Early Notification Warning System for Prototype Head-Up Display: Development and Evaluation of Traffic Congestion and Sharp Turn Warnings

Vassilis Charissis
Glasgow Caledonian University,
Department of Computing & Creative Technology

George Vlachos
University of Strathclyde, Department of Management

Sachi Arafat
University of Glasgow, Department of Computing Science

Warren Chan
University of Glasgow, Digital Design Studio

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ABSTRACT

This paper presents the design and development of a prototype Head-Up Display (HUD) interface that offers early notification warnings of potential collisions under unfavourable weather and traffic conditions. In this work, we particularly focus our effort in the embedment of traffic congestion and sharp turn visual warnings in a working prototype interface. In turn, we present the results of a large scale evaluation of the system on a group of forty users, which contrasted the use of the proposed HUD against a typical HDD. Finally, the paper offers suggestions for further research and a tentative plan for future work.

INTRODUCTION

Driving is a demanding psychomotor activity which may be significantly hampered by adverse weather conditions. In particular, a driver's spatial and situational awareness suffer in such environments, as neighbouring vehicles and other objects are veiled from view and become unnoticeable. Additionally, unexpected traffic congestions and reduced visibility in various road sections can increase dramatically the accident probabilities. Under such unfavourable driving conditions, the inability of in-vehicle notifications to effectively portray information increases the difficulty of the driving task [1].

Moreover, due to the mind-sharing notifications of the assortment of infotainment devices present inside the vehicle, the driver's concentration can be absorbed on ineffective gazing at the dashboard dials, in the case of

Head-Down Displays (HDD), as well as on discerning the misty external scene. Therefore in potential abrupt braking of the lead vehicles, the driver does not have the required time and situational awareness to proceed in a collision avoidance braking manoeuvre. Adhering to the aforementioned observations and 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 constraints, we developed a prototype Human-Machine Interface (HMI) applied in a full Head-Up Display (HUD) system offering crucial information to the driver, under the aforementioned conditions [2,3,4,5]. A series of interface elements have been developed to facilitate navigation specifics with an emphasis in 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.

Particularly this paper introduces a prototype design for an automotive Head-Up Display (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 an HMI has been designed and implemented to fulfil these requirements.

In turn, 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. Principally the evaluation of the proposed HUD interface aimed to determine the actual response times (RT) and headway (HW) benefits derived through its usage and subsequently the real impact in the decrease of accident propensity. Furthermore, the paper entails a thorough data analysis and examines the potential benefits and occurring issues of the proposed HUD interface. Interestingly the preliminary user trials demonstrated that the system delivers on its promise for an efficient, non-distracting information display conduit.

Overall, the paper is organised as follows: The next section presents the generic framework of the proposed HUD interface and describes the two interface design components under investigation. The following sections describe the evaluation methodology, simulation scenario and metrics employed to appraise the efficiency of the interface. Subsequently, we present the simulation results analysed with two different methods. Further data analysis highlights the headway (HW) differentiation of the proposed HUD in contrast to the contemporary HDDs. The paper concludes with a summary of potential benefits and drawbacks of the proposed HUD interface and presents a future plan and areas of further development.

HUD PROTOTYPE INTERFACE

A frequently occurring problem in HUD designs is caused by the quantity of information presented to the user through the interface. Previous HMI studies [6] have indicated that the interface should not accommodate myriads of information as this evidently puzzles the driver. In general, a plurality of information is not always an advantage, particularly in situations where the human senses need to identify a problem instantly (such as an imminent collision). The proposed HUD interface focuses primarily on the development of visual elements that highlight specific information related to motorway driving under low visibility conditions. As such, the number of visual cues has been reserved to a minimum level to accommodate for minimal driver distraction under high-speed driving situations. Various element combinations were tested informally during the development of the interface in order to identify an optimal amount of data that could be presented at any one time.

Critically, the equilibrium maintained between the significance and quantity of information was particularly crucial for successfully conveying data under adverse driving conditions, which, by definition, encumber human senses. As such, the interface elements have been designed to form, with the minimum amount of visual "interference", a comprehensible mental image that refers to elements/objects of the real scene. This minimal approach has been infused into the design implementation of the proposed interface as the number of symbols appearing in a typical driving scenario (i.e. motorway environment and near-zero visibility) is less than four, namely pathway, lead vehicle, the front vehicle in the same lane. An exception to this setup appears only when the driver has been warned about traffic congestion ahead or a sharp road-turn in addition to existing neighbouring objects' warnings as illustrated in Figure 1. Nonetheless, the balance between quality and quantity of information has been further improved with the employment of appropriate "contrast" techniques by the utilisation of colour-coded and size-altering symbols.

