Interface Development for Early Notification Warning System: Full Windshield Head-Up Display Case Study

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Abstract. This paper elaborates on the development of a prototype Head-Up Display (HUD) system designed to offer crucial navigation information to the driver, under adverse weather conditions. In particular the paper presents the implementation process and evaluation of the sharp turn notification and traffic warning cues which reflect some of the most common risks that may be encountered in a collision in a motorway environment under low visibility. Additionally, emphasis was placed on the prioritisation and effective presentation of information available through vehicular sensors, which would assist, without distracting, the driver in successfully navigating the vehicle under low visibility conditions. This information which appear in the form of symbolic representations of real objects, are projected in the vehicle's windscreen and superimposed onto the real scenery. Overall the paper examines the potential benefits and occurring issues of the proposed HUD interface and presents the results of a large scale evaluation of the system on a group of forty users, as performed using a driving simulator.

Keywords: HUD, HMI, Warning systems, Simulator, Driver's Behaviour.

1 Introduction

In recent times, in-vehicle notifications have proliferated with a focus on the exhibition of technological prowess rather than the effective and safe fulfillment of actual driving needs. In effect, information portrayed by automotive infotainment devices, while useful, is often ignored by the driver due to field of view limitations associated with traditional instrumentation panels. Not surprisingly, under adverse visibility conditions and at motorway-level driving speeds, such systems fail to effectively present useful information to the user.

Intuitively, adverse weather conditions have a direct impact on visibility during driving as they significantly reduce an observed object's conspicuity [1]. Consequently, a driver's spatial and situational awareness suffer in such environments, as

J.A. Jacko (Ed.): Human-Computer Interaction, Part IV, HCII 2009, LNCS 5613, pp. 683–692, 2009.

neighbouring vehicles and other objects are veiled from view and become unnoticeable. Under such unfavourable driving conditions the inability of in-vehicle notifications to effectively portray information increases the difficulty of the driving task. Furthermore, due to the attention seeking notifications of the various infotainment devices present inside the vehicle, the driver's attention can be dispersed on fruitless gazing at the instrumentation panel dials, in the case of Head-Down Displays (HDD), as well as on discerning the hazy external scene. Hence if, for instance, one of the lead vehicles breaks abruptly, the driver does not have the required time and situational awareness to proceed in a collision avoidance braking manoeuvre. It would be, thus, fair to conclude that in some cases, notifications compromise rather than enhance the driver's safety [2].

In the framework of human situational awareness, various studies have supported experimental Human-Machine Interfaces (HMIs) in an effort to tackle different issues by utilising customised Head-Up Display interfaces (HUD). In particular, previous observations have suggested that under low driving-load the attention required of the driver is considerably less, which in turn may reduce the driver's overall awareness and subsequently encourage careless or reckless driving [3].

Based on our previous experience with regard to the design and evaluation of automotive HUDs as well as being aware of contemporary technological and cost-related constrains, we developed a series of interface components which enable the driver to anticipate potential hazards [4,5].

This paper introduces a novel design for an automotive HUD interface, which aims to improve the driver's spatial awareness and response times under low visibility conditions with particular emphasis placed in early notification warnings of motorway hazards such as traffic congestion and out-of-view sharp turns. A working prototype of a Human-Machine Interface has been designed and implemented to fulfil these requirements.

2 Automotive Head-Up Displays

Contemporary interface design efforts have targeted the dashboard (or instrument panel) as such an information conduit and have enriched its functionality with visual and audio warning cues from proximity systems [6]. Interestingly, a particular area of intense research focus has been the design and utilization of visual cues embedded in the vehicle's windshield, which effectively becomes a head-up display (HUD). Live trials have convincingly demonstrated that superimposing useful information on a fully operational HUD results in more rapid and stable driving responses compared to traditional instrument panels or Head-Down Displays (HDDs) [7,8,9,10].

