Human Machine Interface for Prototype Head Up Display: Comparative Study between 2D and VR Simulation Results

Vassilis Charissis, Stylianos Papanastasiou and Marianne Patera

Abstract — **Head Up Displays (HUDs) have recently enjoyed substantial research attention due to their wide scope of application and promise of real time information superimposed in the external scene environment. To this end we developed a prototype HUD interface that could enhance driver's spatial and situational awareness under low visibility conditions. The system's effectiveness was evaluated using two different simulation methods: a non-immersive (2D) and a semi-immersive (VR) driving simulator. In order to validate the results of our previous research on the effectiveness of our proposed HUD interface, we conducted a comparative study of the results derived from both simulators. Particular emphasis has been placed on the impact that the two simulation techniques had on drivers' preferences with regard to the interface's functionalities.**

Index Terms —**Human Machine Interaction, Head-Up Display, intelligent transportation systems, collision avoidance, driving simulator, VR.**

I. Introduction

The proliferation of automotive infotainment devices along with advances in related technologies have burdened the modern vehicle's interior with a variety of instrumentation systems. In particular, the driver's surroundings are gradually being transformed into a collective space of devices that announce, project and otherwise call attention to various pieces of information. The end result of these attention-grabbing components is visual clutter as indicators compete intensely for the driver's mind share, which should, however, be mostly dedicated to the main task of driving. Instead of considering a more spartan driving environment, the current research trend is to examine ways of fulfilling the prominent infotainment needs of modern drivers without jeopardising the safety of the driving process.

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) UK. V. Charissis and M. Patera are with the Digital Design Studio, University of Glasgow/Glasgow School of Art (e-mail: v.charissis@gsa.ac.uk; m.patera@gsa.ac.uk). S.Papanastasiou is with the Department of Computing Science, University of Glasgow (stelios@dcs.gla.ac.uk)

Recent developments in vehicular manufacturing have rendered Head-Up Display (HUD) interfaces as an increasingly viable alternative to traditional Head-Down Displays (HDDs). HUDs appear as an alternative method for the depiction of information using symbolic or alphanumeric representation [1] and feature a larger viewing area, i.e. a part of the windscreen, than traditional dashboard instrumentation.

Notably, HUDs present a particularly suitable medium to facilitate infotainment features as they, in contrast to HDDs, may situate visual queues in close proximity to the driver's road-seeking gaze. In this respect, as long as the queues are subtle and non-distracting there is little need for the driver to divert attention away from the driving task. However in order to evaluate the aforementioned attributes it was essential to develop two different types of simulators, namely the Open Source Driving Simulator (OSDS-2D) and the Virtual Reality Driving Simulator (VRDS). The OSDS addressed the effectiveness of the proposed conformal symbology and assessed the interface's ability to convey, in accurate and timely manner, the most vital information useful when driving under low visibility conditions in motorway environment. On the other hand, the VRDS offered supplementary evaluation data with regard to optimal positioning for the superimposed HUD, its ideal depth of field, preferred focusing distance and possible optical issues. Although they were developed to investigate different functionalities of the HUD interface, it was intriguing to identify the similarities and differences into driver's preferences and behaviours.

The rest of the paper is organised as follows: Section II offers a brief overview of the proposed HMI design for a full-windshield HUD system and outlines its main components (symbolic representations). Section III introduces a description of the two driving simulators developed for the evaluation of the proposed HUD interface. Section IV presents an overview of the derivable results from both simulators and discusses the similarities and differences between the simulators' outcomes. Finally Section V offers a conclusion by outlining the experiment's outcomes and a tentative plan for future work.

II.HUD Overview

The HUD interface examined in this work aims to present infotainment as well as relevant safety information in a timely and intuitive manner. Furthermore, the flexibility provided by these interfaces with respect to the type of information projected is well beyond the bounds set by HDDs, partly due to the larger screen estate of HUDs; interestingly, HUDs can also incorporate the instrumentation dials (such as a speedometer) if desired and can, thus, either complement or substitute HDDs. Overall, achieving information portrayal parity between an HDD and an HUD would result in an overloaded and possibly illegible dashboard. Adhering the aforementioned observations we have developed a prototype HUD interface which enhances driver's spatial and situational awareness during driving under near-zero visibility conditions.

