Are HMDs the better HUDs?

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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. In an initial study we evaluated the use of HMDs in cars by means of a typical HUD visualization, using a HUD as baseline output technology. We found no significant differences in terms of driving performance, physical uneasiness or visual distraction. User statements revealed several advantages and drawbacks of the different output technologies apart from technological maturity and ergonomics. These results will hopefully inspire researchers as well as application developers and even might lead us to novel HMD visualization approaches.

Keywords: head-mounted display, head-up display, mixed reality

1 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. 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 [2]. In theory, HMDs have unique advantages over head-up displays: They can be used in every vehicle and content can not only be displayed within the small area covered by the HUD, but within the driver's complete environment. Given their technological challenges, the question remains whether HMDs can be a real alternative or even superior 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 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.

2 COMPARATIVE STUDY

In contrast to prior work [4], which mostly concentrated on using optical see-through HMDs in maintenance or manufacturing, our goal was to examine the use of HMDs while driving a car. 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.

2.1 Study Design

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2.1.1 Apparatus

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 displayable 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 roughly 1m at the center of the mockup's dashboard.

2.1.2 Task, Participants and Procedure

The visualization displayed in the HMD/HUD included the current speed, optional speed limit information, an optional collision warning and a basic guiding functionality (see figure 1). The visualization had a maximum size of 550 x 170 pixels, depending on the amount of content displayed at a given time.

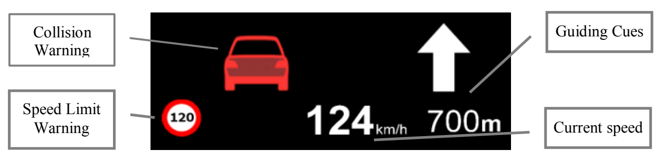

Figure 1: The visualization displayed in the HUD and in the HMD

After an extensive training phase, each test subject (N=34, 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. Particularly the area above the transparent display units bears the risk of partially blocking the driver's vision. 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 [3]. 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. Such indications have also been observed after the use of HMDs [1], 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 (using the head tracking system) 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.

2.2 Results

2.2.1 Quantitative Data Evaluation

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 cannot be supported. There were no significant differences between the two conditions concerning missed targets (M=1.33 / SD=0.83 in the head-stabilized, M=1.44 / SD=0.71 in the cockpit-stabilized condition) and reaction times (M=0.80 sec. / SD=0.13 sec. in the head-stabilized, M=0.77 sec. / SD= 0.11 sec. in the cockpit-stabilized condition).

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 especially in critical situations. Especially when information is primarily available in the visualization - like the hidden speed limit - we expected shorter reaction times. Surprisingly, reaction times did not show any significant differences either in this situation (M=1.20 sec. / SD=0.54 sec. in the head-stabilized, M=1.66 sec. / SD=0.95 sec. in the cockpit-stabilized condition) or in the one with the collision warning (M=0.39 sec. / SD=0.21 sec. in the head-stabilized, M=0.47 sec. / SD=0.36 sec. in the cockpit-stabilized condition).

2.2.2 Subjective Assessments

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 scales. In certain aspects of general usability, the head-stabilized version was rated worse than the cockpit-stabilized one. 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 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 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 favoured 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.

3 Summary and Future Steps

In our formative study, we wanted to collect first insights on benefits and problems with the use of HMDs for car drivers. The biggest advantage of HUDs is the possibility of displaying cockpit-stabilized content without the necessity of using a head tracking system. The spatial stability and steadiness of HUD visualizations minimize the risk of distracting the driver and provide the desired information without blocking his/her vision.

When using head-stabilized visualizations, content can be displayed to drivers also when they are distracted or turning their head away from the road. Even if our study did not reveal any significant differences in reaction times, there might be special situations (e.g. interacting with the car's infotainment system) in which this is the only chance of warning the driver. Coincidentally, just this property of head stabilized content is also its biggest disadvantage. Visualizations are constantly visible, even in situations in which they are superfluous. For example, when checking the rear view mirror or blind spot, head-stabilized content might block the driver's view rather than enhancing it. An interesting proposal, made by nearly one third of the test subjects on their own initiative, is to combine the advantages of both stabilization techniques. We believe that, besides using both technologies coevally, one possible way to accomplish this goal is by using head-stabilized content in combination with layout management techniques. Depending on where the user is turning his/her head, head stabilized content could be dynamically re-arranged in order to prevent it from blocking the driver's vision.

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