Nonetheless, early examples of HUD devices and interfaces have somewhat failed to exploit in full the potential offered by the large-scale projection area of the windshield. Arguably, such issues are not the immediate consequence of limitations in the technology used but mainly derive as a result of the designers approach. Evidently, the focus of early research has been the development of technological features which would improve the performance of the "machine" element. The driver (or the human element) was largely delegated as a secondary consideration in those designs which resulted in an unbalanced, ineffective interface.

In other efforts, HMI designs have produced visually cluttered interfaces that aim to entail every available infotainment cue. These sporadic efforts have shown that there is significant utility in such devices when used with interface HUD projection on the vehicle's windshield [8, 11]. Significantly, HUD projection has currently returned in the focus of automotive manufacturers, as the excessively burdened dashboards seem incapable of accommodating any future infotainment and navigation systems.

3 Proposed HUD Interface

The proposed HMI design aims to identify the needs of the user in a potentially unsafe driving situation under adverse weather conditions. To this end it has been deemed necessary to categorise the incoming information according to significance for each given moment. Opting for minimalistic depictions of the incoming information, we have developed a group of symbols which are instantly recognisable by the drivers [12, 13]. Evidently, the collaboration between human and machine, could offer remarkable results as the machine can rapidly categorise the bulk of information and offer to the driver options between which to decide.

In this paper, we are focusing in the development, implementation and evaluation of a specific group of early warning notifications related mainly with the traffic congestion and the sharp turns typically camouflaged in the terrain as depicted in Figure 1. The traffic congestion symbol aims to warn in advance for potential collisions that occur when leading vehicles rapidly decelerate perhaps as a response to traffic congestion along the road. The sharp turn symbol highlights certain parts of the motorway, such as junctions, intersections and hairpin turns, which can be exceptionally difficult to negotiate, particularly under adverse weather conditions.

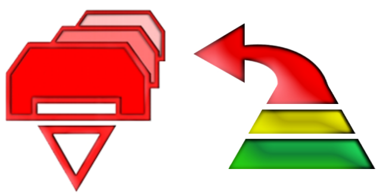

Fig. 1. Traffic congestion and sharp turn situations (second scenario)

A real system implementation enabling the extraction of raw data which would make both notifications realisable, is currently under development with the employment of Vehicular Ad-Hoc Network systems (VANETs), GPS and road mapping software [14, 15].

4 Simulation Set-Up and Experimental Rationale

The complete proposed HMI system has been evaluated in an Open Source Driving Simulator developed explicitly to measure drivers' performance with the proposed

HUD interface and compare its effectiveness to traditional instrumentation techniques [16]. Notably, the preliminary user trials have demonstrated that the system conveys crucial information efficiently and in a non-distracting manner, thereby minimising the accident risk. A screenshot of the actual driving simulator illustrates the HUD interface appearance and the overall simulation environment. The driving simulator comprised a rear-projection screen 1.8m width by 1.2m height, driven from a single PC with two Intel Xeon 3.6GHz processors and a high-end graphics card (nVidia Quadro FX4400), a driver's seat and Logitech steering wheel, gearbox and pedals.

Fig. 2. Screenshot from the actual driving simulation

4.1 Traffic Congestion and Sharp Turn Scenario

The scenario designed for the evaluation of the aforementioned interface components recreated a traffic-congestion scene with 20 participating vehicles. Moreover, a traffic "bottleneck" was positioned in a blind turn under a bridge, which presented a significant accident risk as illustrated in the diagram of Figure 3. Our consequent evaluation of the proposed HUD interface aimed to determine the actual response time benefits derived through its usage and subsequently the real impact in the decrease of accident propensity. Additionally the number of potential collision avoidance manoeuvres could be utilised as another indicator of the system's success or failure.

4.2 Users

The driving simulation trials attracted 40 users which participated voluntarily. All the participants had driving licence and have been randomly selected in order to cover the widest possible array in professions and age and evenly distributed between males and females. This wide variety of drivers aimed to be in accordance with the "average user" (or average driver) norm which has been coined [17] to describe the generic characteristics of a contemporary driver. The definition and clustering of this information aimed to develop a framework of European standards, which need to be addressed by any automotive system designed for operation by the driver. In fact, the proposed human-factors design guidelines [17] present a group of provisions for the rudimentary operation of any automotive system by any user that holds a driving license and falls approximately in the categories described in this nomenclature.

