Perceptual and Safety Aspects of Augmented Reality Head-Up Displays in Cars

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Abstract

This study aimed to design visual information for a navigation feature in an Augmented Reality (AR) Head-Up Display (HUD) and integrate the graphics into a Volvo XC60 concept car. The implemented graphics were then tested with users driving the vehicle on public roads. The results were analyzed to determine whether AR-HUD could enhance perception, attention, and safety. User evaluations revealed that AR-HUD helped drivers keep their eyes on the road more frequently when using AR guidance compared to a conventional HUD. Both qualitative and quantitative data indicated that presenting clear and well-timed information for an optimal duration was the key factor in designing human-machine interfaces that support effective user interactions.

Author Keywords

Augmented Reality (AR), Head-Up Display (HUD), AR-HUD, safety, perception, navigation

1. Introduction

The automotive industry is advancing toward a future of electrification, autonomous vehicles, and connectivity, creating a need to investigate user experience and technological innovation [1]. The progression of automotive technology has made user-centered approaches the norm in the development of Human-Machine Interfaces (HMI), emphasizing user perspectives to ensure system usability [2].

Historically, drivers' information has been positioned on the dashboard, requiring them to shift their attention away from the road, which could increase the risk of accidents [3]. To deliver essential information without diverting drivers' focus, manufacturers began implementing Head-Up Displays (HUDs), which project two-dimensional (2D) visual information. This information can be quickly recognized, helping to minimize road distractions. However, representing the surrounding road environment with 2D graphics proved challenging. Lee*, et al.* [3] suggests that three-dimensional (3D) graphics, capable of projecting virtual images of the real environment, became feasible with the introduction of Augmented Reality (AR) in HUDs. AR, a relatively recent technology [4], opened new possibilities for integrating virtual information and objects into real environments [5], see Figure 1. The earliest AR applications used video-based screens that displayed video with AR overlays, and as technology advanced, they evolved into see-through windshield applications [6]. With ongoing advancements, the most effective AR-HUD solutions are believed to be developed by those who prioritize perceptual and attentional factors in their design [7]. Key challenges in developing driver information systems include determining where to present information, what content to include, how users interact with the system, how to assess usability, and who should be involved in evaluations. Driving remains the primary task, requiring both local guidance and global awareness for navigation. Local guidance pertains to situational awareness and immediate driving tasks, while global awareness involves understanding the route to the destination and the strategic steps to reach it [7].

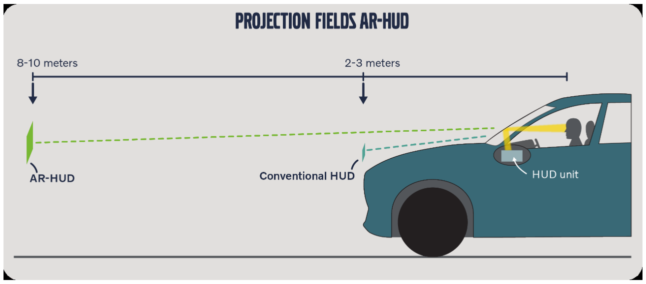

Figure 1: Different virtual image distances of projection between AR-HUD and conventional HUD.

A Head-Up Display (HUD) is a display system that overlays virtual images onto a transparent display within the user's field of view, either on the windshield or a separate combiner [8], see Figure 1. Only in recent years have HUD technology advancements reached a level of maturity sufficient to attract interest from the automotive industry [9]. Augmented Reality (AR) is defined, independent of specific technologies, by the following characteristics [10, 11]:

1) Integration of virtual and real objects within a real-world environment.

2) Real-time interaction.

3) Accurate alignment and registration of virtual and real objects in three dimensions.

The term AR-HUD refers to HUD systems capable of extending projection distances, effectively bringing AR technology closer to practical implementation.