An important initial design consideration (and a target for the subsequent HMI implementation) was to avoid the cognitive capture effect, which comes as a result of visual clutter [2,3] in the driver's field of view. Following this design mantra and through extensive research we have opted for a simplified symbolic representation of the available information in our implementation. Significantly, symbolic representation has been chosen as the most efficient way of depicting contingent information, after having considered contemporary interface guidelines and reports [4]. Further, by introducing an effective mix of techniques, which include colour coding and proportional symbol shape alterations, we have demonstrated that it is possible to convey a multitude of important visual cues without distracting the driver. The symbols incorporated in the proposed HUD interface are depicted in Figure 1 and are thoroughly presented in previous work.

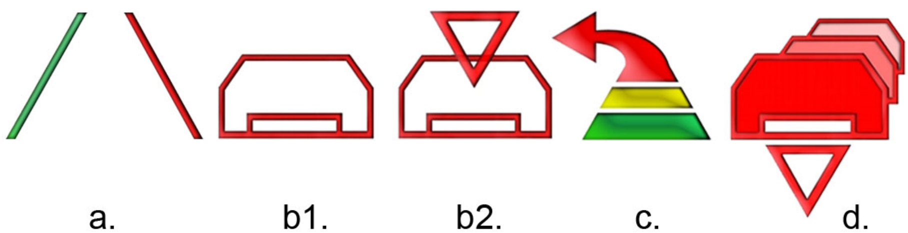


Fig 1: (a) Lane Recognition (Pathway), (b1) lead vehicle detection, and (b2) lead vehicle detection in the same lane, (c) sharp turn notification, and (d) traffic congestion symbol

III. Driving Simulators

To facilitate this research goal, a synthetic driving environment was deemed necessary to evaluate the proposed HUD's effectiveness so as to avoid the costs involved in a real vehicle testing. We therefore opted for a custom simulator that could effectively adapt to the needs of the given experiment. Initially, a 2D version of the simulator was developed and eventually used to evaluate driving behaviour in front collision scenarios when our HUD system was used; the simulator recreated a fleet of intelligent vehicles which could take manoeuvring decisions in real-time and mingle orderly to form mixed traffic environments.

Although our results have shown that the proposed HUD interface improves the driver's reaction times dramatically in view of a collision threat, it was unclear whether these results would hold if a virtual reality (VR) driving simulator were used. The critical difference between the two types of simulators is the additional feeling of perception, i.e. depth of field, that a VR simulation would provide. To explore this issue we therefore proceeded to develop a VR simulator, which allows the driver through stereoscopic vision to experience more accurately the sense of driving under low visibility with the usage of HUD [5]. Notably both simulators recorded user's response times, speed, lane changing maneuvers, and collision occurrences. The test subjects were asked to fill in a pre- and post-test questionnaire. The questionnaires were designed to provide consistency with earlier OSDS test series [1]; yet new questions dealing explicitly with focal distance and simulator sickness issues have been added.

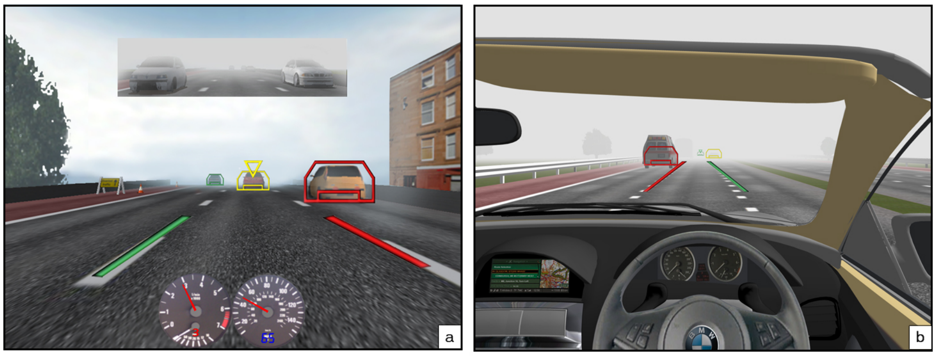


Fig 2: (a) Screenshot from the 2D Open Source Driving Simulator and (b) Screenshot from the Virtual Reality Driving Simulator