Adhering to the above automotive industry dictum, the prototype HUD interface had to be compliant with the majority of the users for validation purposes. As such it was of outmost importance to define not only the structural characteristics of the system (i.e. projection distance) but mainly to identify how the "average user" would utilise the HUD interface and how such system might affect his/her driving under low visibility conditions. All the analysis within the main document followed the above guidelines.

5 Driving Pattern Analysis

In this work, the proposed HUD interface presents the driver with vital information for collision avoidance. Notably, the specific scenario was designed to re-construct typical real-life accidents. Hence the "average user" was expected to misjudge the headway (HW) distance from the traffic congestion and perform last moment panic braking or collision avoidance manoeuvre [5, 16]. Even though this result was highly anticipated, as real life paradigms have unfortunately demonstrated in previous occasions [18], it was unclear how the average user would react with the use of the HUD interface. In this simulation the recorded video and data are suggestive of a typical reaction to the "traffic congestion and unexpected road turn" scenario as shown in Figure 3. Although, broadly, the drivers did not perform inadequately in comparison to the first scenario, the number of collisions that occurred was alarming.

Again, analysis of the collision data brought to light a driver's pattern. A particular user was sampled as he performed with typical reactions to the unexpected sharp turn and to the traffic congestion. Notably, the driver had driven through the second scenario using the instrumentation panel (HDD) and in turn with the assistance of the HUD. However, as mentioned above, the first and second scenarios with their variations (with and without HUD) were presented in a random order to the user in order to avoid any potential detection of similarities of the events. The graphs presented below focus on the last 10 seconds before the driver arrives at the traffic congestion.

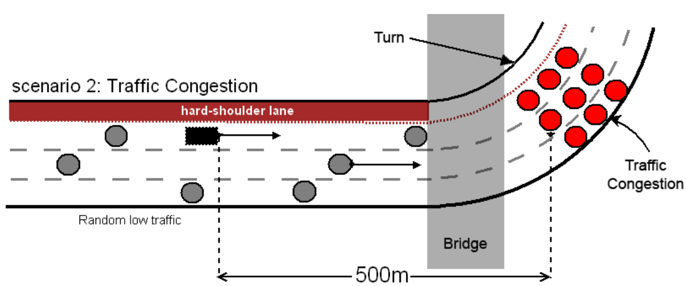

Fig. 3. Traffic congestion and sharp turn situations (second scenario)

In particular Figure 4(a) illustrates the driver's performance regarding the speed maintenance with and without the use of the HUD. From the graph it becomes apparent that the user maintained a higher speed than expected. The reason is that the neighbouring traffic in this scenario was sparse and gave little indication of the final traffic congestion 5km ahead. In close proximity and prior to the traffic congestion a sharp turn underneath a road-bridge formed another challenging element of the simulation. In the fifth second before the potential collision the driver approached the turn with considerably higher speed than ideal for effectively negotiating the curve. Realising that the vehicle could not follow the desired trajectory, the user braked instantly and immediately tried to steer the vehicle clear from danger.