Figure 1: (a) Typical HUD interface configuration, (b) all-symbols configuration

Notably, these symbolic representations have a dual function serving both as visual warnings and visual enhancements. Considering human attention limitations and performance anxiety levels in a driving situation under low visibility in a motorway, it was evident that the system should convey to the user only crucial content information. To facilitate this, HUD peripheral sensors could "feed" the interface with time and distance measurements relevant to the potential hazard objects. During the development of the HUD display, four pieces of information were primarily identified as the most crucial for collision avoidance in motorways. This information was visualised through the iconic representation of actual objects, which thereafter produced four symbols: lane/pathway recognition, lead vehicle detection, traffic warning and sharp turn notification (the symbols are presented in action in Figure 1. A brief description of the proposed HUD symbols system is provided further on.

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 developed a group of symbols which are instantly recognised by the drivers [5,7]. 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.

EARLY NOTIFICATION SYMBOLS

In addition to the primary collision avoidance symbols, in this paper, we are introducing a specific group of early warning notifications related largely with the traffic congestion and the sharp turns typically camouflaged in the terrain. In particular, the traffic congestion symbol is designed to presage forthcoming bottlenecks caused by traffic congestion. In such conditions, the approaching vehicles decelerate rapidly, especially if the traffic congestion is not clearly detectable which could result in a "domino" effect [1].

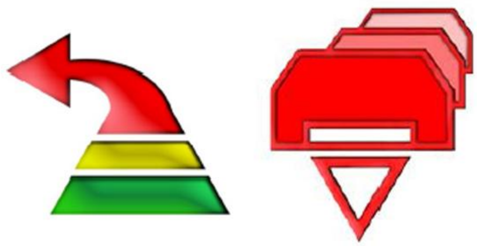


Figure 2: Traffic congestion and sharp turn situations (second scenario).

The sharp turn symbol provides the driver with an early warning with regards to particular sections of the motorway, such as junctions, intersections and hairpin turns, which can be remarkably difficult to negotiate particularly under adverse weather conditions. The colour-coding of the symbol entails four stages of proximity to the top of the forthcoming curve. It appears initially in light blue colour so as to cause little distraction to the driver and gradually it builds up its intensity with the three distinct colour-coded stripes as appears in Figures 2 & 3.

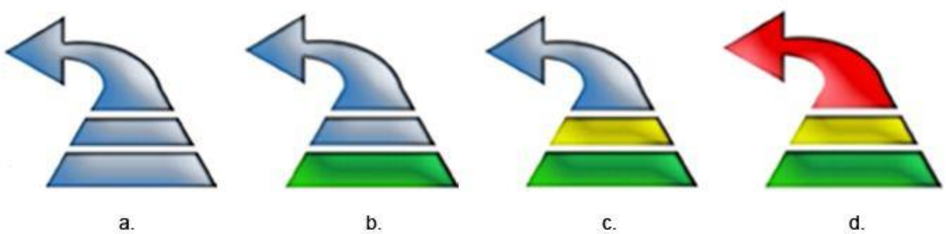


Figure 3: The Turn Symbol and its four stages of approach to the top of the curve. blue bar 500m-150m, (b) green bar 150m-100m,(c) yellow bar100m-50m, (d) red bar 50m-0m.

EVALUATION RATIONALE

SIMULATION SCENARIO

In order to evaluate the effectiveness of the proposed HUD interface a number of accident scenarios were simulated following closely the suggestions and collision data provided by the Strathclyde Police Department [8]. To this end, we focused on two particular scenarios which would evaluate reaction benefits with and without the use of the prototype HUD. For both scenarios, the average user was expected to misjudge the headway (HW) distance and perform last moment panic braking or collision avoidance [2]. The first scenario was designed to identify the potential in abrupt braking situations of the lead vehicles. The analysis of results derived from this experiment provided the study with valuable and encouraging results [2, 3]. Utilising the same experiment methodology we proceeded with a second comparative study (second accident scenario) between the HUD and the HDD interface. This second scenario was designed specifically for the evaluation of the two aforementioned early notification symbols [9, 10]. The second scenario capitalised on the main interface symbols while also evaluating the impact of two additional symbols, namely traffic congestion and sharp turn symbols, which provided early warnings for specific situations that may arise in a motorway environment.

