You've Got the Look: Visualizing Infotainment Shortcuts in Head-Mounted Displays

Felix Lauber
University of Munich (LMU)
Amalienstr. 17, 80333 Munich
felix.lauber@ifi.lmu.de

Claudius Böttcher
University of Munich (LMU)
Amalienstr. 17, 80333 Munich
claudius.boettcher@gmail.com

Andreas Butz
University of Munich (LMU)
Amalienstr. 17, 80333 Munich
butz@ifi.lmu.de

ABSTRACT

Head-mounted displays (HMDs) have great potential to improve the current situation of car drivers. They provide every benefit of a head-up display (HUD), while at the same time showing more flexibility in usage. We built an infotainment system specifically designed to be displayed in an HMD. With this system, we then conducted a dual task study in a driving simulation, comparing different techniques of content stabilization (head- and cockpit stabilized visualizations). Interaction with the system took place via a physical input device (rotary controller) or indirect pointing gestures. While cockpit-stabilized content generally resulted in a slightly better driving performance, HMD visualizations suffered from technological limitations, partly reflected in the secondary task performance and subjective feedback. Regarding input modality, we found that horizontal gesture interaction significantly influenced the quality of lane keeping. Apparently, horizontal interaction with the one hand caused unintentional steering with the other.

Author Keywords

Interaction in cars; indirect interaction; head-up display; automotive user interfaces; head-mounted display; gestures

ACM Classification Keywords

H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION

While cars originally were built solely as a means of transportation, they have now become a personal space in which drivers want to relax, use their accustomed channels of communication and a comprehensive amount of infotainment systems [25]. This is particularly true for luxury brand cars. As a result, introducing more and more digital functionality into the car while minimizing the negative effects on the driving task, is one of the main challenges for today's car manufacturers. It requires them to explore new means of presenting information to the driver and provide novel methods of interaction.

One major drawback of most in-vehicle displays is that they require the driver to avert his/her eyes away from the street. Transparent displays, such as head-up displays (HUDs), superimpose information directly on the driving scene. Prior work has already shown that this can bring advantages in comparison to traditional in-vehicle displays in numerous situations. However, the number of use cases that can be implemented with HUDs is limited, as they provide only a limited field of view (FOV) and their position within the windshield is static. These disadvantages may be overcome by Head-mounted displays (HMDs) as they provide a very flexible FOV where content can be displayed regardless of the driver's line of vision. At the same time, all advantages of a HUD may be preserved, and even the HUD itself can be simulated.

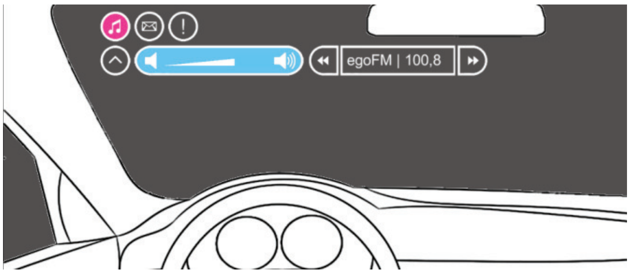

Figure 1: By superimposing visual feedback on the driving scenario, the driver does not need to avert his eyes from the street.

In this paper, we present a visualization and interaction concept for infotainment functions, specifically built for use in an HMD. Its core idea is to superimpose the driving scene with infotainment functions, in case the driver wants to interact with the system (Fig. 1). Thus, drivers do not need to turn their head away from the street in order to interact with the system. We implemented a fully functional prototype and evaluated it in a user study in a driving simulation. In this study, we compared two different interaction modalities (gestures and a physical controller) and two different content stabilization techniques (cockpit- and head-stabilized).

AutomotiveUI '14, September 17 - 19 2014, Seattle, WA, USA

ACM 978-1-4503-3212-5/14/09…$15.00
http://dx.doi.org/10.1145/2667317.2667408

RELATED WORK

Our work is based on prior studies on HMD usage and head-up displays (HUDs) in the car. Additionally we examined work about in-vehicle interaction using hand gestures or a physical controller.

HUDs and HMDs in the Car

HUDs have been widely utilized by the automotive industry in the last decade and there are numerous studies to prove the advantages in comparison to 'traditional' head-down displays (HDD). It has been shown that they lead to shorter eye accommodation times and gaze transitions between the display and the driving scene [12, 26]. Subjects also made fewer errors when completing a guiding task (following the navigation system) [5]. It also has been shown that the average driving speed could be maintained more exactly (indicating decreased cognitive load) and subjects reacted quicker to urgent events [18]. Another study could show that HUDs can provide advantages under unfavorable weather conditions [7] and for elderly drivers [11]. Reviewing the downside of HUD usage in the car, literature mainly refers to two phenomena, both observed in the aerospace domain but very likely to also apply to the automotive domain. They are called cognitive/attention capture and perceptual tunneling, and describe the phenomenon that pilots will unconsciously shift their attention away from the surrounding world towards the HUD visualization, while their peripheral perception is being narrowed down [24].

