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Early Take-Over Preparation in Stereoscopic 3D

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Abstract
Situation awareness in highly automated vehicles can help the driver to get back in the loop during a take-over request (TOR). We propose to present the driver a detailed digital representation of situations causing a TOR via a scaled down digital twin of the highway inside the car. The digital twin virtualizes real time traffic information and is displayed before the actual TOR. In the car cockpit an augmented reality headset or a Stereoscopic 3D (S3D) interface can realize the augmentation. As today's hardware has technical limitations, we build an HMD based mock-up. We conducted a user study (N=20) to assess the driver behavior during a TOR. We found that workload decreases and steering performance raise significantly with the proposed system. We argue that the augmentation of the surrounding world in the car helps to improve performance during TOR due to better awareness of the upcoming situation.

ACM Classification Keywords
H.5.m [Human-centered computing]: Visualization.;
H.5.m [Human computer interaction (HCI)]: Interaction paradigms.

Introduction
Highly automated driving is a key technology in current automotive research. Especially take-over requests

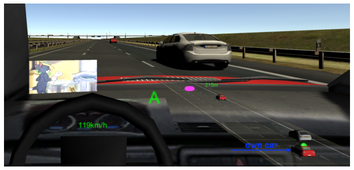

Figure 1: VR Cockpit with digital twin and representation of the own car. Video task as used in the study near the A-Pillar.

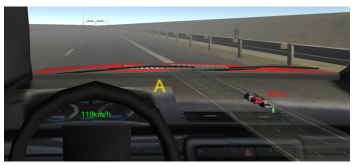

Figure 2: Pre-Warning of accident on own lane.

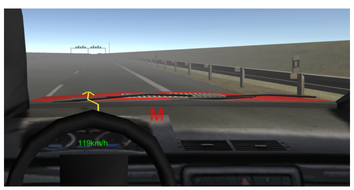

Figure 3: Take-over request with video task turned off.

(TOR), in which the system fails and the driver needs to regain control, is in focus of current research. According to literature [7, 6, 3] the driver needs 7 to 10 seconds to take back control of the vehicle. But even with ten seconds the driver could be in a situation in which he needs more preparation to take over the steering task. In contrast to existing solutions that focus on the TOR itself this paper focuses on the situation before the TOR. The project Providentia [5] sets up a sensor system on the highway to track all vehicles on the road. Those sensors detect the traffic and possible obstructions affecting the traffic flow. Vehicles and drivers get a far-reaching view of the highway for several kilometers in advance. Thus, it is possible to inform the driver early on of a highway situation in several kilometers away and warn him about a possible system limit that requires a take-over of the driver. The sensor information is used to reproduce the real-time traffic situation in a virtual highway, the so-called digital twin. This paper considers a vehicle with SAE Level 3 automation [1]. This means that the car drives autonomously for most of the time but the driver needs to take over the vehicle if the autonomous system fails. The idea behind this work is that a floating 3D AR representation (or S3D) of the real traffic situation within the cockpit improves the driver's take-over performance. By visualizing in a bird's-eye view the traffic situation, the driver is able to assess the appropriate driving trajectory. The AR interface is set next to the driver in the middle of the cockpit above the gearbox. A user study (N=20), comparing our proposed system to a system without a possibility to foresee the situation, was conducted in order to gain insights into driving performance and workload of drivers. In order to be able to simulate this S3D interface and for an easier implementation the study was conducted using a head-mounted display based driving simulator. The S3D representation of the highway (or digital twin) was displayed to the driver before the driver needed to take over the driving task (Figure 1). After informing the driver of the highway situation with the S3D (Figure 2) the TOR itself is executed (Figure 3). The take-over time is set to 10 seconds. The driving task after the TOR is a lane change maneuver in bad weather conditions in order to avoid collision with a broke down car. This paper presents a novel output interface to prepare the driver of a TOR. By showing the driver an accurate traffic representation the driver is able to get more information to plan the driving trajectory of the car. Our study results give good indication that the driving behavior improves due to the digital twin.

Related Work

Augmented reality within the car cockpit is widely under research. HUDs use AR elements to display velocity and navigation cues. At CES 2016 BMW presented HoloActive Touch [8] a haptic touch interface floating in midair. The interface is projected in the car cockpit by a mirror plate to create the effect of floating objects. So far this interface displays buttons and no real-time information similar to our system. In some advanced car cockpits a representation of the detected vehicles on nearby lanes is displayed. Drezet et al. [2] presented a HMI concept for autonomous cars. HUDs can be used to display vehicles' driving behavior and information about the car's sensor perception. In this work the visualization of the sensor perception is extended to infrastructure sensors. This information is not displayed in the car integrated interface but in a S3D interface next to the driver.

