Enhancing Human Responses through Augmented Reality Head-Up Display in Vehicular Environment

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***Abstract*— Contemporary needs for constant provision of information and communication has crowded the modern vehicle's interior with a variety of instrumentation displays. This abundance of automotive infotainment devices can reduce significantly driver's decision making process and response times, leading to higher probability of collision, especially under adverse weather conditions. Typical dashboard instrumentation has proven inefficient to tackle such issues and Head-Up Display (HUD) interfaces deemed as an increasingly viable alternative by recent developments in automotive research and manufacturing. This paper presents our current work towards the development of a full-windshield HUD interface that could enhance human responses and provide time-dependant and only critical information for collisions avoidance. For the evaluation of the system we have developed a VR driving simulator that simulates traffic flow and typical accident scenarios in motorway environment. Finally the paper presents the evaluation results and future work that would improve the interaction between HUD interface and driver.**

Keywords - Head Up Display, Driving Simulator, Virtual Reality, Augmented Reality, Collision Avoidance

I. INTRODUCTION

Recognising and reasoning about the surrounding environment is an inherent human attribute that has evolved significantly, following and adapting to contemporary transportation needs. Yet, current advancements in infotainment can create an overwhelming volume of information for the average user and hinder heavily the ability to perform complex psychomotor activities such as driving a vehicle [1]. Drivers' spatial awareness can be further impeded under adverse weather conditions which might reduce drastically visibility and increase the time for the decision making process. In turn, the latter is elongating response times and evidently increases the accident probabilities [1, 2,3].

A number of solutions have previously been proposed in the automotive industry which typically concentrate in the collection of vehicular and traffic information without effective prioritization of their significance. Consequently, the collected information is presented within existing vehicular means, directly to the driver, irrespectively of different drivers' capabilities, cognitive load and external conditions. In addition to collecting useful information relevant to the vehicle’s safety and - thus of interest to the driver- new approaches to presenting critical information in non-distracting ways have been deemed necessary.

Prior studies suggested that a multimodal Human-Computer Interaction approach would provide substantial benefits in contract to traditional instrumentation and warning systems [1]. Traditionally, such information would be conveyed through dashboard notifications or other Head-Down Display (HDD) interfaces set at a location out-with the driver's direct field of view during the normal driving stance. However, recent developments in vehicular manufacturing have rendered Head-Up Display (HUD) interfaces an increasingly viable alternative to HDDs as they manage to maintain driver’s gaze on the road [1].

Following the aforementioned we have designed and implemented a prototype Head Up Display system that provides crucial information to driver in order to evade potential collisions under low visibility conditions.

Overall, this paper will present the design and development challenges of the proposed HUD system. In turn, it will elaborate on the simulation requirements for a user-trial that evaluates the efficiency of the proposed system against typical dashboard devices. The paper will discuss the evaluation results of the aforementioned trials and offer a succinct depiction of the benefits and drawbacks of the proposed system.

II. PROPOSED HUD INTERFACE RATIONALE

Although use of a HUD could improve the driver's safety, another aspect of driving safety related to the obtaining and transference of information arises, due to the transient nature of road hazards. Essentially, it is not always sufficient to warn of permanent “danger hotspots”, such as blind corners or sharp turns, as road conditions may change rapidly and unpredictably. For instance, the hazard present in an area after a vehicle breakdown or crash, sharply increases for a period of time due to the obstacles present and the increased associated activity. In such cases, it is useful for information reflecting those changing conditions to be passed along to vehicles in the vicinity at the time (transference of information) and their drivers to be informed of the situation in a timely fashion. This could be achieved through inter-vehicle communication, with neighbouring vehicles acting as a link in the communications chain; each being both interested in the information provided and responsible in propagating it further.

A. *Prototype HUD System - Functionality*

Adhering to the above we have accommodated the need of a Vehicular Ad Hoc Network System (VANETS) that could transfer, collect and prioritize traffic information related to transient conditions and transfer them to a prototype HUD system [4]. For the realisation of useful functionality in the HUD information conduit, it was deemed helpful to leverage both intra-vehicle sensors and inter-vehicular communications, as well as fixed-infrastructure sources such as a Traffic Messaging Channel (TMC) or even cellular gateways to the Internet. The combinatory input of these sources enables an up-to-date bird's-eye view of road traffic conditions through collaborative observations in motorway as well as in urban environments. Intuitively, an inter-vehicle communications system would have to be decentralised and tolerant of a dynamic network topology; a vehicular ad-hoc network (VANET) naturally fits such requirements [5].

