View Management for Driver Assistance in an HMD

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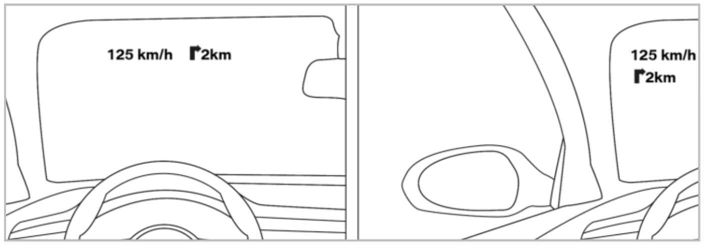


Figure 1. Based on the user's head rotation, head-stabilized content is dynamically assigned to a different position.

Abstract

Head-mounted displays (HMDs) have the potential to overcome some of the technological limitations of currently existing automotive head-up displays (HUDs), such as the limited field of view and the restrictive boundaries of the windshield. However, in a formative study, we identified other, partially known problems with HMDs regarding content stability and occlusion. As a counter-measure we propose a novel layout mechanism for HMD visualization, which, on the one hand, benefits from the unique characteristics of HMDs and, on the other, combines the advantages of head-stabilized and cockpit-stabilized content. By subdividing the HMD's field of view into different slots to which the content is dynamically assigned depending on the user's head rotation, we ensure that the driver's vision is effectively augmented in every possible direction.

Author Keywords

head-mounted display; view management; mixed reality; head-up display; driver assistance

ACM Classification Keywords

H.5.1. Information Interfaces and Presentation: Multimedia Information Systems— Artificial, augmented, and virtual realities; H.5.2. Information Interfaces and Presentation: User Interfaces — Graphical user interfaces (GUI)

Content Stabilization in Cars

When using HMDs, content can be stabilized in three different ways: depending on the reference coordinate system, virtual information can be *head-stabilized*, *body-stabilized* or *world-stabilized* [2].

In aircraft cockpits the pilot's position usually is relatively fixed within the cockpit's coordinate system, allowing four possibilities of content stabilization: *head-stabilized, cockpit-stabilized*, *earth-stabilized* and *space-stabilized* content [3].

In cars, the situation is similar: in a typical driving situation, there is little movement of the driver in the car's cockpit. Thus, typically there are three different types of content stabilization: *head-stabilized*, *cockpit-stabilized* and *world-stabilized* content. *Body-stabilized* content should be considered in situations, when the driver might leave the car without taking off the HMD.

Introduction

While head-mounted displays (HMDs) have a well-established place in the research community, they have not yet attracted the same attention from the consumer market. This might be due to the fact that – apart from watching movies – there have hardly ever been any convincing use cases. Nevertheless, an increasing number of companies have started to develop light-weight and affordable see-through HMDs, which provide an alternative output technology to the growing market of (currently handheld) mobile augmented reality applications. For cars, this setup seems equally plausible and is being discussed in relevant internet technology magazines [6]. Head-up displays are an elegant way of providing information to the driver while looking straight ahead at the street. Unfortunately, HUDs are still expensive and only available in luxury cars. HMDs also have other unique advantages over head-up displays: Content can not only be displayed within the small area covered by the HUD, but within the driver's complete environment, including the cockpit interior. Given their additional technological challenges, the question remains whether HMDs can be a real alternative to the existing HUD technology and, if so, which factors need to be considered by future application developers. In view of this question we performed an initial formative user study with a straightforward HMD setup in a driving simulation. Our goal was to get first insights into the use of HMDs in cars and to identify important aspects for the development of visualizations in this use case. We examined different aspects of driver behavior and perception, from which we derived the need for a new view management concept.

Formative Study

In comparison to HUDs, there are hardly any studies on HMDs as a possible output technology for drivers. Prior work in the automotive context mostly concentrated on video see-through HMDs for simulation or on optical see-through technology in maintenance or manufacturing [10]. In contrast, our goal was to examine the use of HMDs while driving a car and to investigate how they can be used to support drivers in this task. In a driving simulation we compared cockpit-stabilized (using a HUD) and head-stabilized (using a HMD) content, taking a typical head-up display visualization as an exemplary use case.