Similar to HUDs, HMDs also provide the possibility of superimposing virtual content directly on the driving scene. When using a HMD in the car, there are three possibilities of content stabilization. Depending on the coordinate system, to which the virtual content refers to, it is denoted as head-stabilized, cockpit-stabilized or world-stabilized [27]. Reasons for the usage of HMDs in cars are their flexible field of view that allows head-stabilized content and the superimposing of the driver's complete surrounding, their seamless usage within- and outside the car and their easy integration (they need no additional installation space in the car) [14]. Consequently, optical see-through HMDs have been used in the automotive domain to augment virtual traffic participants onto a real test setup [3]. The same system has been successfully implemented to evaluate evasion maneuver visualizations [17]. Lauber and Butz compared HMD and HUD visualizations in the car [14], revealing first insights on the particularities of using optical see through HMDs while driving. In a later study they concluded that in situations of intensive distraction, drivers react more quickly to head-stabilized warning visualizations compared to the same warnings visualized in a HUD (cockpit-stabilized) [15]. Interaction with HUDs was examined by Milicic et al., who conducted a study, in which subjects were able to complete menu interaction tasks faster, when using a HUD in comparison to a head down display [21]. Lauber et al. used a HUD to mirror both the in- and output of a touch screen located in the car's center stack [16].

In General, the usage of HMDs in the car is less evaluated than the usage of HUDs. However, because of the similarity of both technologies, Yeh et al. argue that most results of the studies conducted with HUDs might also be applied to the usage of HMDs [28].

Gesture interaction and physical devices

For interaction with secondary tasks, such as manipulating infotainment functions or the navigational system, many interaction modalities have been considered in prior work. Most manufacturers offering enhanced interaction possibilities, provide touch displays or rotary controllers [10, 22].

As an alternative input modality, prior work continually considers gestures as one alternative to established interaction modalities. One of the main motivations of gesture usage in the car is that it does not necessarily require the driver's eyes to leave the driving scene [23]. Correctly implemented, gestures can be culture-independent, easy to use and might even be preferred to haptic knobs [19]. According to Pickering et al. hand gestures can be clustered into 5 categories: pre-emptive, function associated, context sensitive, global shortcut and natural dialogue gestures [23]. Hand gestures in the car generally can be performed at different locations, such as around the steering wheel [6, 19] or in front of the center stack [2, 13]. There are also approaches that combine pointing gestures with a steering wheel button to select an element, the user is pointing at [13, 15].

CONCEPT

When conceiving an infotainment concept for HMDs, our main motivation was to profit from one of the advantages of HMDs. As with HUDs, this is the reduced need to avert one's gaze away from the street in order to interact with content that would normally be located on a HDD. We tried to maximize the improved gaze behavior by combining HMD visualizations with indirect interaction modalities, such as very simple, indirect pointing gestures or a physical controller.

The superimposed menu is clustered into two levels. The top level consists of 2-3 icons (depending on whether there are traffic notifications available or not), each one associated with one submenu. A focus area is used for selection and can be horizontally moved through menu items. Each submenu only offers a limited range of functionality and is closed by a back button at the very left side of the submenu. Top-level menu icons, as well as the back button and most interactive elements within the submenu cover 144 arcmin (corresponding to 75 Pixels on the HMD's display area). of the user's FOV (vertically and horizontally). Larger elements within the submenu (status panels) have the same height, but cover between 541 and 816 arcmin. of the horizontal FOV. Text is displayed at a size between 29 and 52 arcmin. of the vertical FOV (depending on the symbol and usage).

Use Cases

Instead of including the entire variety of functions available in today's cars, we focused on 4 use cases, which are frequently used during driving. These use cases were an audio control panel, a message center (for incoming text messages being read to the driver), incoming call and a traffic notification center (to adapt the route guidance to traffic alerts).

Input Modalities

Two different input modalities were put under consideration to control the HMD menu. Both input modalities provide indirect interaction and have been selected to minimize gaze aversion and eyes-off the road time.