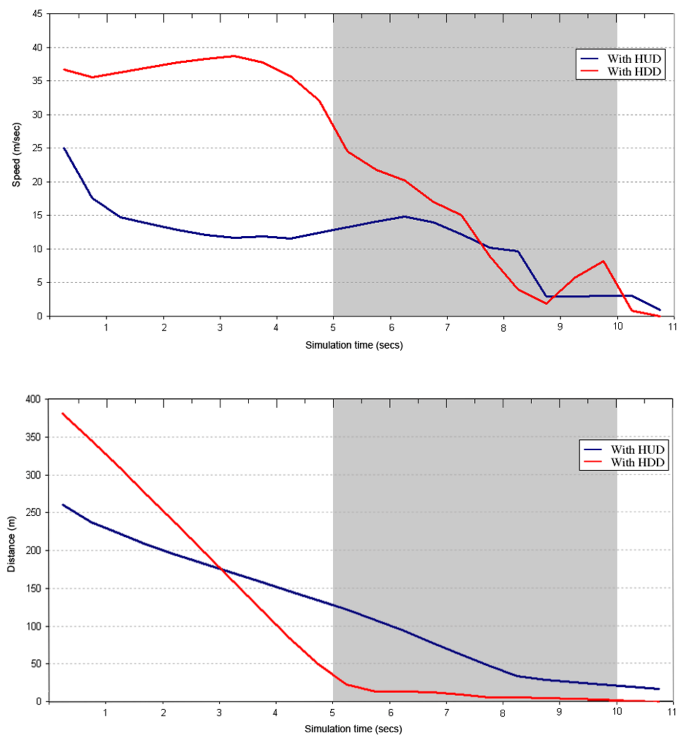

Fig. 4. Graphs showing (a) the distance from the leading vehicle and (b) the driving speed, with and without the HUD

As a result the driver lost control of the vehicle and drifted vertically in the flow-direction. In a desperate second attempt to avoid the collision with the wall, the driver over-steered and headed, this time, towards the congested traffic, which he approached as he performed these different manoeuvres, as depicted by the curve increase between the ninth and tenth seconds before the collision with the traffic. Eventually the user's vehicle stopped as it collided with the bridge wall and in turn with the motionless traffic vehicles. Observing the curve derived from the same user when the HUD was enabled, we can see that the user has a more orderly style of driving. However the user is persistently driving at higher speeds than would be ideal under such conditions. Hence this repeated driving pattern characterises his driving behaviour and is not an “invented” attitude applied solely in the simulation environment. In fact, speeding of this sort is quite common; consider that accident statistics provide estimates that 70-85% of drivers exceed daily the speed limits [19, 20]. Critically, it was made clear to the participants that their driving behaviour or performance would not be graded during the trials.

The evaluation focussed explicitly on the impact of the HUD on their driving performance. Further examination of this “average” user behaviour with the assistance of the HUD interface makes it evident that the user decelerates gradually at the first second mark. Possibly, the user is alarmed by the colour changing of the turn symbol that indicated a rapid approach to the sharp turn. Momentarily, the user then increases speed in order to approach faster the highlighted events. Notably the two indications (traffic and turn symbols) have a direct effect on the user’s behaviour resulting in a minor but constant deceleration. Importantly, the user completes the second simulation with the use of the HUD interface without colliding either with the side barriers or the congested vehicles. The interface’s contribution to this successful performance can also be detected in the driver’s unruffled reactions regarding the potential hazards that lay ahead. The HUD interface contribution was also highlighted by the percentage of collisions occurred with and without the use of the proposed system as Figure 5 illustrates. Notably the system reduced the collisions by 32.5%.

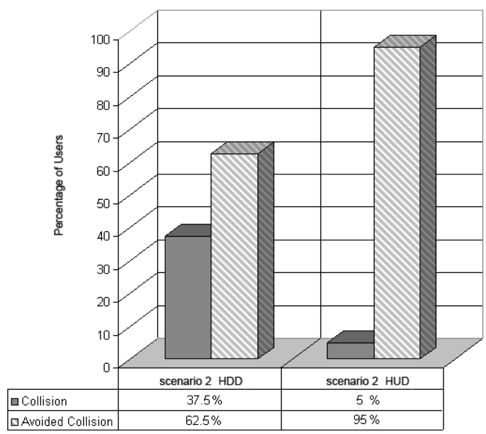

Fig. 5. Number of collisions recorded with and without the HUD interface

Crosschecking between metrics and videos had to be carried out in order to detect a driver’s common reactions and their impact on the vehicle’s manipulation and trajectory. As mentioned previously and as was pointed out by traffic police officers of the city of Strathclyde (whom we consulted during the course of this work), the above “average” user matches the profile of drivers that typically get involved in similar accidents.