Study Design

The study was conducted in an industry grade driving simulation with a high-fidelity car mockup. A large cylindrical projection screen, covering 220 degrees of the driver's field of view was placed 3 meters in front of the mockup and displayed the main driving scene. Content in the rear view mirrors was reflected from three LCD panels, which were positioned accordingly behind the driver's seating position. We used a Vuzix Star™ 1200 HMD with a resolution of 1280 x 720 pixels and a 23 degree diagonal field of view. To simulate a HUD we used an LCD display pointing upward at a combiner mirror (70% transparency) such that its content is reflected towards the driver and appears to hover in front of the driving scene. The driver's head was tracked by an IR-based ART Smarttrack system placed at an average distance to the driver of 96cm at the center of the mockup's dashboard.

The visualization displayed in the HMD/HUD included the current speed, optional speed limit information, an optional collision warning and a basic guiding

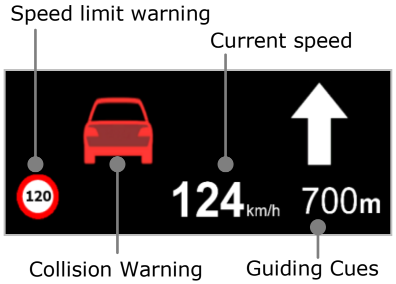


Figure 2. The visualization displayed in the HUD and in the HMD. It had a maximum size of 550 x 170 pixels, depending on the amount of content displayed at a given time.

functionality (see figure 2). After an extensive training phase, each test subject (N=35, age 23-57, M=32.8, SD=8.9, all experienced drivers) was asked to drive a certain route covering important driving situations (motorway, highway and city). Depending on the user's driving speed, the whole scenario was completed within 15 to 18 minutes. Subjects were instructed to drive approximately 140 km/h and to stick to speed limits when necessary. Using a balanced within-subjects design, each subject completed the scenario twice. In one condition, content was displayed cockpit-stabilized (using the HUD), in the other, the same content was displayed head-stabilized (using the HMD). In both conditions the subjects were asked to wear the HMD in order to provide comparable ergonomics. In each condition the subject's behavior was observed after being confronted with two critical situations. In the first situation, a speed limit sign was hidden due to the traffic situation, and therefore only visible in the HUD/ HMD visualization. In the second situation, a collision warning was triggered by a preceding vehicle braking unexpectedly. Additionally, in both conditions subjects executed a peripheral detection task (PDT), a standardized procedure to measure visual distraction in driving situations [9]. In the PDT, drivers react to targets randomly presented in their peripheral view by pressing a button on the steering wheel. After each of the two conditions, subjects were asked to fill out a questionnaire with subjective data. The main aspects of this questionnaire were the level of subjective distraction, the clarity of the visualization, as well as its general benefits and problems. Additionally, we investigated the level of short-term impairments (such as dizziness, headache and eye strain) beyond the usual symptoms of simulator sickness [8]. Such symptoms have also been observed after the use of HMDs [4], so we expected these symptoms to mutually reinforce each other. Finally, each subject was asked to perform a third run in a city environment (approx. 5 minutes, depending on the amount of user feedback). This time, content was cockpit-stabilized and displayed in the HMD. While the user was driving, a semi-structured interview was conducted to collect subjective assessments of the visualization. After the last test run, subjects filled out a final questionnaire asking for a (justified) personal system preference and assessments of the potential of HMD visualizations in this context.

Results

The PDT was performed to reveal potential differences between the two kinds of content stabilization concerning visual distraction. We assumed that head-stabilized content would be more distracting and occluding than car-stabilized content, which is in a constant fixed position and not affected by (head) movements of the driver. Based on the data we collected, this hypothesis could not be supported. There were no significant differences between the two conditions concerning missed targets and reaction times (table 1). A further assumption was that because content is constantly in the driver's field of view, and thus might attract more attention, head-stabilized content could have advantages in critical situations, especially when information is primarily available in the visualization (e.g. hidden speed limit). Surprisingly, reaction times did not show any significant differences either in the situation with the hidden speed limit or in the one with the collision warning (table 1).

