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Design Principles and User Experience of Automotive Head-Up Display Development

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ABSTRACT

The paper presents a comparison of three prototype Head-Up Display interfaces aiming to improve drivers' safety. The evaluation attempts to identify their user-experience commonalities which are prefered by the drivers and improve their driving pattern and safety.

1 Introduction

Visual, auditory and haptic interfaces have been employed in recent years to ringfence driver's attention to the primary task and simplify the interaction with the multiple infotainment systems [1,2]. By offering access to information and interaction through multimodal interfaces current automotive consumer electronics attempt to merge the daily requirements with the in-vehicle infotainment provision. Yet, that multiplicity of sources and interaction has been found to increase significantly the driver's cognitive load and result in fatal or debilitating accidents for the vehicle occupants [3,4].

In our previous work, we developed and tested multiple interface HUD designs and interaction methods in an attempt to control and prioritise the incoming information whilst offering a quick and simple interaction with only the crucial information [5-9]. During the design and development of the aforementioned interfaces, we have identified some commonalities between the systems and the responses of the users in the different evaluation stages. To define accurately these initial findings and inform future interface design and development, we have evaluated the three systems with a focus group of ten users.

The paper presents the design considerations and user experience feedback from the users' focus group that experienced and evaluated all three different Head-Up Display systems aiming to support the driver and reduce vehicular and environmental distractions during driving. These HUD systems were designed to tackle different distraction sources.

The paper also presents the results of the users' mental and physical workload as well as their collision avoidance performance through the comparative study. The paper concludes with a discussion and recommendations for the development of similar HUD interfaces. Finally, the paper presents a tentative plan of work focusing on enhancing further human spatial and situational awareness resulting in improved response times and increased safety.

2 Experiment

To identify the commonalities and differences that affected the users in previous experiments between the three AR HUD interfaces we have developed a test for a group of users to experience all three systems. This group of users would evaluate the three HUD systems in the same VR driving simulator which will record the same types of performance information for each driver and simulation scenario.

2.1 Software and Hardware Requirements

A. Software

The driving simulator is the fourth evolution of a VR driving simulator built to accommodate different terrains, weather and lighting conditions. The simulator presents a simplified version of 28 miles of the motorways around Glasgow. Beyond the life-like sensory stimulus, the simulator records several variables such as vehicle speed, position on the road, distance from neighbouring vehicles, braking and acceleration amongst others. The simulator utilised the Unity3D games' engine.

B. Hardware

The evaluation took place in the Virtual Reality Driving Simulator (VRDS) laboratory which hosts a real-life vehicle (Mercedes A Class 2003) customised to accept different in-vehicle consumer electronics for testing purposes.

A fully immersive VR projection system in a form of CAVE (Cave Automatic Virtual Environment) enhances the visual reality of the simulation. In addition a 5.1 surround audio system and an in-vehicle vibration system immerse further the user in the driving experience as presented in Figure 1.

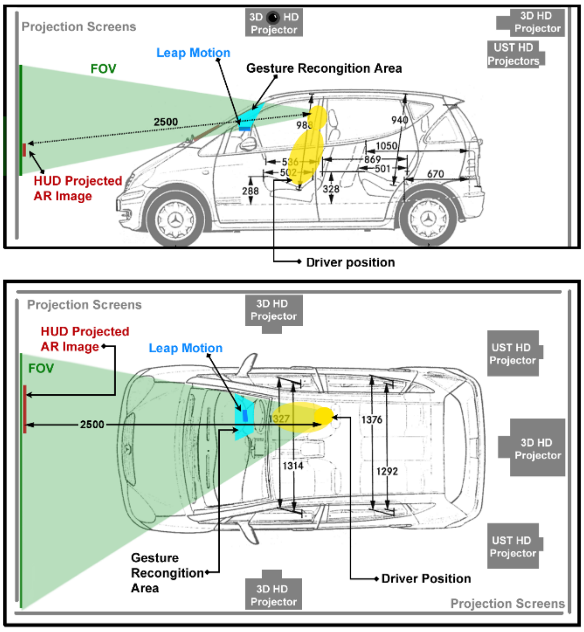

Fig. 1 VR Driving Simulator schematics [8]

2.2 HUD Systems for Evaluation

The three HUD systems selected to evaluate were previously developed respectively to relieve driver's attention from (a) navigation/guidance issues, (b) infotainment sources and (c) passengers distraction as depicted in Figures 2,3 and 4 respectively [10-12]. The latter was a hybrid version combining navigation support for the driver whilst offering a HUD infotainment system for the rear passengers.