User Study

The goal of the proposed system is to increase situational awareness and thus improving the driving trajectory planning. By displaying an as accurately as possible representation of the highway the driver gets more information about possible limitations on the road. Within the VR environment, the driver sits in the cockpit of a highly automated car. Inside the cockpit of the vehicle an AR representation of the highway is displayed above the gearshift. The digital twin displays a sector of the highway the ego-vehicle is driving on. The user can move the section in the digital twin forwards and backwards by pressing a button. They can center the digital twin again on their vehicle if they want to focus on the situation around the ego-vehicle. The distance of the current sector of the highway to the ego-vehicle is shown as a floating digit next to the highway. The virtual environment was set up using Unity 3D. The digital twin appears before the take-over request. A possible reason for a take-over request, like bad weather or an object on the road, is displayed in the digital twin. The user can interact with the digital twin before a take-over request to inform himself about the traffic situation on the highway. He can scroll through the whole traffic situation and change the view to get an overview of the current situation on the highway. With the distance information, the driver knows where the possibly dangerous situation is in respect to the ego-vehicle. 20 participants with a mean age of 25.3 took part in the study, 8 female and 12 male. To test the system the participants were required to perform two driving tasks. The first driving task (Test A) serves as baseline. The second driving task (Test B) includes the AR representation of the highway. The study is designed as a within-subject study, so every participant performs both driving tasks. To eliminate possible learning effects due to this setup the participants were divided up into two groups. Both groups get the same introduction to the setup. Group 1 takes Test A first and then Test B while Group 2 takes Test B first and then takes Test A. Both groups do a preliminary driving test to get used to the system. During the introduction the AR representation of the highway and the functions of the setup are explained. In the next step the take-over process is explained. Within the user study there are four phases:

1. **Autonomous Driving** During this phase the car controls the steering. The driver concentrates on the secondary task. In this study the secondary task consists of watching a movie and counting objects within the movie.
2. **Information Phase** This phase begins by a sound to inform the driver that the digital twin is displayed. The driver can interact with it and thus inform himself about the current traffic situation. The secondary task is not available to the driver anymore. This phase lasts 10 seconds.
3. **Take-over Phase** A take-over request is issued when the ego-vehicle has a time to collision (TTC) of 10 seconds. A warning sound initiates this phase, and the driver is prompted to take over the steering wheel. At the end of the take-over phase, the digital twin disappears.
4. **Manual driving** After the driver regained control of the vehicle, the driver needs to decide on the driving maneuver. In order to avoid a collision with the objects on the road, the participant needs to change lanes.

The participants take the following tests:

Test A The first driving test is the baseline of the study. The driving phases consist of Phase 1 - Phase 3 - Phase 4.

Test B During Test B the introduced system is used. Different to Test A an additional phase is added. The driver switches through Phase 1 - Phase 2 - Phase 3 - Phase 4.

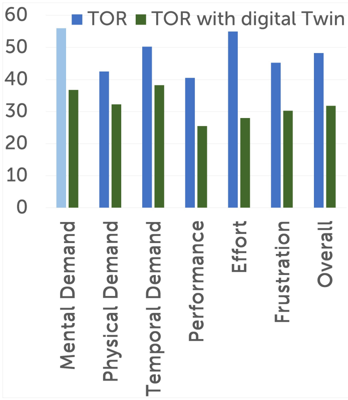

Figure 4: NASA TLX Test Scores.

The system is evaluated by the NASA TLX [4] questionnaire and an acceptance scale questionnaire. To evaluate the significance of the results a paired t-test is used. To evaluate the effect of the system on the driving behavior, the steering wheel angle, velocity and the position of the vehicle is tracked.

Result and Discussion

Take over behavior

The driven trajectory is compared between Test A and Test B. To assess the driven trajectory the lateral lane position is recorded. As the driving task requires the driver to change the lane it was considered better to drive on the lane without the obstruction on the road. In Test B the lateral lane positions were generally closer to the lane without an object and results indicate a significant difference between Test A and Test B ($p = 0.04$). Additionally the steering wheel angle of the driving maneuver is recorded. This gives hints about the steering behavior of the driver, like uncontrolled or smoother lane changes. Though Test B has overall smaller values with a mean of 10.24° and a SD of 4.82° and Test A has higher values with a mean of 15.86° and a SD of 8.45°, the p-value indicates no significant difference between the two tests. As a third evaluation measure the speed was taken into account. The p-value is 0.04, indicating significant differences in the speed values in both tests. The speed in Test B was lower, which indicates that the user adapted the speed earlier and more appropriately.

User Experience

The workload of the system is evaluated using NASA TLX (see figure 4). The temporal demand of Test B is highest, which indicates that the participants needed to spend time on the digital twin to understand the digital representation. The biggest difference between both tests is the effort value. That could be an indication that the digital twin mentally prepares the driver better on the TOR and thus lessens the effort of the TOR. The measurement scales of mental demand, performance, effort and the overall measure show a significant difference between the two tests. Test B has a lower score in most measures and performs better than Test A. The acceptance scale is used to analyze the acceptance of the digital twin. The acceptance is measured by evaluating the usefulness and satisfaction scale. Participants have a positive attitude towards the hologram with a mean of 1.06 in the usefulness and 1.16 in the satisfaction scale. One remark of a participant indicated that he had a better understanding, when he needs to take over the car and in assessing the proper point of time to take-over the vehicle.

Conclusion and Future Work

Within this paper a system is presented that prepares the driver for a take-over request by informing him of the current traffic situation and the possible reason of the necessity to take over the car. This system simulates a possible S3D interface within the car. A floating AR interface is currently just possible with a HMD within cars, in this study it is set up in VR glasses. A further study evaluates this setup with an implementation in AR glasses. Future research investigates, if the driver shows better driving performance because of the longer time between preparation and manual driving in Test B or because of the visualization of the traffic situation. Overall this study shows promising results in improving take-over behavior of the driver by displaying a digital twin within the vehicle cockpit. Further research needs to be done to evaluate the improvement of situational awareness, changing output modalities and usefulness of the system.

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