Evaluating Automotive Augmented Reality Head-up Display Effects on Driver Performance and Distraction

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ABSTRACT

As the automotive industry progresses towards the car of the future, we have seen increasing interest using augmented reality (AR) head-up displays (HUD) in driving. AR HUDs provide a fundamentally new driving experience in which drivers still have to respond to both the road and the information provided by the system, creating the perfect atmosphere for potentially unsafe and distracting interfaces. As we start fielding and designing for new AR HUDs displays, the complexities of interface design and its impacts on driver performance must be further understood before AR HUDs can be broadly and safely incorporated into vehicles. Nevertheless, existing methods for assessing the usefulness of computer-based user interfaces may not be sufficiently rich to measure the overall impact of AR HUD interfaces on human performance. Therefore, in my Ph.D. research, I focus on developing and testing methods to evaluate AR HUDs' effects on driver distraction and performance. My primary goal is to assess glance allocation and visual capabilities of drivers with AR HUDs and apply this knowledge to inform new methods of AR HUD assessment that account for inattentional blindness and cognitive tunneling.

Keywords: Augmented Reality, Head-Up Display, Driving.

Index Terms: H.5.1: Multimedia Information Systems — Artificial, Augmented, and Virtual Realities; H.5.2: User Interfaces — Ergonomics, Evaluation / Methodology, Screen Design, Style Guides

1 INTRODUCTION

The role of Augmented Reality (AR) in the automotive industry has increased considerably over the last decades. Vehicles with AR graphics delivered via head-up displays (HUDs) are nearing mainstream commercial feasibility, and very shortly, we expect increasingly large AR HUD field of views at varying depths. This technological advance will allow information to be placed in several locations, from windshield-fixed positions to conformal graphics which appear to be linked to real-world objects. The cognitive and perceptual separation between AR graphics and real-world visual stimuli will, therefore, be more difficult to quantify.

Quantifying the visual and cognitive requirements of AR HUDs is crucial for assessing whether the technology is hazardous and distracting for use in transportation applications. Nevertheless, current methods for evaluating user interfaces in this space do not account for the fact that AR HUDs are not merely in the environment, but are instead an integrated part of the environment. Specifically, AR HUD interfaces exist within the line of sight needed to perform the primary visual driving task; moreover, these AR interfaces may be present independent of whether or not drivers should be attending them.

In this context, this work herein aims to address the following question: *When AR HUD user interfaces are visually integrated into the primary task space, what are the best methods to assess AR HUD's effect on driver performance?* To examine the uniqueness of attention management in visually integrated environments, I will explore two crucial psychological perceptual phenomena: cognitive tunneling and inattentional blindness. Such definitions will be clarified in the next section.

2 BACKGROUND

Without attention, people fail to perceive important visual features of the environment they are looking at [1]. This phenomenon is known as *inattentional blindness* [2], that in simple words, means looking without seeing. Because the primary task of driving poses high cognitive demand on the driver, the visual information presented in the user's field of view by AR HUDs could be overlooked if the person's attention is focused on another activity or the environment. It is, therefore, essential to examine and consider how AR HUDs affect these perception breakdowns in dangerous driving situations in which drivers must respond quickly to centralized road hazards, such as other vehicles and pedestrians. In this study, I will use the Central Detection Task (CDT) to examine inattentional blindness. CDT is a well-established method for examining inattentional blindness of important real-world events while performing secondary AR HUD tasks. In transportation research, CDT has been used to investigate inattentional blindness in terms of drivers' ability to perceive a shift in traffic light color [3, 4] and a lead car's brake [5].

Cognitive tunneling is a phenomenon in which people involuntary fix mental resources on one aspect of the interface at the expense of other sources of information [6]. This effect is often studied using the peripheral detection task (PDT) method in which drivers' visual distraction in driving can be assessed by measuring the cognitive selectivity of attention [7]. In this study, the PDT task will place targets directly on the road scene at different levels of eccentricity, as used by Huisingh et al. [8].

