Evaluating Locomotion Techniques for Pedestrian Simulation

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Figure 1: Simulation of an intersection with multimodal traffic participants within the MoSAIC laboratory supporting connected human-in-the-loop simulators

Abstract

Realistic behaviour of pedestrians in virtual environments is essential for the validation automated vehicles. However, existing behavior models of vulnerable road users (VRUs) often fail to capture the complexity of human decision making. Human-in-the-Loop simulator studies offer an alternative, which can integrate real user behavior. But, pedestrian locomotion methods that promote realistic pedestrian behavior and decision making remain a challenge. In this late breaking report, we introduce a study to compare three locomotion techniques (by controller, walk-in-place, and omnidirectional treadmill) to evaluate their impact on usability, immersion, and behavioral realism. These locomotion methods will be compared across different obstacle courses and within an urban environment. Key research questions will address the influence of locomotion techniques on naturalistic behavior, decision making, presence, and simulation sickness. Our goal is to establish best practices for integrating unlimited pedestrian movement into VR simulations, improving scenario validity for traffic research and automated vehicle testing. With this report, we seek to engage in discussions on study design, movement patterns, and scenario selection to refine our approach and advance VRU behavior modeling in simulation-based validation.

Index terms: Simulation, Virtual Reality, Locomotion, Pedestrian Simulator, Human in the Loop

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Introduction

The validation of automated vehicle systems requires comprehensive testing in complex traffic environments [1]. Multimodal intersections, where dynamic interactions among pedestrians, cyclists, and motorized vehicles occur (see Figure 2), present significant challenges for ensuring safety and system robustness [2]. Testing in the real world is often too risky and costly. Hence, simulation is a very important tool for controlled and scalable testing (see Figure 1).

Figure 2: Example picture of a complex situation within a German city with multimodal traffic participants

Figure 3: MoSAIC laboratory human-in-the-loop simulators: left cyclist, center pedestrian (Omnideck), right driver

Existing behavior models of vulnerable road users (VRUs) are still limited in their ability to capture the full complexity of human decision-making, leading to unrealistic interactions in simulations [3]. However, virtual-reality (VR) -based simulation with Human-in-the-loop simulators allows integration of complex human behavior and decision making into the simulation [11]. Natural simulation studies allow the extraction of relevant and realistic scenarios by means of scenario mining as well as the validation and refinement of VRU behavior models. Additionally, simulator studies allow testing in a save and controllable environment.

However, a central challenge remains: how can we design Human-in-the-Loop studies to elicit natural behavior and decision making?

One important aspect necessary for natural behavior is a high immersion and presence level within the simulation [5]. The ability to move continuously, naturally and precisely through the scenario is one of the decisive factors here. Especially for human integration into a pedestrian simulation there are a number of locomotion techniques available on the market [6]. They range from simple game controllers, tracker-based input devices up to expensive high-fidelity treadmills such as the Omnideck [12]. The MoSAIC laboratory (see Figure 3) offers a diverse range of simulation environments, including a high end omnidirectional pedestrian simulator, a 2DoF bicycle simulator, as well as two fix base driving simulators and the possibility for multi-user interactions between all these simulators within simulated scenarios [10].

Various parameters can be selected for the movement of pedestrians in the simulation and these can be estimated across the various input methods (see Table 1). For example, the Omnideck offers advantages such as natural walking motion and reduced simulation sickness but comes with significant costs, both in terms of acquisition and calibration time [4]. In contrast, controller-based walking solutions are inexpensive, mobile, and require minimal training, but they introduce artificial movement patterns and increase the risk of simulation sickness [8].

Table 1. MoSAIC laboratory locomotion devices for human-in-the-loop pedestrian simulation with expert rating as starting point for the locomotion evaluation study

	Virtual Reality (VR) controller	Cyber shoes	Walk in place	Omnideck	Open space
Presence	Medium	Medium	High	High	High
Simulation sickness	High	Medium	Low	Very low	Very low
Task mastery	Precise	Vague	Vague	Precise	Very precise
User behavior	Abnormal	Abnormal	Abnormal	Normal	Normal
Rapid speed and direction changes	High	High	Medium	Low	Low
Locomotion distance	Unlimited	Unlimited	Unlimited	Unlimited	Limited
Naturalness of locomotion	None	Artificial (seated)	Artificial (walking on the spot)	Naturally (active surface)	Naturally
Costs (acquisition and maintenance)	Very low	Low	Low	Very high	High
Familiarization duration	Low	Medium	Medium	High	None to Low
Preparation time (calibration)	None to low	Low	Medium	Medium	Medium
Transportability (for extern studies or demos)	High	High	High	None	Low

In order to go beyond the expert rating and gain a clearer understanding of the different input options, especially focusing on Human-in-the-Loop simulation in the context of research in the automotive domain, we are planning a comparative study to investigate several relevant pedestrian locomotion methods in VR.

In this study, we plan to compare different locomotion methods in VR to determine which approach best supports natural behaviour and decision making. As a result of this research, we aim to achieve a more robust and systematic comparison of various input devices for pedestrian movement in VR simulations used for traffic research. By evaluating techniques such as game controllers and omnidirectional treadmills, we aim to assess their impact on behavioural realism, usability and their potential for training and refining of behavioural models. A key question in this context is the cost-benefit ratio between high-fidelity systems, such as the Omnideck, and more affordable alternatives, such as game controllers.