Fig. 2 HUD1: AR HUD for navigation/guidance.

Fig. 3 HUD2: AR and gesture recognition HUD for infotainment.

Fig. 4 HUD3: AR and gesture recognition HUD for passenger infotainment and driver's HUD interface for navigation.

2.3 Participants

The results presented in this paper are based on the evaluation of 10 users; 5 female and 5 male, aged between 20 and 65. All the participants held valid UK driving licences.

2.4 Evaluation Process

The evaluation process entailed a pre-questionnaire (a) aiming to identify users' demographic information, previous experiences with simulations, gaming, VR and other elements that might affect their performance or responses.

The second stage of the experiment presented a (b) collision accident scenario in the VR driving simulator with and without a HUD interface. The simulation presented in low visibility conditions to challenge further the users and the HUDs' functionality. The three HUD interfaces were evaluated in sequence. The duration of each experiment was approximately 10 minutes.

After the completion of the simulations, the participants offered their subjective feedback on a post-questionnaire (c). In particular, in the post questionnaire, the three interfaces were evaluated based on their ability to present information and offer interactivity based on eight main user interface characteristics namely:

(1) Clear, (2) Concise, (3) Familiar, (4) Responsive, (5) Efficient, (6) Consistent, (7) Forgiving and (8) Attractive, as presented in Table 1. The questions utilised a 5 point Likert scheme varying from (1) Strongly Disagree to (5) Strongly Agree. In addition, the colour-coding and design of the symbols utilised was also investigated as well the manner of interaction such as visual, auditory and haptic. In the following section, the paper will present the results in particular questions of interest that highlighted the commonalities between the three systems that affected the most the user experience.

3 Results

The subjective feedback received from the users on the post questionnaire reflected closely their driving performance and collision occurrences throughout the different simulations.

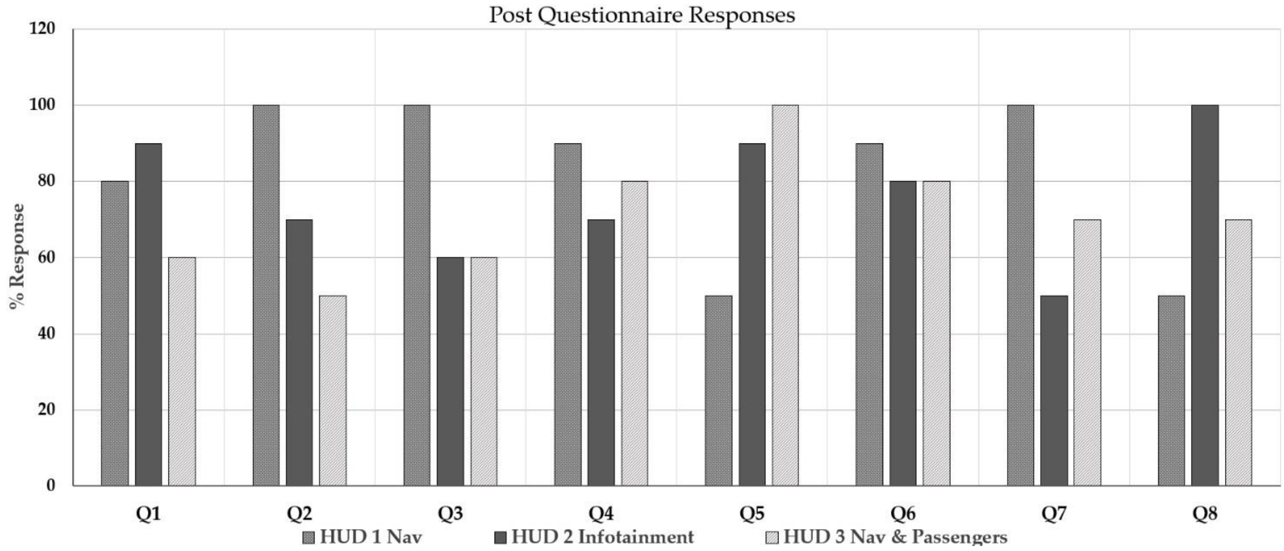

Fig. 5 Post Questionnaire Responses in the three HUD evaluations.