First, as an example for an integrated physical input device, we used a rotary controller. Scrolling the selection area (highlighted menu item) through the menu meant turning the controller. Selecting a highlighted element meant pushing it. As an alternative input modality, we implemented static and indirect pointing gestures. Horizontal hand movements are directly translated into horizontal movements of the selection area in the menu. To select a highlighted menu item, the user must press a button on the left side of the steering wheel. To avoid potential interferences with vertical movements of the car, such as those resulting from street surface irregularities, only horizontal hand movements are interpreted. For comfortable interaction, drivers are able to place their arm on an elevated arm rest and move only their hand horizontally.

Both, hand gestures and interaction with the physical controller were performed on the driver's right hand side (the steering wheel in our car mockup was on the left).

System Interruptibility

According to the Alliance of Automobile Manufacturers (AAM), one of the main principles of in-vehicle interaction is that any sequence of visual/manual interaction should be interruptible in a meaningful way [1]. This means that - in case of an interruption - the driver must have the possibility to resume any sequence of interaction at the point of interruption. We considered this recommendation in our system, so that the system state was internally maintained in case of interruption during interaction.

However, we believe that displays that are able to superimpose information on the driving scene require additional effort to provide 'interruptibility'. Situations in which drivers intend to interrupt the secondary task, typically might be such that require maximum attention on the driving task. This is the reason we provide a possibility to detect the driver's intention to interact with the system. Therefore, content in the HMD is only visible after the driver has moved his/her right hand into the area of interaction. In our case, this is the area above the rotary controller. Using a proximity sensor (in our case the Leap Motion sensor), the system detects the presence of the driver's hand in this area, derives the intention of interaction and activates the visualization on the HMD. Once the absence of the driver's hand is detected, the visualization is deactivated. We realized this principle with both input modalities, the indirect pointing gestures and the rotary controller.

STUDY

To assess the performance of our concept and find possible effects of different display conditions and interaction modalities we conducted a user study in a driving simulation.

Goals

The first goal of the study was to examine the effect of the content stabilization technique on driving and secondary task performance. As prior work indicates [14], it is very challenging to realize convincing cockpit-stabilized content with an HMD. Two major problems were identified: first the latency and jitter of today's state-of-the-art optical tracking devices still do not fulfill the requirements of such visualizations. Second, the small display area within the HMD's field of view crops the displayed content when doing very small head rotations. Wickens et al. argue that the costs of information access in a cockpit-stabilized visualization are the same as with cockpit-mounted screens [27]. Therefore, we additionally used a technologically mature HUD mockup for this cockpit-stabilized content. This would allow us to make sure that this stabilization technique would not fail because of technological immaturity. Additionally, it was interesting for us to examine potential effects of the interaction modality on driving and secondary task performance.

Apparatus

We used an industry-grade car mockup and driving simulation for the user study. The driving scene was shown on a cylindrical projection screen, approximately 3 meters in front of the car mockup. Rear view mirrors reflected the content of 3 accordingly positioned LCD-displays behind the seating position of the driver. In the HMD conditions, the driver was wearing a LUMUS DK-32 HMD with a 40° diagonal FOV, showing a 1200 x 720 px. virtual image at a distance of approximately 3 m.

For the physical input device we used a rotary controller, placed at the lower right side of the driver in the car mockup's center stack. A Leap Motion controller was mounted in front of the controller and tracked the user's hand once it was inside the tracking volume (approx. 3-20 cm above the device within an area of approx. 30 x 30 cm). It was utilized in the condition with the physical controller to detect the presence of the user's hand and to derive the intention to interact with the system. In the other condition it detected indirect pointing gestures: horizontal hand movements were directly translated into movements of the selection area in the displayed menu. A selection was accepted by pressing a button on the steering wheel. To provide comfortable interaction in both input conditions, we provided an elevated armrest, allowing the user to comfortably move his/her hand in the area of the controller without having to carry any net weight.

For the HUD mockup we used a semi-transparent mirror (70% transparency), reflecting the content of a 50” plasma screen mounted on the roof of the car mockup (Fig. 3). This resulted in a virtual image hovering at approximately 3 m in front of the driving scene.

Figure 2: Visualization of the use case ‘call’ on the HUD in front of the driving scene from the driver’s perspective.

For better comparability with the HMD condition, we chose an elevated position for the HUD mockup, such that the HUD content was not (as usually) covering the road, but was hovering right above the vehicles in front (Fig. 2).

Figure 3: The HUD mockup in the simulation.