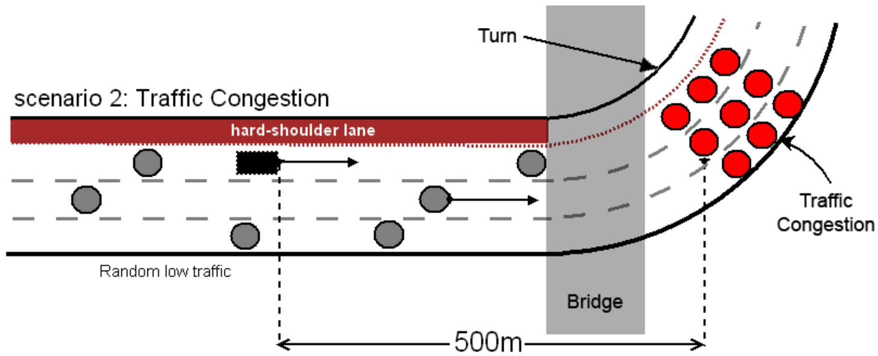


Figure 4: Traffic congestion and sharp turn situations (second scenario).

In particular, the second scenario recreated a traffic congestion scene with 20 participating vehicles. In this case, the traffic "bottleneck" had been positioned strategically in a reduced visibility position, covered partially under a bridge. Furthermore, this difficult road scenario was enhanced by a preceding blind turn. The low-visibility of the actual road was amplified by the use of heavy fog. In contrast to the first scenario, the drivers were expected to be in a fairly heightened alert status as they have been aware that road turns are inherently more hazardous to navigate because of limited visibility at the point of turn. Note that the appropriate driver's reaction to this event would be to brake until the vehicle has reached a full stop as there was no way around the traffic jam.

SIMULATION METRICS

During the trials, the simulator software was recording distance (from the start) and speed of the lead and the user's vehicle respectively. In addition, lane changes, time and error occurrences formed a trail of data that demonstrated the trajectory of the vehicles involved in a collision. The log-data were transformed into time and distance differences between lead (agent) and following vehicle (user). The aforementioned metrics used in assessing the system's (HUD) effectiveness were then translated to response times (RTs), time-to-collision (TTC) and headway (HW) data described below. The time estimation of TTC derives from the distance difference Dx between the lead vehicle and the user's car, divided by the difference of the vehicles' velocities (V1 following (user's) – V2 lead). In our case, the lead vehicle's (V2 lead) speed equals zero as the vehicle is stopped in traffic. Table 1 presents the equations utilised for Time-to collision and Headway calculations respectively

Time To Collision	Headway
$TTC = \left\| \dfrac{Dx}{V_{1\,(following)} - V_{2\,(lead)}} \right\|$	$HW = \dfrac{Dx}{V_{1\,(following)}}$

Table 1: Time-To-Collision (TTC) & Headway (HW)

Furthermore, video footage was captured by two remote-controlled video cameras, with one focusing on the simulator's monitor and the other on the driver (Figure 5). As a result, apart from the measurements obtained by recording the simulation data, it was also possible to conduct a subjective appraisal of the driver's alertness state and emotional response to the simulation events.

PARTICIPANTS

Following our previous comparative methods, the second scenario trials attracted 40 volunteer drivers. For their participation was mandatory to have a valid driving license. Overall their selections were random and have been selected in order to represent the largest possible segment of driving population with regards to driving experience, profession and age.