A. OSDS Characteristics

An extensive market research analysis estimated that financial costs for software and hardware development would be considerable even for building a medium-fidelity driving simulator. Renting a simulator facility was also not a viable solution, as the high daily rates could not be covered by the research funds. It was therefore vital for the study to develop a custom simulating system with minimum expenditure. This necessity instigated the interest of a group of young researchers to join forces and work collaboratively on the development of such a simulator. The open source programme namely, The Open Racing Car Simulator (TORCS), provided an ideal solution for developing further a custom driving simulator [7]. This software formed the base for the development of the OSDS. The navigation of the vehicles can be achieved through the use of a keyboard, mouse, joystick or steering wheel. Due to the racing nature of the software, the "robot" vehicles imported into the OSDS required substantial reprogramming in order to adhere to the British Highway Code.

As a full-windshield HUD evaluation required a "close-to-real" driving environment it was deemed essential the purchase of a "off-the shelf" steering wheel (Logitech Driving Force Pro GT4). Obviously this hardware belonged to the gaming industry products, yet the specific steering wheel offered quite realistic features (three rotation circles from left to right) and a well-implemented force feedback (transferring realistically, road bumps and vehicle's drifting or braking feeling). The steering wheel was also accompanied with a bundle of other equipment which entailed foot pedals for accelerator and brake Overall, two common driving situations of a "car-following" scenario have been developed for the test-bed experiments based on observations and accident prompt strategies produced in previous research [8,9]. All the scenarios were presented in a motorway environment with heavy fog featuring low visibility (clear view being available at under 50m distance). In total 40 users had participated in the trials, 12female and 28 male aged between 19 and 75.

The experiment was hosted in Glasgow Caledonian University which offered generously the E-motion Lab of Mathematical and Computing Sciences Department. The particular lab was explicitly equipped with numerous recording and observation devices such as video cameras, eye-fixation recorders, motion detectors and a fully developed observation suite and a control room.

B. VRDS Characteristics

The rationale behind the development of a Virtual Reality Driving Simulator (VRDS) stemmed from the intent to achieve a more realistic driving environment as regards calibration and positioning of the HMI components. Evidently such experiment could not be conducted with a typical 2D simulator as the OSDS, as the two dimensional projection could not re-create any depth of field effects. Furthermore, the use of a Virtual Reality (VR) environment enabled the study to simulate a large range of configuration options without the need to build a physical mock-up. Based on the model of the car interior depicted in Fig. 2(b) and a motorway environment, it was feasible to simulate the effects of different symbols' types, positioning, and global calibration parameters. A simulation at 1:1 scale that included effects of depth perception was carried out using a spatially immersive, stereoscopic display. The virtual perception created by the holographic environment provided an affordable method for testing the functionality of the HUD interface in low visibility conditions. The primary aim of the experiments conducted with the VRDS was to address HUD issues related to calibration and depth of field projection.

Furthermore, the use of a Virtual Reality (VR) environment enabled the study to simulate a large range of configuration options without the need to build a physical mock-up. Apart from standard VR software applications such as stereoscopic rendering and device interfacing, VEGA Prime offers realistic simulations of environment including time-of-day, weather and visibility effects such as fog, snow and rain.

Additionally, the driving simulation has been moved towards an interactive driving experience and instrumented with status logging and scenario management imitating partially the OSDS environment. For maintaining a consistency between the two experiments both versions shared common software and hardware components, which are presented in turn below. However the VRDS has predominantly addressed the depth of field and users' focusing preferences, thus the AI of the "robot" vehicles were not explicitly developed as in the OSDS simulator.