Hence it was crucial for this work to investigate the reactions, body posture, facial expressions, accelerating metrics, braking, manoeuvring and lane changing of every user individually. The majority of these data were graphically represented particularly

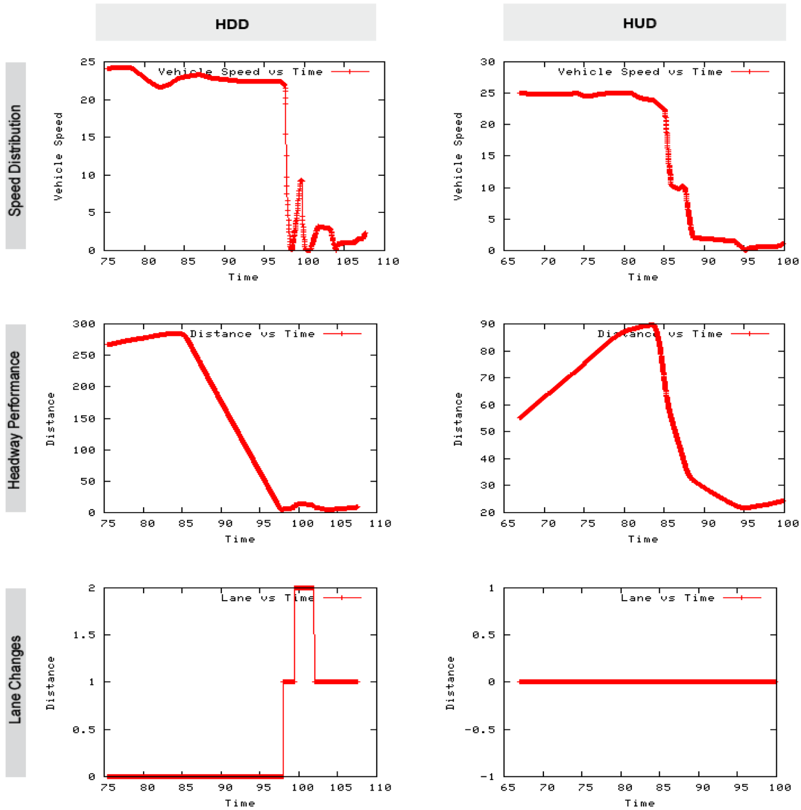

Fig. 6. A sample of graphical representations developed during the evaluation process

for the moments just prior to a potential collision as Figure 6 illustrates. The most popular actions repeated by the majority of subjects were clustered in groups of similar behaviours. In turn, the user with the most clear and common reaction was selected for further commenting and analysis. This process enabled us to understand how a typical driver negotiates with adverse weather and driving conditions with the use of contemporary equipment provided by the instrumentation panel. The HUD's assistance resulted in measurable improvements in the driver's behaviour and minimized substantially any panic reactions.

6 Conclusions

Overall, this study has outlined the evolution of the HUD interface design, elaborated on its interface design philosophy and presented the outcome of the user trials that contrasted the use of the proposed HUD against a typical Head-Down Display (HDD). This paper has elaborated on the development process used for the design and evaluation of the sharp turn notification and traffic warning cues which reflected some of the most common risks present in a motorway environment under low visibility. Throughout this work emphasis was placed on the prioritisation and effective presentation of information available through vehicular sensors in view of aiding the driver in successfully navigating the vehicle under low visibility conditions. The harmonic collaboration between the human (driver) and machine (vehicle) elements has been supported by utilizing the machine as a collecting and distilling hub of information. In turn, the human agent has been urged towards improved decision making through careful consideration of user characteristics and needs. This positive effect on the driver has been achieved by conveying the distilled information through carefully placed visual cues on the HUD interface.

In future work, we aim to improve on the HMI characteristics of the HUD and expand the number and quality of the acquired data necessary for the HUD functionality. To achieve this goal, we aim to make use extensive use of Vehicular Networks functionality and consider the use of more diverse in-vehicle sensors.

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