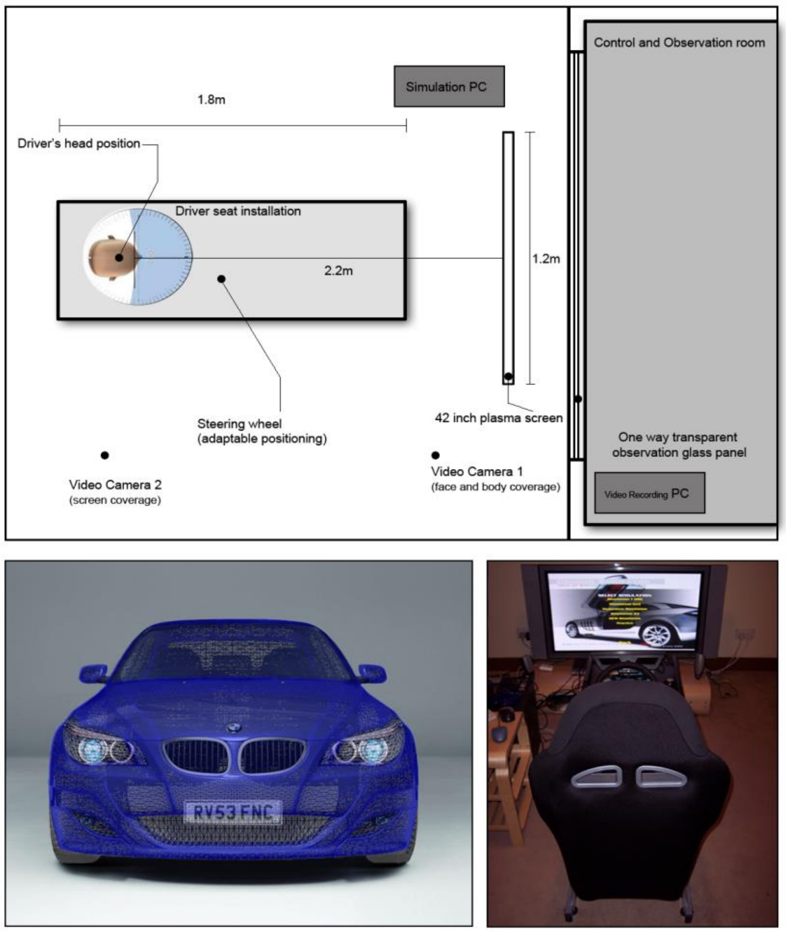


Figure 5: Driving simulator set-up

COLLISION OCCURRENCES RESULTS

An antecedent data evaluation to the extensive headway analysis is the revealing assessment of the effectiveness of the HUD system through the collision occurrences per trial, with and without the HUD interface. These data are presented in Figure 6. Interestingly, the use of the proposed interface resulted in a remarkable decrease in collisions in this particular scenario. In particular, 37.5% of the drivers collided without the use of the HUD. In contrast, only 5% of the users experienced a collision when the HUD system was deployed as depicted in Figure 6. Although these results might be encouraging we were inclined to identify the suitability of such interface for the majority of drivers and not exclusively for the small sample of participants. Consequently, the significance of results was extrapolated from the sample of the study to the overall population of drivers by employing a large sample confidence interval for the population mean. This was calculated primarily by employing the traditional large sample confidence interval (CI) statistical analysis method. According to this method, the collision occurrences results were calculated with the confidence of 95%, which suggests a margin of 5% of potential error that is acceptable for the nature of this evaluation.