The objectives of this study were to design and assess user interaction in an AR-HUD to enhance user experience and determine its potential contribution to safer driving. These objectives can be divided into two parts: the first focuses on evaluating visual information design. The second examines user experience by assessing drivers' perception, attention, and safety when operating a vehicle equipped with an AR-HUD. This paper primarily focuses on the latter. For a comprehensive report, see [12].

2. Method

A set of navigation graphics was designed using a slightly modified version of the iterative human-centered design cycle [13], see also [12]. To evaluate them and gather insights into perception, attention, and safety, a user study was conducted. The evaluation was planned to take place in a Volvo concept test car on public roads. To enable visualization without developing a full navigation system, specific routes were selected, and navigation graphics were pre-programmed to appear based on GPS positions.

The user tests were conducted in a test car that was operable on

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public roads. The test car was a series-production Volvo XC60, where the standard HUD had been removed and replaced with a prototype AR-HUD featuring two separate image planes: a far-field virtual image projected 8 meters from the driver's eyes and a near-field virtual image plane projected 2 meters away, positioned in the lower part of the driver's field of vision, as schematically shown in Figure 1. Thus, the same vehicle and head-up display setup allowed for a comparison between AR visualizations in the far field and "conventional" (non-AR) visualizations in the near field.

Two routes were chosen, starting from Volvo Cars in Göteborg, Sweden, to a destination approximately 7 km away, with a nearly identical return route. In the first part, drivers were guided using AR graphics. This route included both highway segments and smaller urban or community roads. In the second part, drivers followed traditional turn-by-turn navigation displayed in the conventional HUD projection field. Each route took around 10 minutes, leading to a total driving evaluation time of 20 minutes.

Test drivers were invited to the test vehicle, where they signed a consent form and received instructions on their tasks. They were informed that they could withdraw from the experiment at any time without any negative consequences.

The drivers were observed during the test drive and video recorded for later analysis. The audio recordings captured verbalized thoughts about the interaction while driving. Safety-related actions, general behavior, and appropriate safety checks were analyzed from the video recordings of users operating the vehicle. To examine when information was presented in the two projection fields and its effect on user attention, the number of downward glances toward either the near field or the driver information module (DIM; i.e., the instrument cluster) was recorded. The frequency of drivers shifting their gaze away from the road served as an indicator of whether information presented in the AR-HUD contributed to safer driving. A visual analysis of the recorded videos was conducted to compare downward glances toward the near-field HUD or DIM with focus on the AR field or the road. When participants focused on the AR field or the road, their gaze resembled the left image in Figure 2. When seeking information in the near-field HUD or DIM, drivers' gaze was directed further downward, as shown in the right image of Figure 2.

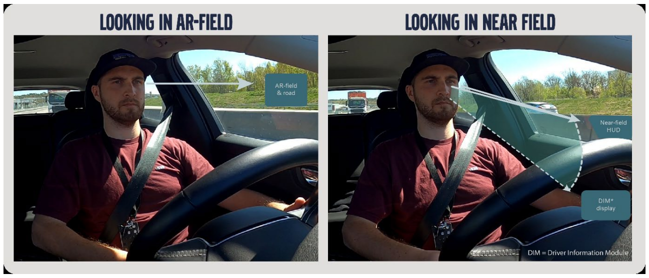

Figure 2: The difference in eye gaze focusing on road and near-field.

After the completing the drive the test participants filled in a post questionnaire. The following questions were asked:

Q1. How well was your ability to safely operate the car with guidence from the AR graphics? (Rating scale: 0 to 5; 0 = Not well at all; 5 = Very well) Why?

Q2. How useful was the the information given by the AR graphics when operating the car? (Rating scale: 0 to 5; 0 = Not useful at all; 5 = Very useful) Why?

Q3. How well timed was the graphics? (Rating scale: 0 to 5; 0 = Not well time at all; 5 = Very well timed) Why?