Yet the generation of real-time extensive information (i.e. positioning, speed, proximity etc.) can hinder the efficient data translation to a comprehensive to driver Human-Computer Interaction. As such we have developed a sequence of prioritization algorithms that distill the information and provide only the relevant and time-dependant information. Based on our previous work in HUD interfaces we improved the current version by minimizing even further the potential distraction factors and improving the quality of provided information [7].

B. *Prototype HUD System - Interface Design*

The proposed HUD interface following our previous designs can operate in a full-windshield mode for increased immersion with the environment. The projection is calculated to be in approximately 2,5 meters in front of drivers field of view enhancing further the augmented reality effect between projected information and real environment. Additionally this distance was deemed ideal for avoiding any visual accommodation effects [7].

The HUD interface design has evolved through numerous experiments which optimized the type, amount and visualisation of the projected information [3,4,7]. As such the system highlights predominantly the high probability collision objects ahead or in the blind spots or our vehicle.

Through further analysis, four pieces of information were mainly identified as the most crucial for collision avoidance in motorways, under low visibility conditions. This information was visualised through symbolic representation of the actual objects, which in turn fashioned five symbols namely: lane/pathway recognition, lead vehicle detection, neighbouring vehicle identification and traffic warning as presented in Figure 1. A fifth symbols has been designed for sharp turn notification, however we will examine the first four symbols that are relevant to the simulated accident scenario.

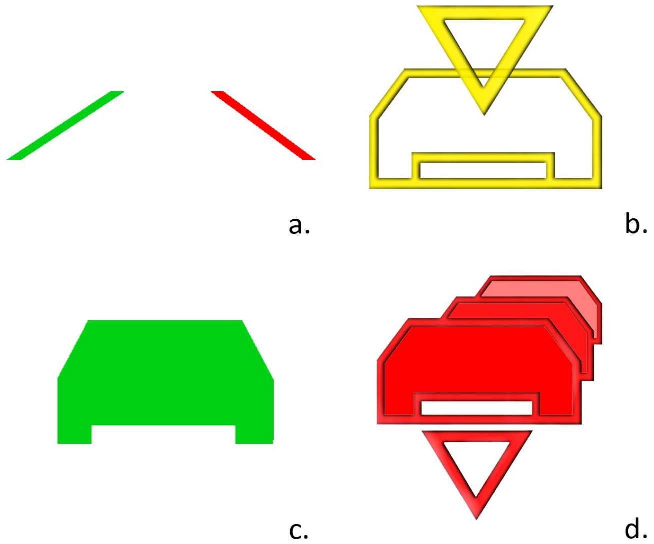

Figure 1: The five collision avoidance symbols:

(a) The *lane pathway symbol acts as early warning system for the incoming vehicles through the back and side black-spots*
(b) Lead Vehicle symbol- tracka constantly the lead vehicle up to 400m ahead
(c) Neighbouring vehicle identification
(d) Traffic Warning symbol

The symbols follow a clear pattern of colour-coding, such as green, amber and red according to international automotive instrumentation standards [8].

Figure 2: Screenshot of the actual VR Drivign Simulator with enabled HUD interface.

Furthermore the symbols offer a size-shifting capability in order to follow the perspective view of each potentially hazardous object in the motorway as depicted in Figure 2.

The symbols simplification facilitate a clear and timely manner of presenting an immensely large amount of data that have to translated efficiently to the user. Evidently the driver do not need to be informed or presented with all the incoming data. The point of the proposed system is highlight only the crucial information that could further focus driver's attention on the road and highlight in uncomplicated manner

Previous automotive attempts to offer complete data, mainly through alphanumeric or complex symbolic representations rendered the HUD interfaces as attention seeking devices that could themselves result in a potential collision [9]. This inability to translate incoming data to minimum and visually functional snippets of information, delayed significantly the introduction of the particular technology in the market. Currently few manufacturers are offering HUDs with minimum functionalities presenting mainly tachometer and navigation information.