Previous Research

In preparation of the study several preliminary studies have been conducted to investigate the effects of different locomotion methods in VR. One study focused on the impact of the VR headset itself on walking behavior. Participants were asked to complete a predefined walking course in an open space, both with and without a VR headset (see Figure 5). In line with the literature e.g. from Menegoni [7], the results revealed notable differences between real-world walking and VR locomotion. Tasks requiring high precision, such as slalom walking, were significantly more challenging in VR, as indicated by both performance metrics and subjective questionnaire responses. Additionally, participants completed the course at a slower pace in VR. However, no substantial differences were observed in normal curve walking when no time pressure was applied.

Further preliminary studies explored parameters for controller-based and walk-in-place locomotion. These studies aimed to optimize factors such as movement speed and acceleration behavior to enhance usability and naturalism in VR locomotion. The analysis of the data collected there is still ongoing. The results of the preliminary studies should ensure that the best possible locomotion solutions are being compared with each other in terms of usability, technology and parameterisation.

Since we expect that new users will require the most time to familiarize themselves with the Omnideck before reaching a proficiency level where they can focus on study-relevant content, we have conducted an additional study exploring different

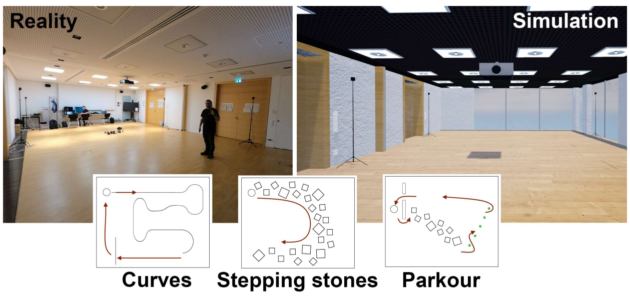

Figure 5: Pre-study open space setup and walking tasks

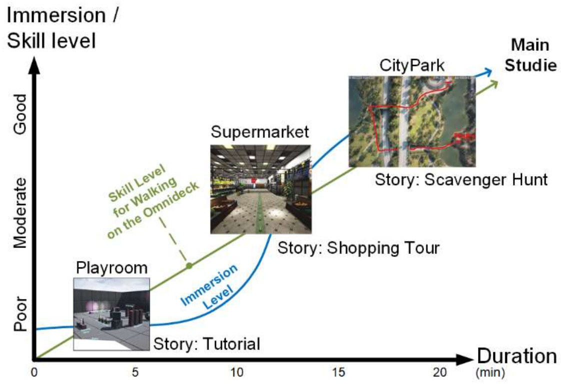

Figure 4: Pedestrian simulator training procedure

approaches to training users to the required minimum skill level [9] (see Figure 4).

Research Proposal

To investigate these locomotion techniques in more detail, we propose a comparative study focusing on some input methods first: controller-based locomotion, walk-in-place techniques, and the Omnideck. The objective is to identify the most effective input method in terms of usability, immersion, and behavioral realism.

Proposed Study Design

A within-subject study is planned with 20-30 participants. The study will compare minimum three locomotion techniques under different conditions to determine their effectiveness in eliciting natural pedestrian behavior in VR simulations. A training will be conducted for each of the locomotion techniques. The necessary content and extent of the training will be determined for the input that requires most training (the Omnideck) and will be applied to all other input devices to ensure comparability. The scenarios used in the study will include:

- Artificial Parcours (Baseline): A structured obstacle course designed to evaluate precision and locomotion efficiency.
- Realistic Urban Scenarios: Digital Twin scenarios: urban environments representing real street / intersection in Braunschweig.
- Critical Traffic Situations: Scenarios based on current research discussions on the most relevant pedestrian-vehicle interactions and safety-critical situations.

The main research questions of the upcoming study are:

- Which integration method best enables naturalistic pedestrian behaviour in simulation?
- Which method best promotes natural behaviour and realistic decision-making among users?
- How does the locomotion method impact presence in the simulation?
- What levels of simulation sickness can be expected for each input method?

CONCLUSION

As a basis for the validation of simulators in a traffic research context, we see a significant need to better understand the Human-in-the-Loop tools available to us, in order to ensure their usability and the transferability of the generated data. The presented study design aims to help close gaps in our understanding.

At this stage, the study is still in a preparation phase. Our current focus is on establishing optimal settings for each of the locomotion methods, in order to be able to compare the best possible version of all the methods. Further we are developing training sequences that guarantee that participants acquire the necessary skills before the actual comparison takes place.

For us, the most valuable aspect of the Late Braking Report and the accompanying workshop is the opportunity for discussion and exchange with other researchers in this field. In particular, we are interested in aspects such as the overall setup of the study, critical movement patterns, locomotion methods, relevant literature references, and important scenarios that should be considered in our main study or preliminary studies.

FIGURE CREDITS

Figure 1-4, image credit: DLR-TS

Figure 4, image credit: Temme et al. / DSC 2024 [8] 2024, page3

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