Table 1. Post-Questionnaire Characteristics

Q1.	I found the HUD interface clear and simple.
Q2.	The HUD was concise and easy to understand.
Q3.	The HUD interface was responsive (no lags).
Q4.	The interface was efficient and fast to operate.
Q5.	The interface was using familiar symbols.
Q6.	The user-interface design was consistent.
Q7.	The interface could easily revert from accidental or wrong choices by the user (forgiving interface).
Q8.	The interface design was aesthetically pleasing.

In particular, the three HUD interfaces presented some differences related primarily to their multimodal interactions as presented in Figure 5. As such the HUD 3 (Navigation and Passenger Infotainment system) scored 100% on the Q5 related to familiarity in contrast to the HUD 1 Navigation and guidance which scored only 50% as the majority of the symbols used are not currently available on the vast majority of the cars. However, HUD 1 was designed to be a fast and simple interface assisting the driver in collision avoidance manoeuvres so it scored highly in Q2 and Q3 where the other interfaces were not as successful.

Regarding the aesthetics of the interfaces investigated in Q8, highlighted that familiarity and aesthetics were closely related as the users prefered designs that stylistically resemble symbols and design cues from the smartphone domain. As these are currently dominating users' daily life, it is understandable that they gradually guide the users' aesthetics and requirements through the evolution of these user interfaces (UIs).

The collision avoidance results though painted a different picture that was not related directly to the users' preferences and aesthetics but was rather towards the speed and efficiency to operate as can be seen by the collision occurrences that occurred in total by all 10 drivers per HUD interface simulation as illustrated in Figure 6. The collisions that occurred with the HUDs were significantly less than without (HUD1 3 collisions, HUD2 6 collisions and HUD3 8 collisions vs 16, 22 and 12 respectively without HUD).

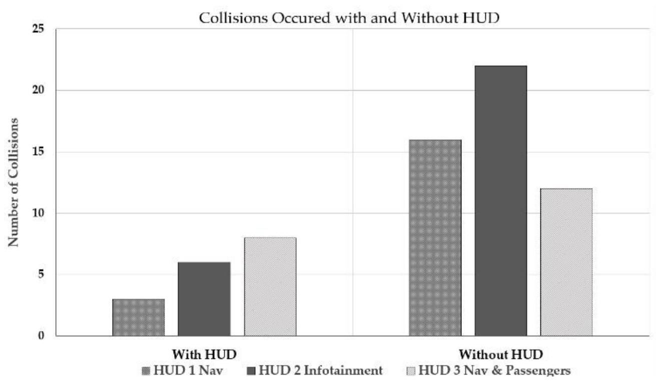

Fig. 6 Collision Occurences of the 10 drivers with and without HUD for all three HUD simulations

4 Discussion

The above results highlighted that the HUD interfaces presented better results than the traditional systems currently utilised in the vehicular interiors. As all three interfaces were explicitly designed to reduce driver distractions from external or internal sources these results confirmed the previous evaluations and the efficiency of all three systems.

However, it was observed that the feedback provided on each individual HUD interface presented some anomalies in contrast to the feedback and rating provided on the comparison of the three HUDs.

As such the usability perception of the drivers for each HUD interface was heavily affected by the aesthetics and familiarity of the interface design rather than by the actual functionality of the system. The latter was evident by the collision occurrences presented in Figure 6. Notably, the less aesthetically pleasing interface produced better results. This could also be attributed to the fact that this system had only visual and audio interfaces in contrast to the other two HUDs which entailed a gesture recognition selection system.

5 Conclusions

The paper presented an initial evaluation of three prototype HUD interfaces. For the evaluation of the systems, a full-scale VR driving simulator was employed. The evaluation process aimed to identify the elements that were considered useful or interesting by the users whilst comparing their subjective feedback with the actual performance on the simulator. The evaluation highlighted that the familiarity of the interface design is a desirable factor yet the commonalities between the systems appeared towards the speed and efficiency of the interface. To this end, the multimodality of the interfaces that entail gesture recognition could affect in some occasions the overall efficiency of the system. A future tentative plan for further work is to explore these systems in different traffic and weather conditions and with larger user cohorts aiming got define better the elements that need to be further improved, removed or added in the next generation AR HUD systems.

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