In the questionnaire, subjects were asked to complete after each test condition, they had to evaluate several characteristics of the visualization via 7-point Likert

	Head Stabilized (HMD)	Cockpit Stabilized (HUD)
PDT Missed Targets	M=1.33 SD=0.83	M=1.44 SD=0.71
PDT Reaction Time	M=0.80s SD=0.13s	M=0.77s SD=0.11s
Speed Limit Reaction Time	M=1.20s SD=0.54s	M=1.66s SD=0.95
Collision Warning Reaction Time	M=1.52s SD=0.31s	M=1.09s SD=0.24s

Table 1. To detect differences between the two kinds of content stabilization, reaction times and driving data were logged with a frequency of 50 Hz and analyzed using mean (M) and standard deviation (SD). Independent samples t-tests based on a between-subjects design (evaluating only the first contact with the critical situation per subject) did not reveal any significant differences.

scales. In certain aspects of general usability, the head-stabilized version was rated comparatively negative to the cockpit-stabilized version. Seven subjects stated it to be confusing (none in the cockpit-stabilized version), 13 subjects felt it to be interfering with the driving task (3 in the cockpit-stabilized version) and 16 subjects felt distracted by the head-stabilized visualization (3 in the cockpit-stabilized version). Fortunately, none of the conditions induced any serious short-term impairments. On a 5-point scale from “0: Not at all” to “5: Very strong”, the average level of eyestrain, dizziness, headache and nausea in both conditions was below 1. While subjects were driving in the third test condition, the cockpit-stabilized version of the HMD, a semi-structured interview was performed. On the positive side, subjects stated that this visualization was less disruptive than the head-stabilized version (9 subjects) and expected advantages compared to the head-stabilized version in situations such as checking the rear-view mirror (3 subjects). Two subjects also emphasized the importance of a z-axis (in-depth axis) stabilization in HMDs; the upward orientation of the content regardless of the orientation of the wearer’s head seemed to be an important aspect. On the other hand, they criticized the spatial stability in comparison to the HUD-version due to tracking latency and jitter (27 subjects) and some unsolved technological problems, such as the small field of view (4 subjects).
In the final questionnaire, subjects were asked to state their preferred visualization type and explain their choice. Unsurprisingly, the cockpit-stabilized visualization using the HUD was preferred by 28 subjects, 6 subjects favored the head-stabilized visualization and only 1 subject voted for the cockpit-stabilized visualization in the HMD. Technologically, the main advantage of the HUD technology was found to be its steadiness and spatial stability (8 subjects), as well as its technological maturity (3 subjects). The main advantages of the HMD were that information could be seen independently from head rotation (5 subjects) and that it could be projected onto the complete surrounding. Consequently, eight subjects proposed a combination of both technologies.

Discussion and Implications

In our formative study, we wanted to collect first insights on the benefits and challenges of the use of HMDs for car drivers. Initial concerns that using HMD visualizations while driving in the simulation might increase simulator sickness and physical uneasiness, could fortunately not be verified. From the questionnaire and the statements in the semi-structured interviews, we derived several interesting implications for this special use case. Both head-stabilized and cockpit-stabilized content have their own advantages and drawbacks. When using head-stabilized visualizations, content can be displayed to drivers even when they are distracted or are turning their head away from the road. Even if our study did not reveal any significant differences in reaction times, there might be situations in which this is the only chance of warning the driver. Coincidentally, precisely this property of head stabilized content is also its biggest disadvantage. Visualizations are constantly visible, even in situations in which they are superfluous. When checking the rear view mirror or blind spot, only a brief glance out of the side window is required. In these situations, head-stabilized content visualization blocks the driver’s view, which might lead to longer periods of averting the eyes from the street. Keeping this in mind, we will propose a visualization approach, which combines the advantages of head-stabilized and cockpit-stabilized content.