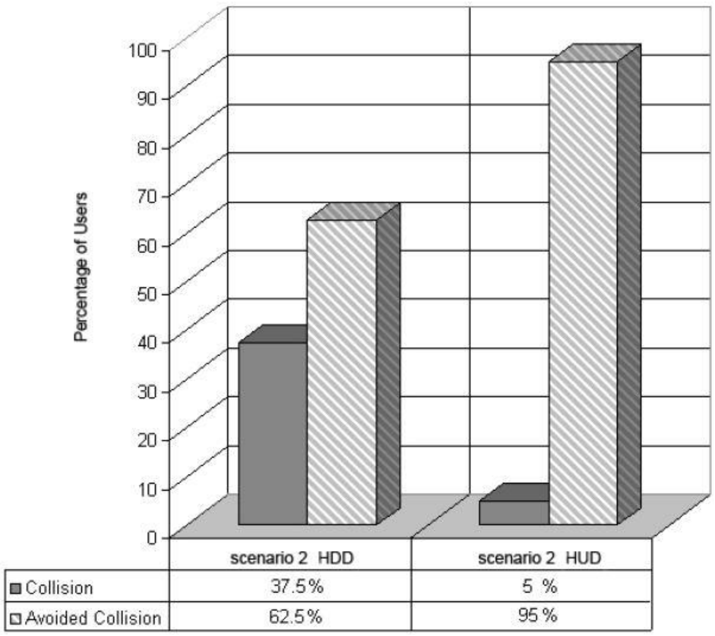
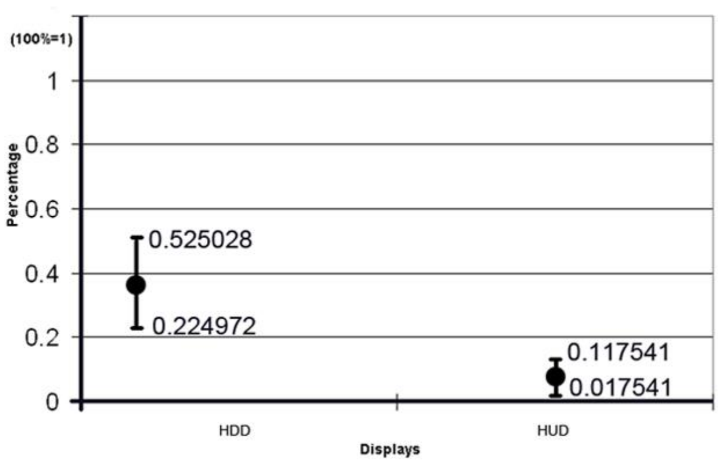


Figure 6: Number of collisions recorded with and without the HUD interface

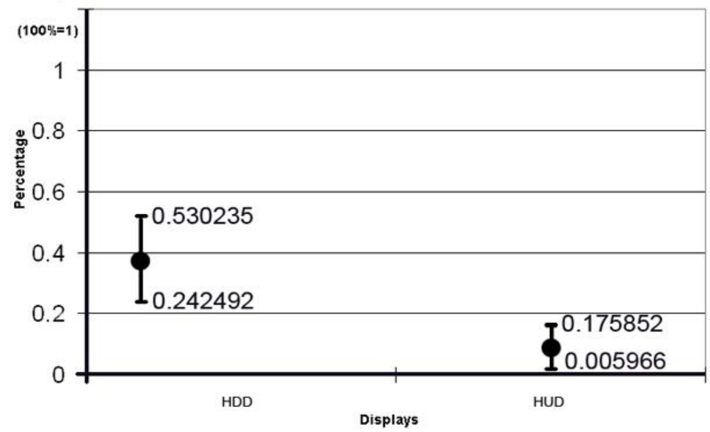
The analysis suggested that drivers have a probability of average 37.5% (0.525028 - 0.224972) to collide when they use the contemporary dashboard (HDD) as an information conduit. In turn, this number was decreased to 5% (0.117541 - 0.017541) when the proposed HUD interface was utilised as a guidance system in the same conditions as presented in Chart 1.



37.5% Proportion for drivers who collided using HDD					
CI_L1P n=(40) x=(15) c=(.95).					
Traditional Large sample CI for one proportion					
ptrad	zstar	se_trad	etrad	*low_trad*	*up_trad*
.375000	-1.959964	.076547	.150028	.224972	.525028
5% Proportion for drivers who collided using HUD					
CI_L1P n=(40) x=(2) c=(.95).					
Traditional Large sample CI for one proportion					
ptrad	zstar	se_trad	etrad	*low_trad*	*up_trad*
.050000	-1.959964	.034460	.067541	.017541	.117541

Chart1: Collision Occurrences using HDD vs HUD

For validity purposes the extrapolation of data results was repeated with the use of the “Wilson formula” or Wilson score interval. The particular formula is an improvement over the typical approximation interval, offering detailed estimations particularly for minute number participants or experiments. According to the Wilson analysis, the drivers appeared to have almost identical collision probabilities to the first method as depicted in Chart 2. This remarkably close indication verifies the significance of the initial analysis.