Task and Procedure

We used a mixed 2x3 design for the study (stabilization technique as a within and input modality as a between-subjects factor) to not exceed three test drives per subject. Thus, half of the subjects used the rotary controller as input device, while the other half used hand gestures in combination with the button on the steering wheel to interact with the displayed content. As a within-subjects factor, all of the subjects experienced all possible content stabilization techniques: HMD head-stabilized, HMD cockpit-stabilized and the HUD as a baseline. The order of the three display conditions was permuted to avoid possible training effects. Subjects (N=37, age 19-56, M=33.86, SD=9.86) were mostly male (N=28), right-handed (N=32) and had a technical professional background (N=32). All of the subjects were experienced drivers and had normal or corrected to normal vision. After a short training phase (approx. 5 min.), where subjects were able to get accustomed to the driving simulation and the primary task, they were introduced to the interaction concept. Afterwards they had approximately 5 min. to practice the assigned input modality and the menu navigation and to explore the implemented use cases. Subsequently, subjects had a further test run in which they were allowed to practice menu interaction during driving. Finally, each subject did 3 consecutive test runs, in which driving data and secondary task data were collected.

The primary task in the study was to follow a leading vehicle in the right lane at a distance of 50 m and to maintain a speed of 100 km/h in a motorway scenario. For the secondary task, we assigned 4 slots (after 2.1, 4.0, 6.0 and 8.0 km) on the driving route in which subjects consecutively processed the 4 use cases. All slots had the same length of approximately 72 seconds. Well in time before each slot, the investigator instructed the participant on the task to be fulfilled in the following slot.

Use Case 1. Music Player: Within the submenu of the audio controls, subjects were asked to increase the music volume from initially 15% to about 50% and to change the radio station. The task was completed with the correct radio station selection. In case, the volume was not within the range of 20% to 80%, one task error was logged.

Use Case 2. Message Center: Subjects were instructed to replay a message from a certain sender. The task was completed as soon as the play button was pressed. In case the wrong message was played, one task error was added.

Use Case 3. Incoming Call: The subject was instructed to reject an incoming call by pressing the appropriate button. The task was completed after pushing one of the buttons. One task error was added in case the call was accepted.

Use Case 4. Traffic Notification Center: The system presented a selection of 2 different traffic notifications, each one consisting of a traffic obstruction and an adequate bypass recommendation. Subjects were instructed to select the one recommendation that implicated a temporal advantage instead of sticking to the current route. The task was completed, once a bypass recommendation was selected. In case the wrong recommendation was accepted, one task error was added. In addition to these task specific errors, there were three other possible sources of error. Selecting a submenu (1) or a function (2) within a submenu not essential for the current task, or not being able to complete the current task within the time slot (3) was counted as one task error.

After each test drive, subjects were asked to complete two standardized questionnaires, the System Usability Scale (SUS) [4] and the NASA Raw Task Load Index (Nasa RTLX), a variation of the original NASA TLX [8], in which items are not weighted [9]. Additionally, subjects had to complete several scenario-specific 5-point Likert scales, in which they were asked for their assessments on aspects such as text readability, occlusion and the level of subjective distraction.

Results

Out of the total number of 37 subjects we had to exclude 2 subjects due to technical problems with the setup. In regard to driving data, we excluded another 3 as outliers (more than 3 times the interquartile range above the mean), so that results are calculated from a total of 32 remaining subjects. In regard to secondary task data, a total of 4 subjects were excluded, resulting in 33 valid subject data sets. For secondary task performance the *audio player* task was excluded from evaluation. During evaluation, we assessed that in a total of 55 cases subjects ignored the instructed interaction sequence, which dramatically biased the results.

In the following reports, we use the standard deviation of lateral position (SDLP) and the standard deviation of the distance to the leading vehicle (SD (distance)) as measures for the driving performance. For secondary task performance, we use the total task time (TTT) and the task errors (TE). All results are described by reporting mean values (M) and the standard deviation (SD). For statistical analysis we used an analysis of variance (ANOVA) and corrected t-tests (post-hoc) where possible and Friedmann tests with pairwise Wilcoxon post-hoc tests otherwise.

Effects of Stabilization Technique

Our study did not reveal any significant effect of the stabilization technique on driving performance data (longitudinal and lateral vehicle control). There were only little differences across conditions, but in both cases the lowest values were measured in the HMD cockpit stabilized condition (Fig. 4).

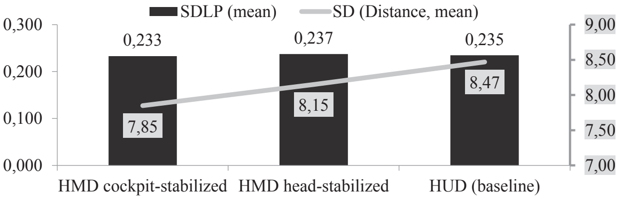

Figure 4: Lateral (SDLP in meters) and longitudinal control of the car for each content stabilization technique.