III. SIMULATION REQUIREMENTS

In order to evaluate the proposed HUD system we have developed the third generation of our in-house Virtual Reality driving simulator presented in action in Figure 2. This third generation of our simulator is capable to embed VANET simulation data and improve the realism of the data transmission during the driving simulation. The simulation is further enriched with re-enactment of actual accident scenarios based on regional traffic police information.

The evaluation of the proposed new HUD system was implemented with the use of our third generation Virtual Reality Driving Simulator. The latter has significantly improved visualisation in contrast to our previous simulator [7]. Additional the 3rd generation VR Simulator has improved Artificial Intelligence for the neighbouring vehicle agents (AI vehicle-agents) that adapt to users driving patterns in order to create the required accident scenarios.

A. *Simulation Scenarios*

Our 3rd generation driving simulator capitalizes on the previous versions and offers a number of major improvements that enhance the user experience [3,6,7]. As such the simulator has a new Artificial Intelligence system that can enable the vehicle-agents to simulate realistic traffic flow. In particular the vehicle-agents can constantly adapt their driving patterns based on real-time user's patterns. This constant adaptation is essential for the traffic escalation that will create the required accident scenarios. For consistency purposes we have implemented the same accident scenarios previously used on our experiments for earlier version of the prototype HUD interface. These scenarios are briefly presented below:

Scenario 1, adheres to a generic car-following model developed previously [10, 11] and additionally embeds the instructions of the local traffic police department that encounters a large number of similar accidents in annual basis. In particular in this first scenario, the driver is moving along the motorway under low visibility conditions and after having traveled approximately a distance of 2km the lead vehicle agents create an abrupt braking situation.

This event increases dramatically the collision probability and offers some possible options of driver's reactions. Driver's performance map has been mapped in previous studies [8] and is comprised of four driving states, namely; low risk, conflict, near crash and crash imminent, corresponding to four different warnings respectively. Following the aforementioned guidelines, the first scenario was designed in order to challenge and produce these potential driver's reactions. In turn the driver's decision and response time would offer an evaluation of the HUD's capacity to convey effectively these four collision states to the driver. Contrasting driver's decisions and performance with and without the use of HUD provided the study with advantage of being able to identify the impact of the HUD information as compared to a contemporary HDD.

Scenario 2, is a variation of the first scenario model and

(a) VR driving simulator in normal visibility and without HUD

(b) VR simulation in low visibility and with HUD enabled

Figure 3: Screenshots of the VR driving simulator in action

provokes a driver's response on a similar manner by evaluating driver's response time and decision making process. However second scenario is more complex due to a traffic congestion of immobile vehicles, hidden behind a sharp curve under a bridge. Notably this scenario is based on an existing real-life accident cases that appear frequently on particular motorway exits. However in this paper we will focus on the first scenario and discuss the average driver's performance with and without HUD support.

B. *Simulation Environment*

The driving simulator offers a 28 miles realistic driving environment in a closed circuit route replicating faithfully three major motorway sections between Glasgow - Edinburg and Stirling in Scotland (Figure 2). The vehicular interior is based on a BMW 5 series F10 saloon model. the reason for selecting the particular vehicle is the fact that can accommodate a HUD therefore could be an ideal candidate for future laboratory hardware experimentations.

The visualisation and immersion of the vehicular interior, external scenery and HUD interface is further increased by the use of High Definition stereoscopic projection system. The driving conditions were with clear visibility on the familiarisation round, and on zero visibility for the following four comparative rounds.

C. *Simulation Software and Hardware*

Our 3rd generation VR driving simulator operates in a dedicated simulation laboratory that offers a 2.8 meters width and 2 meters height projection surface. Notably the simulator can be operated with minor optimisations in a even through and average performance laptop. This can be achieved as the engine behind the simulator is the Unity 3D gaming engine that provides a cost efficient software solution and has better results that previous dedicated simulation engines [3,4,6].

D. *Traffic and VR Simulators Integration*

Another new aspect of our latest driving simulator is the capacity to incorporate traffic flow information produced through dedicated traffic simulation systems. For this role we have used a customised version of the SUMO traffic simulator [12] which simulates and predicts traffic situations as estimated on actual road topologies. The SUMO simulator is predominanlty used as a microscopic traffic simulator, which could simulate the individual vehicles positions and routing in a given road network.