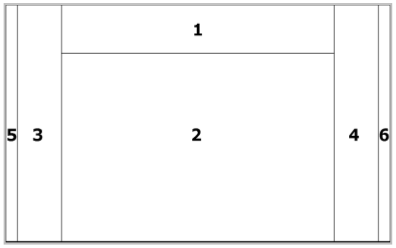


Figure 3. The HMD's field of view divided into different slots

Related Work

Toennis et al. investigated different approaches of augmenting the location of a possible danger around the car. They state that warnings should not be placed directly at the place of danger but always within the driver's field of view [12]. By augmenting only a small part of the driving scene, occlusion problems between the visualization and the real world have only a minor impact and thus have not been addressed. This problem in turn was analyzed by Bell et al., who dealt with a different use case. In an augmented reality meeting scenario they avoided possible occlusions between real world content and virtual annotations displayed in a see-through HMD by proposing a layout management technique [1]. Not only occlusion problems, but also the general visibility of HMD content due to background properties such as complexity [7] and brightness [11] can be improved by using layout management techniques. In contrast to these approaches, the problem we are addressing is based on a very static setup concerning the spatial relationships between the driver and the car. Therefore, there is no need for exact environmental tracking or prior background analysis.

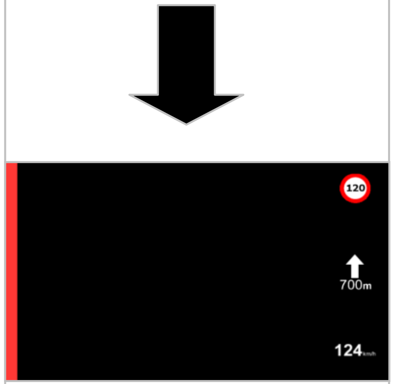
Proposal: Slotted View Management

The basic idea of our approach is to divide the HMD's field of view into different slots to which content can be assigned, depending on the driving situation and the actions of the driver. Figure 3 shows how the field of view (outer frame) is divided into different segments marked with numbers from 1 to 6. The segment in the top centre (marked as 1 in figure 3) is the main slot for content that is constantly visible. On this location, the basic HUD functionality can be visualized, such as guiding information or an indication of the current driving speed. In our initial study, users emphasized the importance of upright content in the HMD. Therefore, content in this slot is presented in an upright orientation independent from the user's head rotation. This increases text readability and prevents symbols from being misinterpreted. In order to avoid content blocking the driver's vision, in certain situations visualizations originally located in this slot are dynamically assigned to the slots on the sides of the field of view (marked as 3 and 4 in figure 3). For example, when the driver turns his/her head to the left, content is switched to the corresponding slot on the right. At the same time the amount of content can be reduced or be presented in a more compact way. Figure 4 shows how content moves between segments when the driver turns his/her head to the left. The other segment in the centre of the field of view (marked as 2 in figure 3) is used to display for vital information, which must be displayed only for a short amount of time. A collision warning is a typical example of content for this segment. There is plenty of space to prominently visualize the warning which might aid in improving the driver's reaction time in critical situations. The two segments located at the left and right edges of the field of view (marked as slot 5 respectively 6 in figure 3) can be used to warn drivers changing lanes if another vehicle is in their blind spot. This is done by marking the entire segment with a salient color.

Summary and Future Steps

In this paper we presented a formative study comparing different possibilities of content stabilization. Based on its results, we proposed a new layout management technique for HMD use in cars. In comparison to purely head-stabilized content, content

Driver is looking ahead; collision warning is active



Driver is checking left rear view mirror; collision warning is inactive, lane change warning is active (leftmost segment is colored)

Figure 4. Content is changing segments depending on the driver's head rotation

is rearranged if necessary in order to prevent it from blocking the driver's view. Theoretically, this goal could also be achieved by cockpit-stabilized content. This, however, would require a very complex tracking infrastructure. The lag of optical head tracking systems is one of the main limiting factors of augmented reality visualizations, especially in settings in which the head rotation around the y-axis (vertical axis) might change very quickly. The use of other tracking technologies (e.g. electromagnetic, acoustic or inertial) is extremely limited in cars due to the high number of disturbance factors. Another problem is that the quality of world- and cockpit-stabilized content strongly depends on the field of view which is covered by the HMD's display unit. If content is not displayed, although it would be still in the driver's field of view, the impression of world- or cockpit-stabilization can easily be corrupted. The visualization technique introduced in this paper circumnavigates these technological limitations. It can be applied very easily in any car and works with low-cost tracking technology. Even though the visualization technique performed well in initial tests, we must conduct a more thorough evaluation. It will be important to not only investigate key factors of the visualization itself (e.g. thresholds for head rotation, content distribution and presentation) but also to evaluate it under real conditions in the car.

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