The results presented in this paper are based on 12 user tests. All test subjects 7 female and 5 male, aged between 25 and 57. One test had to be aborted due to acute simulator sickness. The trials were accommodated in the VR facilities of the Digital design Studio of the Glasgow School of Art / University of Glasgow.

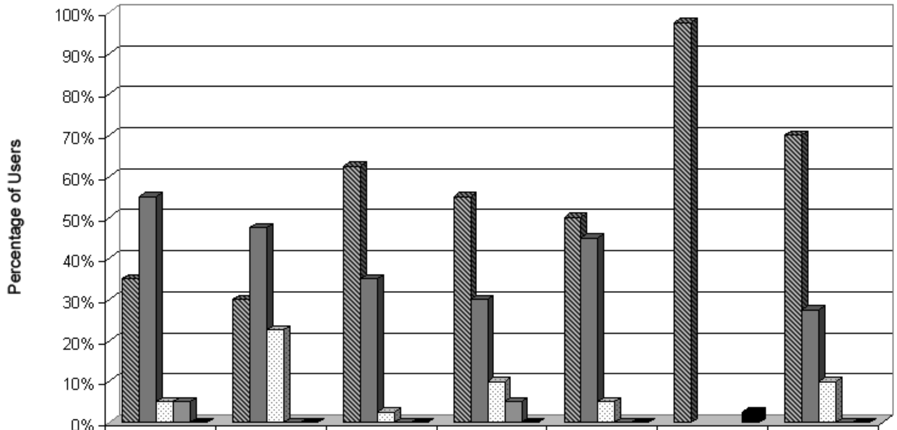
IV.Comparative Results

The HUD interface was evaluated and compared against contemporary dashboard dials with favourable results. After having completed a trial, each participant was asked to complete a questionnaire that gauged their views with regard to the HUD. The relevant questionnaire content as well as the user responses are outlined in the following Figures. Users' questionnaire replies are complementary to the trial evaluation results presented above. Essentially, users were asked to evaluate the system's features on a scale starting from "Extremely helpful" to "Not helpful at all", as depicted in the chart in Figure (3) and (4). The lane symbol revealed some interesting results for both its functions. Specifically, the users' impressions of the system provide an indication of the perceived effectiveness of the interface, whilst the trial results demonstrate its actual effectiveness (Figure 3).

Furthermore, the questionnaires recorded participants' preferences and feedback on the visual elements. Figure 3 presents users' opinions in relevance to critical design attributes of the interface. Additionally questions 6 and 8 depict the users' acceptability and future suggestions to incorporate the system in contemporary vehicles. Evidently the response times could not be of particular use as the two simulators re-enacted different simulation car-following scenarios. However the functionality of the interface symbols and the overall acceptability of the system could be of further investigation of the comparative study between the two simulations. Therefore the questionnaires can highlight the impact of different simulation techniques into the usability investigation of a HUD system. The common questions in both post-tests are summarized in Table 1 below.

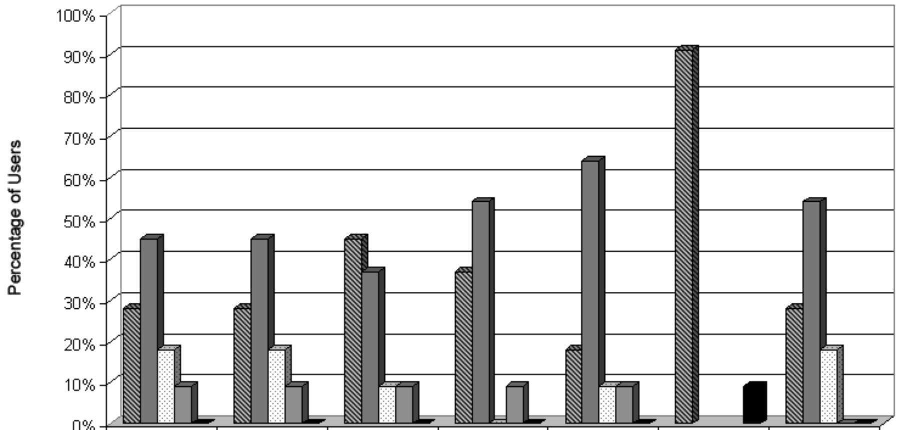
TABLE 1.