3 PROPOSED WORK

The proposed work will be carried out in four major phases, which will be described below. To accomplish the goals outlined in this paper, I will be working at the Virginia Polytechnic Institute and State University with my dissertation advisor, Dr. Joseph L. Gabbard. I will collect empiric human-factor data for each step through a series of carefully designed user studies, using a fixed-based, medium-fidelity driving simulator at the Cogent Lab. This simulator is composed of the front half of a 2014 Mini Cooper cab fitted with a curved projection with 94 degrees of view displaying a simulated road scene and contains both side and rear-view mirrors that allow participants to view their surrounding environment. The simulator also contains a 7" Lilliput USB monitor mounted directly behind the steering wheel to convey vehicle speed information.

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Additionally, the simulator is equipped with a Pioneer Cyber Navi HUD with conformal AR graphics capabilities. The area displayed on HUD is 780x260 pixels, FOV is 15 degrees and the virtual image position is approximately 3m away from the eyepoint. The driving simulator software is integrated with customized software, developed using X3D and Python, so that the AR HUD can provide real-time 3D AR graphics perceptually overlaid into the dynamic CG-generated driving scene. That is, unlike other studies that render AR directly into a simulated environment (e.g. using virtual reality), our testbed renders AR graphics onto an aftermarket HUD, calibrated to a projected road scene to produce a more ecologically valid driver experience

Figure 1: Lab's AR HUD can be display graphics that are both screen-relative and conformal to the simulated world (top left). Top view (right) and side view (bottom right) of driving simulator

Phase 1: Establishing thresholds for AR HUD glance duration. We conducted three human-factors user studies in which we have employed generic psychophysical and ecologically-valid AR HUD tasks to systematically examine the effects of extended single glance durations on driver performance. In this phase, we aimed to answer two main questions *(1) How long can a driver safely glance at an AR HUD? (2) How long will a driver safely glance at an AR HUD?*

For question 1, recent work by Gabbard [9] suggested that AR HUDs can afford more prolonged glances with no decrement in driver performance; thus, the current upper threshold standard of 20 seconds [10] may not be applicable for AR HUDs. Therefore, we used a random letter reveal technique to examine longer sustained AR HUD glance durations (e.g., 2, 5, 10, 15, 20, 30, 40, and 50 seconds) on driver performance and distraction. For question 2, we developed two ecologically-valid secondary tasks (e.g., incoming text messaging and picking from a list) to investigate how long drivers choose to glance at an AR HUD. The findings of this process are still at the analysis level.

Phase 2: Developing Central Detection Task (CDT) methods and metrics to assess the effects of AR HUD visual demand on inattentional blindness. **Phase 3:** Developing Peripheral Detection Task (PDT) methods and metrics to evaluate the effects of AR HUD visual demand on cognitive tunneling.

For these two stages, I need to understand better how to create an experimental task that engages participants in the driving task while attending to HUD graphics. I will welcome input and insight into the AR tasks to be used, the theoretical nature of both CDT and PDT tasks, and the complexities of the simulation system to be designed.

Phase 4: Validating combined CDT and PDT methods - We plan to conduct a final human factors user study to test our CDT and PDT methods on an actual roadway (Virginia Smart Road). Here an open question to be discussed: How can real-world variables be mitigated when using AR is used in open environments to test AR interfaces built-in a close environement driving simulator?

4 Conclusion

We still have much to learn on how attending to integrated AR HUD graphics affects driving performance, how well we can leverage AR graphics to guide visual attention to important real-world hazards, and to what extent the visual onset of HUD graphics draws attention away from the driving scene. Because this work is still in its infancy, I would like to highlight some of the questions that could be discussed during the consortium that will better shape my work:a) Is inattentional blindness and cognitive tunneling the best measures of distraction when using AR HUDs? b) Are there any other AR perceptual considerations that I should include in the context of my work? (c) What are the best methods for assessing the ecological validity of the AR tasks used in this research? Finally, I am also seeking feedback on the design of the user studies, and on the metrics that will be used to evaluate these new methods.

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