Q4. What was your experience comparing navigation graphics displayed in the upper and lower projection fields? (open question)

Q5. Do you have any thoughts or feelings about your experience driving and the concept? Any thoughts of improvements and why? (open question)

3. Results

3.1. Participants

The test included 15 participants—4 women and 11 men—ranging in age from 24 to 56 years. The average age was 39, with a median age of 40. Four participants had previously been involved in this project, either in a development or evaluation phase. All participants had at least 7 years of driving experience (mean: 20 years) and drove more than 2 hours per week, with most exceeding this, averaging 9 hours. They regularly used navigation systems, with the majority preferring built-in options. Most participants had prior experience with HUDs, and four had used AR-HUD. All had driven the Volkswagen ID.3 or ID.4.

3.2. Glance frequency

The glance frequencies, i.e., the number of glances per second, for the AR-HUD compared to the conventional HUD across all participants, are presented in Figure 3. All participants showed higher glance frequencies when information was displayed in the near field (corresponding to the conventional HUD) than in the far field of the AR-HUD.

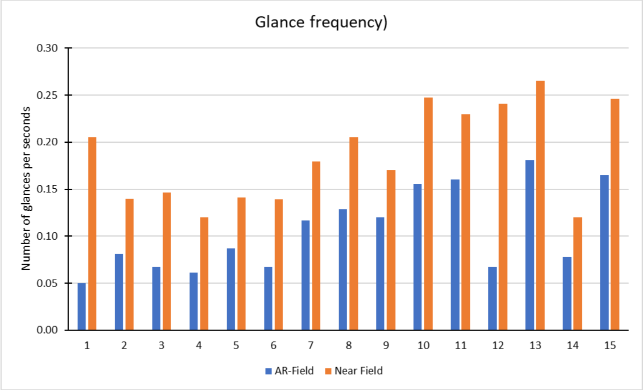

Figure 3: Number of glances in near-field or DIM per second of driving. Observed from video recordings.

Another way to illustrate the difference is by comparing the mean glance frequency, as shown in Figure 4. The error bars represent 95% confidence intervals. A two-sided paired Student's t-test indicates that the difference between the means is statistically significant ($p < 0.0001$).

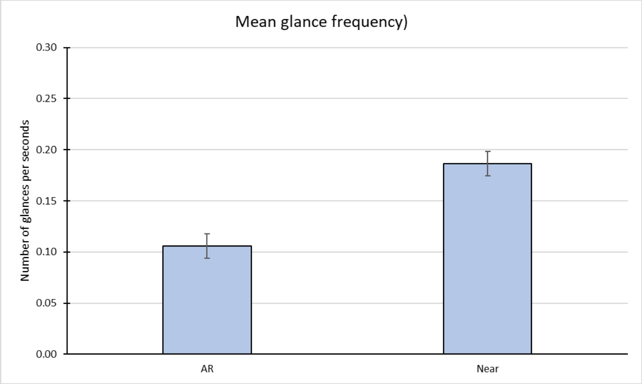

Figure 4: Mean number of glances in near-field or DIM per second of driving. Observed from video recordings. Error bars represent 95% confidence intervals.

3.3. Post questionnaire

The results from the scale response to Q1 in the post-questionnaire are shown in the left bar of Figure 5, displaying the mean and 95% confidence interval. It suggests that most participants felt confident in their ability to operate the vehicle safely. The majority stated that driving with the AR-HUD did not differ significantly from driving without a HUD in terms of keeping their eyes on the road. They also reported that the graphics were easy to understand and helpful for navigation.

The results regarding the usefulness of information displayed in the AR field (Q2) received an equally positive response frequency, as shown in the middle bar of Figure 5. The qualitative responses indicated that the presented information was both useful and easy to understand. Some participants expressed a need for additional details about the distance to upcoming actions. There was also a desire for supplementary lane change graphics, including clearer indications of the current lane and more precise lane information. Some participants wanted an indication that the AR-HUD was still active, as the graphics only appeared when an action was required. The "keep straight for 2 kilometers" graphic was appreciated, as it provided reassurance that no immediate action was needed, allowing drivers to focus on the road.