Q (1): How helpful were the lane symbols (pathway symbol) for lane navigation?
Q (2): How helpful were the lane symbols (pathway symbol) for overtaking?
Q (3): How helpful were the vehicle identification symbols (lead vehicle symbols) for collision avoidance?
Q (4): How helpful was the traffic identification symbols (traffic symbol) for collision avoidance information?
Q (5): How satisfied were you with the symbols' positioning? (scale in this case is: Extremely Satisfied / Very Satisfied / Neutral / Not Very Satisfied / Not Satisfied At All)
Q (6): Would you use this HUD navigation system under low visibility conditions?
Q (8): Do you think it would be a helpful system to integrate in future vehicles?



	Q1	Q2	Q3	Q4	Q5	Q6	Q8
Extremely helpful	35%	30%	62.50%	55%	50%	97.50%	70%
Very helpful	55%	47.50%	35%	30%	45%		27.50%
Neutral	5.00%	22.50%	2.50%	10%	5%		10.00%
Not Very helpful	5.00%	0	0	5%	0%		0
Not helpful At All	0	0	0	0	0%	2.50%	0

Fig. 3: Subjects' feedback after the OSDS trials.



	Q1	Q2	Q3	Q4	Q5	Q6	Q8
Extremely helpful	28%	28%	45%	37%	18%	91%	28%
Very helpful	45%	45%	37%	54%	64%		54%
Neutral	18%	18%	9%	0	9%		18%
Not Very helpful	9%	9%	9%	9%	9%		0
Not helpful At All	0	0	0	0	0	9%	0

Fig. 4: Subjects' feedback after the VRDS trials.

The observation of the Figures (3 & 4) shows very similar user feedback. In the OSDS the first function (the lane navigation) was assessed as "extremely helpful" by 35% of the participants while 55% thought it was "very helpful". It was stressed that the primary function of the lane symbol was to effectively assist the users to maintain the vehicle position within the lane boundaries. Its second function of facilitating overtaking was ranked as "extremely helpful" by 30% of the users and as "very helpful" by 47.5%. Further analysis of the collected data showed that 22.5% of users who had rated the function as "neutral", had not tried it out, as they had preferred to remain in the slow speed lane and avoid any lane changes. Some users even suggested that the second function of the lane symbol (overtaking), should be preferably activated manually by the indicators (if technically possible).Interestingly both functions of the lane (pathway symbol) were rated equally in the VR simulator with 28% "Extremely helpful" and 45% "Very helpful". The percentage of neutral responses rose however to 18%.

The most highly rated symbol was the lead-vehicle warning as 62.5% of the drivers ranked it as "extremely helpful", 35% as "very helpful" and only 2.5% as "neutral". Drivers reported that the symbol was boosting their confidence by increasing their spatial awareness and significantly reducing distance misjudgement. Similarly the lead-vehicle symbol was rated higher than any other functionality during the VRDS trials, with 45% of the drivers ranked it as "extremely helpful", 37% as "very helpful", 9% as "neutral" and "not very helpful".

Note that although the symbols provide an approximate distance information (through colour coding and size altering), it was proved to be more than adequate for enhancing human spatial awareness as the results exhibit above. The traffic symbol received equally good feedback despite the technical and design challenges encountered during its implementation.

Specifically, 55% of the interviewees considered it as "extremely helpful", 30% as "very helpful", a 10% as "neutral" and a 5% regarded it as "not very helpful". A few users suggested to emphasise further the traffic warning information by making the icon bigger or accompanying it with an audio cue.

The positioning of the symbols with regard to driver's field of view was rated as "extremely satisfied" by 50%, "very satisfied" by 45% and "neutral" by 5%, which marks it as a moderate success. In contrast the positioning in the VR simulation was rated with 18% as "extremely satisfied" by 50%, "very satisfied” by 45% and by 9%, as “neutral” and not very helpful. Notably the focusing distance had also affected the responses in this question.

