment. First results show that it is even easier for the test subject to ride without electric support.
- Motion sickness frequently occurred, especially with untrained participants in VR and driving simulators. Depending on the study goal, it should be discussed whether a solution with screens is sufficient.

Conclusion and Outlook

The presented electric cargo bicycle simulator enables experiencing traffic scenarios virtually and can be used for investigating communication concepts via the board computer (e.g., collision warnings, see Lindner, et al., 2022), the transportation of children and goods, or simulation parameter validation. The hardware and software components for this setup do not greatly differ from those of bicycle simulators (e.g., visualization and the micro-simulation). The main difference is a detailed physical model, which enables the investigation of different vehicle sizes and load configurations. The simulator setup will be compared with real test rides for calibration and validation and in the future, we aim at giving a recommendation in which cases VR should be preferred over screens.

References

Keler, A., Kaths, J., Chucholowski, F., Chucholowski, M., Grigoropoulos, G., Spangler, M., Kaths, H., and Busch, F., 2018. A bicycle simulator for experiencing microscopic traffic flow simulation in urban environments. *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, pp. 3020–3023.

Lindner, J., Grigoropoulos, G., Keler, A., Malcolm, P., Denk, F., Brunner, P., and Bogenberger, K., 2022. A mobile application for resolving bicyclist and automated vehicle interactions at intersections.

Ullmann, D., Kreimeier, J., Götzelmann, T., and Kipke, H., 2020. BikeVR: a virtual reality bicycle simulator towards sustainable urban space and traffic planning. In: F. Alt, S. Schneegass, and E. Hornecker eds. *Mensch und Computer 2020 - Tagungsband*. New York: ACM, 511–514.