A Comparison of HMD and CAVE-Driven Visualization for Hand Interaction in Driving Simulators

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Abstract *– Projection-based visualizations like CAVE's enable subjects to see and use their hands and feet to interact with the steering wheel, pedals or operate with other car functions, e.g., displays. Regarding to costs and flexibility as well as immersion aspects HMDs are a good alternative and are gaining more importance for visualization. In this work, a study was made to compare a CAVE and an HMD variant of a dynamic driving simulator with a real car ride. Within the study design the performance during the completion of secondary/tertiary tasks was recorded. The measured data indicate that the CAVE variant is closer to the data of the real ride. Finally, it can be shown that the CAVE visualization variant offers a higher validity and level of realism than the HMD-based variant where interactions with car functions via hands are relevant.*

Keywords: *Visualization System, Validation, CAVE, HMD, Human Machine Interaction*

Introduction

In the vehicle development process, the usage of driving simulators as a development tool is currently a common method, which becomes more important. The visualization is a core component of driving simulators, since drivers perceive most of the necessary information for a driving task visually (Wiedemann, 2016).

CAVE's (Cave Automatic Virtual Environment) represent a manifestation of projection-based visualizations. Especially, for the visualization of the vehicle interior concepts, a CAVE is a common visualization system (Bues and Dangelmaier, 2006). Regarding to costs, flexibility and immersion aspects stereoscopic imaging HMD's are a good valid alternative and gaining more importance to being used for visualization (Ihemedu-Steinke, et al., 2017). The integration of virtual hands for interaction tasks in dynamic driving simulators with HMD is still immature and not satisfying (Hartfiel, 2022). It can lead to technical challenges with HMD-based visualizations which was proven by a study using a Leap Motion system (Tekcan, 2019).

Considering further studies with interaction tasks in a driving simulator, lead to the question, which type of visualization should be preferred to be more close to a real ride. This study investigates this question and compares CAVE- and HMD-based visualization with a real ride regarding touch interactions at a display. Finally, a recommendation will be given, which variant is more suitable.

Methodology

The study was carried out on the dynamic driving simulator at the technical university Berlin. The base of the motion system consists of two rails for translational movements in x (longitudinal) and y (lateral). The driver´s seat is placed on a hexapod with 6 degrees of freedom and air cushion technology. A four-sided CAVE or an HMD can be used as visualization system in this simulator. To determine whether subjects behave more realistically in a CAVE-based or in an HMD-based driving simulator compared to real world driving, this study is based on a within subject´s design. To track the gaze behaviour areas of interest (AOI - windshield, steering wheel, touch display) are defined. Therefore, eye tracking will be used.

The first test environment is represented by a real car which is equipped with TobiiPro data glasses for eye tracking and a touch display for the conduction of the secondary/tertiary tasks. In the simulator variant with CAVE-based visualization shutter glasses are used to generate a stereoscopic view of the virtual parts of the driving scene. In this simulator variant the subjects can see the steering wheel, the dashboard, the touch display and their hands in real,

while the test track and also the rest of the car model are implemented in the virtual world. The third test variant is characterized by using an HMD (HTC Vive Pro) as visualization system in the same driving simulator instead of the CAVE-based visualization. All components of the driving scene (e.g., steering wheel, touch display, car model, test track and hands) are implemented in the virtual environment. The subjects accomplished all three variants within a week. While driving, the subjects had to type numbers between 5-130 on the touch display, which were randomized and specified by the instructor. The investigation is based on the combination of objective and subjective criteria. The objective criteria are represented by the performance of the secondary and tertiary tasks, the gaze behaviour, and the relative head movement.

Results and Discussion

The objective evaluation for the mean number of gaze and duration shows a significant difference between the HMD variant compared to real drive and CAVE variant regarding number of gazes at the tablet and on the street (Tab. 1). Subjects needed to look significantly less often at the tablet and street but it took longer. Another significant difference is that subjects needed to rotate their heads more with the HMD.

Table 1: Results for real drive, HMD and CAVE variant

Parameters	Real Drive	HMD	CAVE
mean number of gazes at the tablet [SD]	59 [8.3]	35 [4.8]	58 [5.6]
mean gaze duration tablet (s) [SD]	0.8 [0.2]	5.3 [0.3]	0.65 [0.2]
relative total gaze duration tablet in %	14.80	19.20	11.20
mean gaze duration road (s) [SD]	0.5 [0.2]	1.4 [0.3]	0.9 [0.2]
relative total gaze duration road in %	78.10	72.10	83.80
number left/right rotation of the head [SD]	118 [26]	186 [31]	110 [23]
left/right rotation angle of the head (min-left/ max right/ average)	-4° 49° 52°	-5° 62° 78°	-1° 34° 52°
mean number of entered numbers [SD]	23.4 [1.3]	19.8 [1.1]	21.2 [1.2]
mean number of errors [SD]	5.8 [2,2]	12.4 [1.3]	6.2 [2.6]
mean omitted input attempts	0	3.5	0.3
Error rate in %	24.70	62.60	29.40

Potential reason for these results can be the interruptions of the hand tracking in the HMD where hands disappear for a moment and appear again. This phenomenon can cause the subjects to need longer time to perceive, process and react in the virtual environment. Another potential reason can be the low resolution of the HMD. This problem can cause that subjects need long time to read the shown numbers in tablet. Last remark on these results is the limited field of view in the HMD.

Further objective evaluations of the study show that there was a significant difference regarding the performance of the subjects on given interaction tasks on the tablet. Average number of errors, average number of missed input attempts and error rate were significantly higher with the HMD in compare to the CAVE and real drive where the CAVE results were closer to real drive.

Conclusion

In this work, the usage of a CAVE-based and an HMD-based visualization in a driving simulator are compared to a real drive. The results show that the CAVE-based variant is closer to the real drive (Tab. 1). It can be anticipated that the simulator variant with CAVE-based visualization leads to higher validity compared to the real car interaction than an HMD. Accordingly, for use cases that focus on interaction, CAVE-based visualization should be clearly preferred.

Current trend in HMD with mixed reality solutions, where users can see real contents with virtual contents combined, could overcome the mentioned drawbacks with HMDs. Mixed reality solutions offer the possibility to overlay a virtual scene with own hands instead of the need of virtual hands. This approach could provide better hand interaction possibilities.

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