Reviewing the secondary task performance, we evaluated the tasks independently from one another, because the effort of interaction was not comparable between tasks (e.g., phone call vs. traffic notifications). Generally the HUD condition tended to yield lower task completion times than the HMD conditions (Fig. 5). In the phone task this difference was significant in comparison to the HMD cockpit-stabilized condition (t(32)=2.54, p<.05). In the traffic notification task the HUD yielded a significantly lower total task time than the HMD cockpit-stabilized condition (t(32)=2.18, p<.05) and the HMD head-stabilized condition (t(32)=2.14, p<.05).

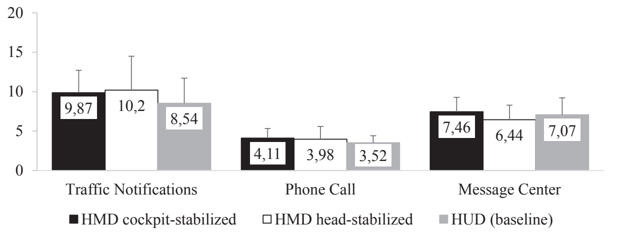

Figure 5: Total Task Times for each task in sec.

In regard to the message task, the HMD head-stabilized condition yielded significantly lower task times than the HMD cockpit-stabilized condition (t(32)=3.40, p<.05). This task was the only one in which the ANOVA test revealed a significant main effect of the stabilization technique (F(1.74, 53.84)=4.0, p<.05). In this case, the prerequisite of sphericity was violated (Mauchly test was significant), so we adjusted the degrees of freedom by using a Huynh-Feldt correction. For the average task errors, there is the tendency that task completion with the HUD generally was more error prone than with the HMD visualizations. This difference was not significant in either condition due to the high standard deviation values (Fig. 6).

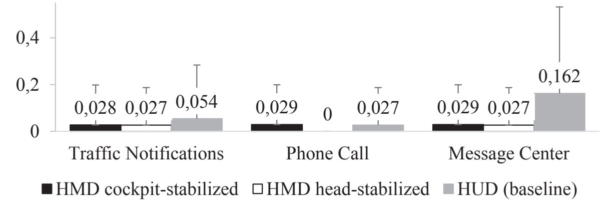

Figure 6: Average task errors across display conditions.

We also assessed the influence of the stabilization technique on the standardized subjective questionnaires, NASA RTLX and SUS. We conducted ANOVA tests and, if effects occurred, paired post-hoc t-tests. Regarding the NASA RTLX (Fig. 7), we found a significant effect of the stabilization technique (F(2,70)=10.9, p<.05).

Paired t-tests revealed that the HUD received significantly lower ratings than both the HMD head-stabilized condition (t(36)=3.27, p<.05) and the HMD cockpit-stabilized visualization (t(36)=4.29, p<.05). Similar effects have also been obtained while evaluating the SUS-ratings (Fig. 7). Again, the effect of the display condition was significant (F(2,70)=21.38, p<.05). The HUD was rated with a higher usability score than both, the HMD head-stabilized visualization (t(36)=3.83, p<.05) and the HMD cockpit-stabilized visualization (t(36)=6.05, p<.05). Additionally, the cockpit-stabilized HMD visualization received lower rankings than the HMD head-stabilized condition (t(36)=3.01, p<.05).

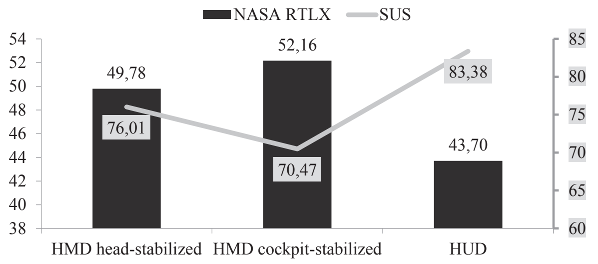

Figure 7: NASA RTLX and SUS values across display conditions.

Effects of Input Modality

In the following paragraph we describe the effects of input modality on driving and secondary task performance.

In general, driving performance was better when subjects used the rotary controller instead of hand gestures (Fig. 8). However, this effect was only significant in regard to the lateral control of the vehicle. Subjects using the rotary controller were able to maintain the ideal track significantly better than those using hand gestures (F(1,30)=5.60, p<.05).