With the use of SUMO it was made possible to design selected traffic flow simulations which were in turn embedded in our low-visibility trial scenarios, in the VR simulator. The achieved traffic simulator integration enriches the driving scenarios with actual traffic information derived by real cities road network and offers to the driver a real-life experience of road conditions.

Evidently the realism of the produced information further enhances the driving realism and experience in the VR simulator. Furthermore this data integration was deemed ideal for the generation of additional new scenarios, or minor flow alterations that could further challenge particular users.

IV. EVALUATION & DISCUSSION

The proposed HUD system was evaluated in contrast to existing Head Down Display interface by twenty users with promising results. The users were equally selected by both genders and they held a valid driving license. An instant appraisal of the proposed system's effectiveness can be achieved by the collisions occurrences with and without the HUD assistance. Notably the use of HUD reduced the collisions by 75% as illustrated in Figure 4 and improved vehicle's average headway by approximately 12 seconds, results which are in par with our previous HUD versions' evaluations [3, 4, 6].

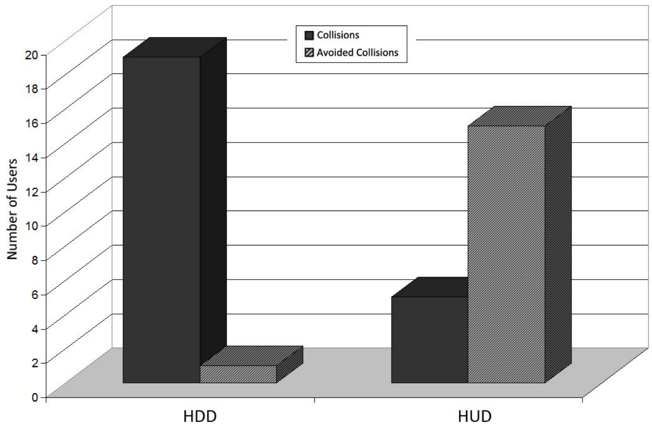

Figure 4: Number of users that had a Collision with HDD and with HUD

Although the collision occurrences can be a strong indication of the success of a system it was deemed essential to analyse our recorded data namely; driver's vehicle, speed, position, relative position to lead vehicles, distance covered, lane, every 0,05 seconds. Additionally we recorded speed, lane positioning and formation of lead and surrounding vehicles in the same time-rate as the driver's vehicle. However in this paper we would elaborate and present the results related to the different driving patterns that occurred through the simulations by offering an analysis of the most typical pattern.

Evidently the most interesting pattern that confirms our findings in this case can be observed through User 13. The particular driver kept a similar driving pace through both simulation trials with average speed varying between 44Km/h without HUD and 48Km/h with HUD system. It is clear that without the HUD the driver had two main collisions depicted as red vertical lines in the graphs below (Figure 5). Please note that the drivers could drive without any planned accident on the familiarization round (with typical duration of 10 minutes) so as to avoid any "unintentional accidents" related to hardware manipulation issues.

The *first collision* without HUD occurred in the early stages of the simulation although the particular driver was exceptionally cautious and maintained half of the motorway recommended speed. In turn the driver tried to maintain a visual tracking of