The timing of graphics (Q3) was the primary aspect participants provided feedback on after the test. The scale responses indicated that participants found the timing insufficient, as shown in the right bar of Figure 5. These results were not entirely negative but suggested that there was room for improvement in timing. Most of the qualitative feedback focused on the timing of the graphics, with participants stating that the graphics appeared too late and that the information should remain visible for a longer duration. They expressed a preference for receiving information earlier to better plan their driving. The situations that received the most feedback regarding timing were lane changes before intersections and guidance before roundabouts. Participants wanted an earlier "heads-up" when approaching intersections.

The qualitative question on user experience compared the AR field with the near field. Most participants stated that the AR field was superior, more enjoyable, and easier to use due to the larger graphics. Participants also appreciated not having to divert their gaze from the road to seek guidance. It was easier to miss instructions in the near field because the graphics were smaller, making them feel the need to focus more on that area.

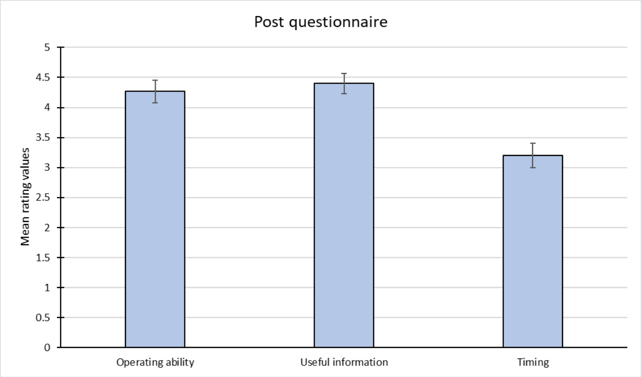

Figure 5: Results of the rating scale questions in the post questionnaire. Error bars represent 95% confidence intervals

4. Discussion

The primary purpose of AR-HUD is to allow drivers to keep their eyes on the road while simultaneously receiving critical information about upcoming events. Observing users operating the vehicle and analyzing the effects of AR-HUD navigation versus traditional HUD navigation on attention and distraction, the results clearly showed that AR graphics were less distracting than a traditional HUD. Observations indicated that users scanned their surroundings more frequently when using AR graphics, enhancing situational awareness and promoting safer driving. Although this evaluation provided evidence supporting AR navigation, there are also potential risks associated with projecting graphics in the driver's field of view. If graphics are designed to be overly attention-grabbing or too visually dominant, they could distract the driver and create hazardous situations. Therefore, the technological limitation of the system in the concept car may be advantageous, as it restricts the area of the windshield available for projections.

The manual analysis of gaze direction from video recordings was less accurate than it would have been with an eye tracker. This may have influenced the results. However, the difference between the two cases was substantial. It is therefore likely that the findings would remain valid even with a more precise measurement method.

The concept developed was a predefined implementation of a set route with a small participant sample. Future research should first focus on evaluating the concept with a larger sample size, ensuring a more balanced distribution of male and female participants. Furthermore, the evaluation would also benefit from involving external users beyond Volvo Cars to reduce potential bias. The statistical significance of the results would then be more generalizable, further validating the benefits of using AR-HUD. Additionally, if an eye-tracking device were used, eye movements—previously analyzed through video observations in this study—could be measured more accurately.

5. Conclusions

This project adopted a human-centered approach, which is strongly recommended for future development efforts. User evaluations clearly indicated that all participants had different experiences while driving the vehicle equipped with an AR-HUD. Therefore, user experience and the interaction between the user and the system are recommended as the most critical factors. This project also demonstrated that qualitative data from evaluations is just as essential as measurable data. Maintaining a balanced mix of data types is therefore crucial for obtaining a comprehensive understanding of users' interactions with the system.

From the quantitative gaze data, the AR-HUD demonstrated a clear safety advantage by enabling drivers to keep their eyes on the road. It was easy to use, and the information was valuable, though the timing required improvement.

6. Acknowledgements

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