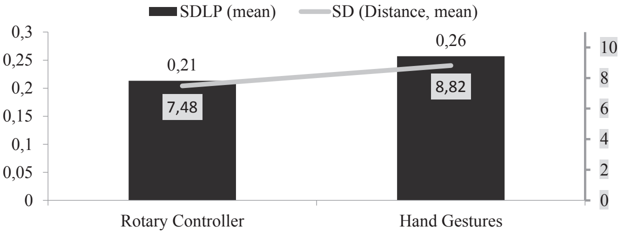

Figure 8: Lateral (SDLP in m) and longitudinal (standard deviation of distance to leading vehicle in m) control of the car for both input modalities.

Analog to the driving performance, the secondary task performance is evaluated separately for each task. In review of the task completion times, there is no clear tendency in favor of one of the input modalities (Fig. 9).

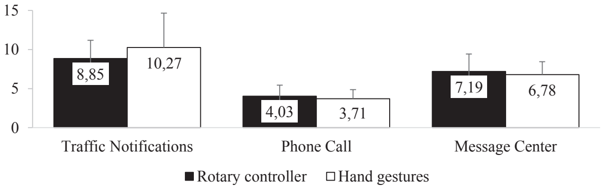

Figure 9: Secondary task completion times (TTT) across input modalities and tasks in seconds.

Subjects were able to complete the message center task and the phone call slightly faster by gesturing. In contrast, the rotary controller was faster in the traffic notification use case. None of these differences was significant. For the task errors we generally obtained very low values, however the rotary controller showed slight advantages in comparison to the hand gestures (Fig. 10). Due to the relatively high standard deviations, this difference was not significant in either condition.

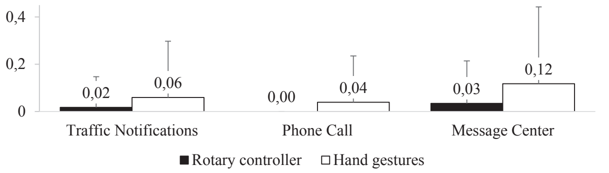

Figure 10: Secondary task errors across input modalities and tasks.

In regard to the subjective cognitive load (NASA RTLX, see Fig. 11), subjects using the hand gestures assessed a higher cognitive workload than the subjects using the rotary controller (t(109)=3.2, p<.01).

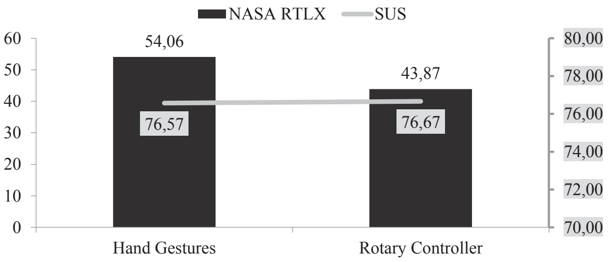

Figure 11: NASA RTLX and SUS values for each input modality.

This tendency was revealed while evaluating the SUS values across input conditions (see Fig. 11). Hand gestures received slightly lower values than the rotary controller. The effect was not significant.

Qualitative Results

Additional differences between conditions were revealed by comparing the mean (M) values of the scenario specific 5-point Likert-scales (level of agreement from 1-'not at all' until 5-'absolutely'). The readability of the text and the steadiness of the visualization both had a significant influence on the data. The HUD was considered to be more comfortable to read (M=4.81) than the HMD cockpit-stabilized (M=3.08) and the HMD head-stabilized (M=3.81) visualization. Subjects agreed that HMD visualizations suffered from unsteady presentation: in the cockpit-stabilized version (M=4.03) this is a result from tracking lag and jitter of the tracking device while in the head-stabilized visualization (M=2.54) this is caused by little head movements, which occur during driving and cause the content to continually move in relation to the background. In the HUD condition this was not considered to be an issue (M=1.24). We also asked subjects if visualizations would occlude any important information from their surroundings. As expected, the head-stabilized HMD visualization was considered to occlude more information (M=2.32) than the HMD cockpit stabilized information (M=1.89) but the difference was not as high as expected and values are generally quite low. Looking at subjective distraction, there were no differences between display conditions, yet interaction with the rotary controller (M=2.68) seemed to be less distracting than gesture interaction (M=3.18). One subject stated that he would prefer vertical gestures, because horizontal gestures 'leaded to unintentional steering movements'.

DISCUSSION

While comparing driving performance with different stabilization techniques, we were surprised that the technologically mature HUD did not outperform all HMD conditions. Instead, the best values in both SDLP and standard deviation of the distance to the leading vehicle, were obtained with the HMD cockpit-stabilized concept variation. This difference, however, is not significant and certainly does not mean that driving with an HMD is safer than with a HUD. However, the technological differences, even for a stabilization technique that relies on head tracking (cockpit-stabilized), seemed not to be the crucial factor for fulfilling the primary task in this scenario.