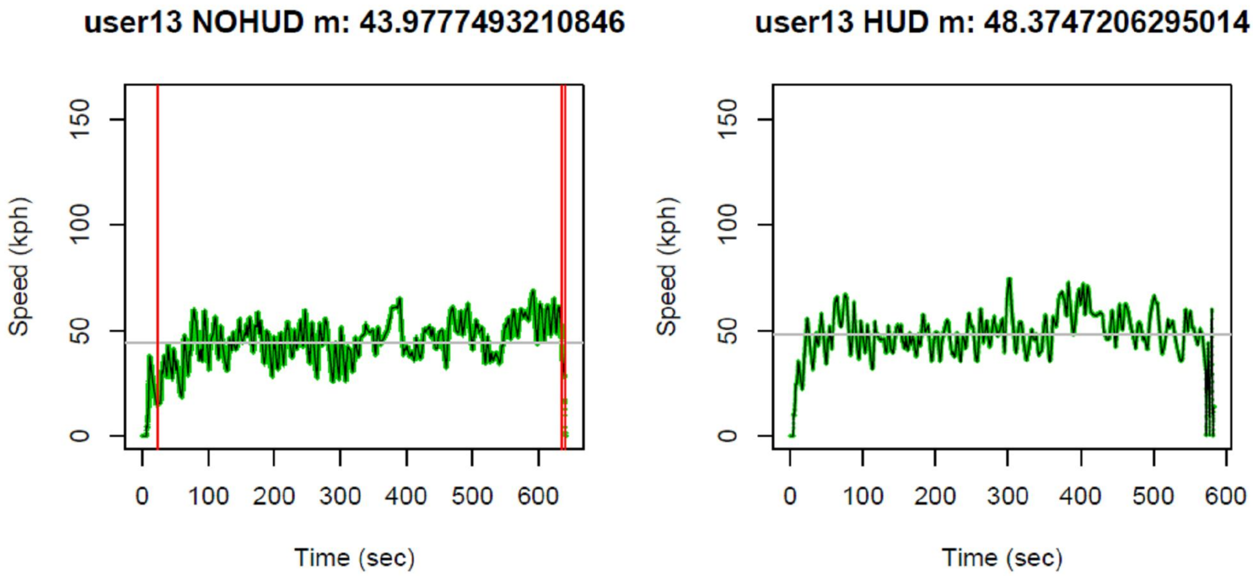

Figure 5: Comparative Graphs for typical driver responses without and with HUD interface.
Left : Typical Driver's speed patterns during time without the HUD system
Right: The same driver's speed flactuations in the same period with the use of HUD

the lead vehicles which was proven temporarily a successful tactic. Yet as the AI vehicle-agents changed their driving pattern was difficult to follow them in zero visibility conditions. This resulted on a second double collision as the vehicle-agents ahead stopped abruptly. This appears as the double redline at the end of the simulation in Figure 2.

In contrast the particular driver (User 13) performed marginally faster, although within limits, and maintained the same driving pattern as on the trial without the HUD. Most importantly the driver managed to avoid all the seemingly random accidents that materialised abruptly and ahead of the user's vehicle. On the last major accident the user managed to gradually brake the vehicle to a safe stop.

In the debriefing interview and post-trial questionnaire all the users suggested that driving with the particular HUD interface under such adverse weather conditions was a more relaxing experience and they maintained full concentration on the driving task without the performance anxiety, experienced in the trial without HUD. The latter was confirmed from an initial appraisal of their driving patterns and the recorded body postures throughout the simulation process.

The proposed HUD interface is designed for use in low visibility conditions and in a motorway environment. As such the system might offer little support in a bright day with clear visibility. In the latter conditions the system could even potentially overload cognitively the driver due to the abundance of visual information appearing on the real environment and the superimposed augmented reality information from the HUD. Other HUD systems have exhibited similar issues in the past [9]. On our near-future experiments we aim to facilitate the actual evaluation of the proposed HUD system under normal weather conditions and identify the potential risks. Further interface iterations could possibly introduce a clear-weather HUD version that could facilitate alternative type of information relevant to the driver or the passengers.

CONCLUSIONS

This paper presented the design and implementation considerations for the development of a full-windshield HUD interface for low visibility conditions in motorway environment. The proposed system accommodated contemporary VANETS system that provided early warning information. To facilitate an appraisal of the system, we have conducted a comparative evaluation, contrasting the proposed HUD interface against the contemporary HDD interface (dashboard). The results suggested that the users could navigate successfully, with the support of the HUD interface, through exceptionally challenging, “accident-prone” situations. Conversely the typical dashboard instrumentation (HDD) was insufficient in providing any crucial information that could prevent the driver from collision. The user's feedback has positively supported the embedding of the HUD system on future vehicles. The proposed HUD interface was characterised as "life-saving" device in contrast to various other systems that were highlighted as "gadgets". The latter were the main reason that the users were skeptical of such systems prior to the simulation trial.

Overall the paper presented the evaluation results of the collisions occurrences and discussed in detail the decision making process and performance of a typical, average driver that evaluated the HUD efficiency in the simulated environment.

Finally, our future plans aim to enhance our new prototype HUD with gesture recognition data manipulation system. Our initial work has shown that such system could further improve intra-vehicular interactivity and potentially enable the driver to perform additional tasks without affecting the cognitive load in particular situations. In addition we aim to further enhance our system with the use of complementary audio and haptic cues aiming towards creating a complete and effective, non-distracting information pathway.

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