A Virtual Reality Wheelchair Simulator for Realistic Road User Behavior in Driving Simulations

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Abstract - *We designed a novel virtual reality wheelchair simulator for investigating wheelchair users' driving behavior and road user interaction. The approach is unique because, unlike earlier design approaches, we do not use a fixed-base simulator. We allow the wheelchair user to move like in non-simulator conditions while only visual stimuli are substituted or augmented. In this paper, we present the simulator design and examine its advantages and disadvantages in comparison to the fixed-base simulator architecture.*

Keywords: *Wheelchair Simulator; Virtual Reality; Driving Simulation; Digital Twins*

Introduction

Mobility is a fundamental principle of social participation. In transportation planning and research, some user groups are more in the focus than others. This refers in particular to research in the field of automated driving and autonomous shuttle services. This new technology could bring many benefits like an increase in traffic safety and efficiency but might also remove social barriers. Today, the availability of wheelchair-accessible taxis or accessible public transport stations is insufficient to have a comparative service quality as for non-wheelchair users. Since automated vehicles and shuttle services are still under development, we have the chance to include previously neglected user groups. Also today, it is mandatory in public transportation to design vehicles and stations accessible for all user groups. This will also apply to automated shuttle services in public transport in the future. We, therefore, present a new design approach for wheelchair simulators to investigate the interaction between wheelchair drivers and other road users. The novelty of the approach is that we do not use a fixed-base simulator like in previous design approaches. We enable the wheelchair driver to move in the real world while only the visual stimuli are replaced or augmented using XR technology.

Research question

In this paper, we want to address the research questions of (1) how to implement a real-motion wheelchair simulator and (2) what limitations arise due to the state of development of wireless Virtual Reality (VR) headsets.

State of the art of wheelchair simulators

As researched in Pithon, et al. (2009), there are two overall study goals of wheelchair simulators: technical objectives and functional objectives. Studies with technical objectives focus on topics like realism, presence and validity in wheelchair simulator studies, i.e. the applicability of Virtual Reality (VR) technology. Studies with functional goals are mainly concerned with the field of wheelchair driver training, the development and testing of new wheelchair concepts, and raising the awareness of planners and authorities of accessibility issues. However, there is a lack in transportation research that makes use of wheelchair simulators. Govindarajan, Archambault, and Haili (2022) presented two studies in which a wheelchair simulator was applied to train wheelchair drivers in how to act at a crosswalk or in groups of people. However, these traffic scenarios were analyzed from a training perspective, and do not directly refer to transportation research.

The predominating simulator design for wheelchairs in literature is a static, fixed-base design. The wheelchair is placed on roller trainers to measure the wheel rotations and simulate driving resistance. Besides experimental simulators, also a patent for a fixed-base wheelchair training platform exists (Wu, Chen, and Chen, 2006). Uneven surfaces can be imitated by vibrations generated from subwoofer systems and slopes by a tilting platform (Ly, et al., 2022; Wu, Chen, and Chen, 2006). Extensively used are cable-connected VR headsets for visualization (Ly, et al., 2022; Pithon, et al., 2009). With the progress in VR technology, wireless VR headsets are available for several years. A new wheelchair simulator design is now possible – the real-motion wheelchair simulator. In such a simulator, the visual inputs of the wheelchair driver are replaced or augmented with a virtual world while the driver moves in the real world.

Hard- and software components

Current approach

The simulator hardware includes a wheelchair, a wireless VR headset (HTC VIVE), and VR track-

Figure 1: Wheelchair Simulator (left: wheelchair simulator setup, right: virtual model in Unity 3D)

ers (VIVE Trackers) connected to VR base stations. The wheelchair can move freely, just like in non-simulator conditions (Fig. 1, left). It is equipped with trackers on the wheels' center that measure the position and rotation in the detection space. The VR headset rotation and position are measured separately. With these two independent measurements, not only the wheelchair but also the personâs movement can be analyzed. This two-fold measuring approach is novel in comparison to recent wheelchair simulator concepts and improves the investigation of road-user interaction significantly. For further improvement of presence and interaction validity, the test subject can wear VR gloves to accurately represent hand movement. The simulation environment and the wheelchair model are created using Unity 3D (Fig. 1, right). We use a modified version of an existing wheelchair simulation project (Majetich, 2021). However, for the novel design approach, custom controls are necessary.

Outlook

Because of the comparatively new technology of wireless VR headsets, the current approach has some limitations. The tracking space of the base stations is limited by the maximum number of combinable base stations and their spatial arrangement. These constraints result in a maximum tracking space of about 10x10 m for a square area. A new tracking concept called *inside-out-tracking* might solve this issue in near future. With this concept, no external sensors are necessary to locate the headsets and controllers' position due to internal sensors and outside-facing cameras.

Discussion

The presented wheelchair simulator design has some clear benefits compared to the fixed-base wheelchair simulator design. With the new approach, the most complex and expensive task (Pithon, et al., 2009) – replicating real driving behavior – is bypassed. Only the real-world test area has to be compatible with the virtual test environment. For even higher experiment validity augmented reality can be used for certain studies, for example for the investigation of safety-critical traffic scenarios. The current wheelchair simulator design faces the issue of limited tracking space. Depending on the study scenario, a smaller tracking space is already sufficient. As described above, this might be only a temporary issue due to the development of headset-tracking technology to detect the study participants' movement. Regardless of the tracking technology, a real-world replicate of the virtual test environment must exist for the simulation. When using slopes, stairs, or obstacles in buildings a pure virtual representation on a fixed-base wheelchair simulator might be still simpler to implement. For research questions in the field of transportation, however, a real-world replicate usually exists in real urban infrastructure or experimental test sites.

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