Additional comments verified that the symbols were very simple and easy to use. To this end, during the post-test interview, some users admitted that they often feel mentally intimidated by complicated contemporary navigation and other infotainment systems. They expected that an “unusual” system such as the proposed HUD would follow a similar design mantra. On the contrary, they found it very simple and exceptionally useful for the specific driving conditions. Consequently the HUD gained the approval of the vast majority (Q6: 97.5%) of participants who indicated that they would like to use it under low visibility conditions, while most (Q8: 97.5%) would also support its integration in future vehicles. Equally high results were achieved also in the VR simulation with 91% of users manifesting their intention to use this HUD interface in low-visibility conditions. Consequently the 28% of the users responded that the system would be extremely helpful and 54% very helpful to be integrated in future vehicles.

Apart from improving the driver’s RTs, the HUD attained encouraging comments by reducing the performance anxiety during adverse driving conditions. The results suggest that the proposed HUD interface had overall succeeded in its role of augmenting the already existing road signs, by also providing the driver with crucial information for collision avoidance under adverse weather conditions.

V. Conclusions

We presented a comparative study between two different simulation techniques employed to evaluate a prototype full-windshield HUD interface. The comparison has provided considerable insight to the similarities and differences of driving performance under the two simulator types and has further helped to evaluate the degree of approximation of each to a potential actual test-bed implementation. Evidently the profound similarities between the results from both simulators show that the simulation fidelity (or projection method) does not affect considerably user’s opinion regarding a new automotive product. Our future research aims entail a second series of comparative studies, which will evaluate a variety of identical collision scenarios for both simulation systems. Finally, we entertain the possibility of improving the HUD interface components for additional functionality and expand on the scope and increasing the realism of our VR driving simulator.

REFERENCES

[1] V. Charissis, S. Arafat, W. Chan and C. Christomanos, “Driving Simulator for Head Up Display Evaluation: Driver’s Response Time on Accident Simulation Cases”, Driving Simulation Conference DSC’06, Asia/Pacific,Tsukuba/Tokyo, Japan, 2006.

[2] Y. C. Liu, “Effects of Using Head-Up Display in Automotive Context on Attention Demand and Driving”, Elsevier Internation Journal of Displays 24 2003, p.p. 157–165,

[3] Ward, N. J., & Parkes, A.M., “Head-up displays and their automotive application: An overview of human factors issues affecting safety”, In International Journal of Accident Analysis and Prevention, 26 (6), 703-717. Elsevier Ltd. 1994.

[4] P. Dourish, “Where the Action Is: The Foundations of Embodied Interaction”, The MIT Press, Cambridge Massachusetts ISBN 0262041960, 2001.

[5] V. Charissis and M. Naef, “Evaluation of Prototype Automotive Head-Up Display Interface: Testing Driver's Focusing Ability through a VR simulation”, in Proceedings of: IEEE International Intelligent Vehicle Symposium, (IV’07), Istanbul, Turkey, 2007.

[6] A. Stevens, A. Quimby, A. Broard, T. Kersloot and P. Burns, (2002), Design Guideleines for Safety of In-Vehicle Information Systems, Transport Research Laboratories, TRL report PA3721/01

[7] B., Wymann, “T.O.R.C.S. Manual Installation and Robot Tutorial”, Manuscript,http://torcs.sourceforge.net/index.php?name=News&file=print &sid=57, last accessed, 12th of July 2007. (2006).

[8] Smith D.L., Najm W.G. & Lam A.H., “Analysis of Braking and Steering Performance, in Car-Following Scenarios”, Society of Automotive Engineers, 2003.

[9] Daganzo C.FA Behavioural Theory of Multi-Lane Traffic Flow. Part 1 Long Homogenous Freeway Sections, Research Report UCB-ITS-RR-99-5, Institute of Transportation Studies, University of California, Berkley,1999.