For secondary task completion times, we obtained slightly better values for the HUD condition, even though the error rate was a bit higher (in 2 of 3 use cases). Most likely, subjects had the impression that they could manage to solve the tasks quickly, which in turn proved to be more error prone. Between the two HMD conditions there were only little differences regarding secondary task completion. We generally obtained larger differences between display conditions in the subjective questionnaires than with objective data. Generally, output techniques can be sorted by technological maturity. As a result HMD output was rated worse than HUD output and HMD cockpit stabilized content (implies tracking) worse than HMD head-stabilized visualizations. In this context it is remarkable that color fidelity, sharpness of the display and the bad ergonomics of the used HMD seemed to be perceived worse than they influenced objective study data.

A very interesting effect could be revealed for horizontal hand gesture interaction. While longitudinal vehicle control did not significantly suffer from gesture interaction, there was a significant negative effect on the lateral control of the vehicle. We believe that this is connected to one of the main characteristics of the used hand gestures: interaction was always aligned horizontally. In contrast, with the rotary controller condition, the hand rested in one steady position. One possible explanation could be that he was unintentionally steering while interacting with his right hand, as given by one subject.

Another interesting aspect is that there was no interaction effect between the content stabilization techniques and the interaction modalities. At least in this use case and scenario, there was no input modality, being more suitable for one specific stabilization technique. This was surprising, as we expected that at least the cockpit-stabilized visualization, being very unsteady and constantly moving due to of head tracking inaccuracies, would interfere with hand gestures.

CONCLUSION AND FUTURE WORK

We developed and successfully evaluated a user interface for HMDs with indirect interaction. We varied content stabilization and the interaction modality, measured potential effects on driving performance and secondary task performance and collected subjective feedback on task workload and remaining problems. Our study could not show any significant effect of the stabilization technique on driving performance. The best results were measured for the HMD cockpit-stabilized visualization, followed by the HUD (also cockpit-stabilized). This might be an indication for possible advantages of cockpit-stabilized content, but more work in this direction will be necessary. When the primary task gets more demanding, potential differences might show up more clearly. Specifically measuring the situation awareness in different driving scenarios under varying stabilization conditions will be very interesting.

The negative effects of horizontal gesture interaction on the lateral control of the car (SDLP-values) are interesting findings, which might question the usefulness of gesture interaction in cars. While vertical gestures potentially are influenced by bad road conditions, horizontal gestures seem to implicate unintentional steering with the other hand. However, this is an aspect, which also needs to be examined more carefully. Future studies might explicitly compare vertical and horizontal gestures in this aspect.

The subjective feedback on interaction with an HMD user interface is highly biased by the technological state of current hardware prototypes. Dynamic tracking errors as well as the HMD's low display quality, its narrow field of view and poor ergonomics will be the key factors to be solved by manufacturers and they will determine whether or not those systems will establish themselves in the mass market.

We had one prerequisite while developing our concept: we combined a new technology, supposed to be advantageous in regard to gaze behavior with indirect interaction techniques, which also do not need any direct hand-eye coordination. However, we have not yet been able to prove that this combination really improves gaze behavior as we assumed in light of prior work. In order to successfully track the user's eyes while wearing an HMD, two problems must be solved. First, the sensor must be mounted on the glasses itself (e.g., with a swan-neck camera) and directly focus on the user's eye without being disrupted by the glasses themselves. Secondly, one must be able to differentiate between the fixation of virtual content in the glass and elements of the surrounding world. This especially is demanding in the context of driving simulations, as the simulation is typically located at approximately the same distance as the glasses' projection plane.

REFERENCES

[1] AAM Driver Focus-Telematics Working Group. *Statement of principles, criteria and verification procedures on driver interactions with advanced in-vehicle information and communication systems*, June 2006

[2] Akyol, S., Canzler, U., Bengler, K. and Hahn, W. Gesture control for use in automobiles. *IAPR Workshop on Machine Vision Applications 2000*.

[3] Bock, T., Maurer, M. and Färber, G. Vehicle in the Loop (VIL) - A new simulator set-up for testing Advanced Driving Assistance Systems. *Driving Simulation Conference*, 2007.

[4] Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability evaluation in industry*, 189, 194.

[5] Burnett, G. E. A road-based evaluation of a head-up display for presenting navigation information. *Proc. of the HCI international conference* 2003.

[6] Cairnie, N., Ricketts, I.W., McKenna, S.J., McAllister, G. Using finger-pointing to operate secondary controls in automobiles. In *Proc. of Intelligent Vehicles Symposium 2000*. IEEE, 2000.

[7] Charissis, V., Papanastasiou S. and Vlachos, G. Interface Development for Early Notification Warning System: Full Windshield Head-Up Display Case Study. *Human-Computer Interaction. Interacting in Various Application Domains*, Springer, 2009.

[8] Hart, S. G. NASA-task load index (NASA-TLX); 20 years later. In *Proc. of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 50, No. 9, pp. 904-908). Sage Publications. 2006.

[9] Hart, S. G. and Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology*, 52, 139-183.

[10] Harvey, C., Stanton, N. A., Pickering, C. A., McDonald, M., & Zheng, P. To twist or poke? A method for identifying usability issues with the rotary controller and touch screen for control of in-vehicle information systems. In *Ergonomics*, 54(7), 609-625.

[11] Kiefer, R. Older Drivers' Pedestrian Detection Times Surrounding Head-Up Versus Head-Down Speedometer Glances. *Vision in Vehicles* -VII, Elsevier, 2000.

[12] Kiefer, R. Defining the “HUD benefit time window“. *Vision in Vehicles*-VI, 1998.

[13] Laquai, F., Ablassmeier M., Poitschke, T. and Rigoll, G. Using 3D Touch Interaction for a Multimodal Zoomable User Interface. Proc. *on Human Interface* 2009.

[14] Lauber, F., and Butz, A. Are HMDs the better HUDs? In *Proc. ISMAR ’13*. IEEE, 2013.

[15] Lauber, F. and Butz, A. In-Your-Face, Yet Unseen? Improving Head Stabilized Warnings To Reduce Reaction Time. In *Proc. CHI ’14*. ACM (2014).

[16] Lauber, F., Follmann, A., Butz, A. What You See Is What You Touch: Visualizing Touch Screen Interaction in the Head-Up Display. In *Proc. DIS ’14*.

[17] Laschinsky, Y., von Neumann-Cosel, K., Gonter, M., Wegwerth, C., Dubitzky, R. and Knoll, A. Evaluation of an Active Safety Light using Virtual Test Drive within Vehicle in the Loop. In *ICIT 2010*, IEEE.

[18] Liu, Y.-C. and Wen, M.-H. Comparison of head-up display (HUD) vs. head-down display (HDD): driving performance of commercial vehicle operators in Taiwan. *International Journal of Human-Computer Studies*, 2004.

[19] Löhmann, S., Knobel, M., Lamara, M., and Butz, A. Culturally Independent Gestures for In-Car Interactions. In *Proc. INTERACT ‘13*. Springer 2013.

[20] Mahr, A., Endres, C., Müller, C. and Schneeberger, T. Determining human-centered parameters of ergonomic micro-gesture interaction for drivers using the theater approach. In *Proc. AutomotiveUI 2011*. ACM (2011).

[21] Milicic, N. and Lindberg, T. Menu interaction in Head-Up Displays. *Human Factors and Ergonomic Society*, 2008.

[22] Neureiter, K., Meschtscherjakov, A., Wilfinger, D. and Tscheligi, M. Investigating the Usage of Multifunctional Rotary Knobs in the Center Stack with a Contextual Inquiry. In *Adj. Proc. AutomotiveUI 2011*. ACM (2011).

[23] Pickering, C. A., Burnham, K. J. and Richardson, M. J. A research study of hand gesture recognition technologies and applications for human vehicle interaction. *Automotive Electronics, 2007*. IET.

[24] Prinzel, L., and Risser, M. Head-up displays and attention capture. *NASA Technical Memorandum*, 213000, 2004.

[25] Schmidt, A., Dey, Kun, A.L., and Spiessl W. Automotive user interfaces: human computer interaction in the car. In *CHI EA 2010*. ACM, New York, NY, USA, 3177-3180.

[26] Sojourner, R. J. and Antin, J. F. The Effects of a Simulated Head-Up Display Speedometer on Perceptual Task Performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 32(3):329–339, 1990.

[27] Wickens, C. D., Vincow, M., and Yeh, M. Design applications of visual spatial thinking: The importance of frame of reference. *The Cambridge handbook of visuospatial thinking* (2005): 383-425.

[28] Yeh, M., Wickens, C.D., and Seagull F. J. Effects of frame of reference and viewing condition on attentional issues with helmet mounted displays. No. ARL-98-1/ARMY-FED-LAB-98-1. Illinois Univ., 1998.