95% Proportion for drivers who collided HDD					
CI_L1P n=(40) x=(15) c=(.95).					
Wilson Large sample CI for one proportion					
pwlsn	zstar	se_wlsn	ewlsn	*low_wlsn*	*up_wlsn*
.386364	-1.959964	.073405	.143872	.242492	.530235

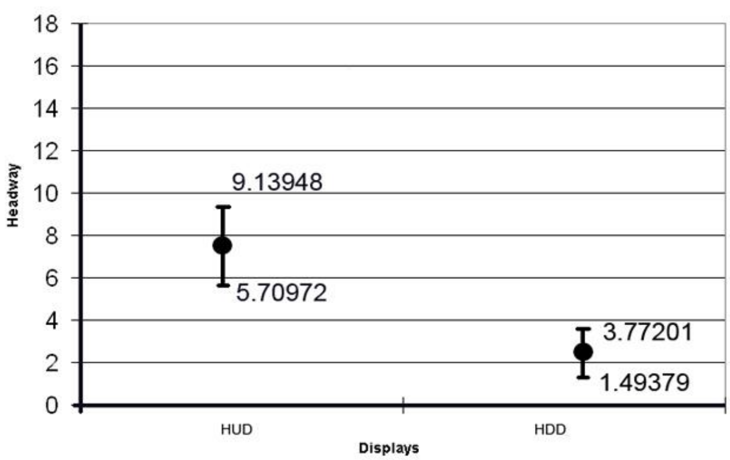
95% Proportion for drivers who collided HUD					
CI_L1P n=(40) x=(2) c=(.95).					
Wilson Large sample CI for one proportion					
pwlsn	zstar	se_wlsn	ewlsn	*low_wlsn*	*up_wlsn*
.090909	-1.959964	.043339	.084943	.005966	.175852

Chart 2: Collision Occurrences HDD vs HUD (Wilson Method)

Overall the derived results clearly present that, the HUD interface can be more efficient than a contemporary HDD under specific driving conditions. This is evident by the significant decrease of collisions recorded. Both analyses indicated that the two symbolic early notification symbols warned the driver in a non-distracting and timely manner with regard to the forthcoming hazardous, sharp curve and the traffic congestion. To this point, it has to be highlighted that even the two collisions that occurred with the HUD assistance were at very low speeds which could not be fatal or serious for the vehicle occupiers.

COMPARATIVE HEADWAY RESULTS

Further analysis of the trial data was deemed essential in order to identify the significance of the HUD interface to the headway developed between the user’s vehicle and the immobile traffic. In this case, the evaluation results were calculated with a 95% confidence interval.



95% CI for Headway HUD						
CI_S1M n = (40) x_bar = (0.95).						
Small sample confidence interval for the population mean						
n	x_bar	TiL	SE	err	*Lower*	*Upper*
40	7.42460	2.02269	0.84782	1.71488	5.70972	9.13948

95% CI for Headway HDD						
CI_S1M n = (40) x_bar = (0.95).						
Small sample confidence interval for the population mean						
n	x_bar	TiL	SE	err	*Lower*	*Upper*
40	2.63290	2.02269	0.56317	1.13911	1.49379	3.77201

Chart 3: Headway HUD vs HDD

Chart 3 above presents the 95% interval values for the population mean HUD, ranged from 5.70972 - 9.13948 while the mean for HDD was 1.49379 - 3.77201.

The impact of the HUD on the group of participants in relation to the HW time (small sample confidence interval for the population mean), is significant as the confidence intervals do not have any overlap. The graph further highlights the significant benefits of the HUD use which result to an average headway of 7.4 seconds, almost double the time suggested as minimum safe TTC or HW according to Bloomfield et al. (1998) [11, 12]. This time excess provided by the early warning notification interface translates approximately to an early warning of 180 - 250m for speeds up to 100km/h [7].

CONCLUSIONS

This paper presented an evaluation of a prototype Human-Machine Interface developed for automotive HUD. The interface's main objective is to enhance driver's spatial awareness in low visibility conditions in a motorway environment. In this work, we examined closely the design rationale of two early notification symbols embedded in our continuously developing HUD interface [3, 13].

In turn, we conducted a comparative study in order to compare the HUD design with a contemporary HDD interface (dashboard). Forty user trials were conducted, following our previous experiment methodology. The derived results strongly suggested that drivers could be warned well in advance by the proposed HUD notification symbols for forthcoming traffic congestion and sharp turns, particularly under low visibility conditions. In contrary, the HDD interface appeared to be insufficient to provide the driver with any if not the necessary information required to avoid a potential collision with the immobile traffic or the borders of a sharp motorway turn. For verification purposes we analysed the data through different methods [14] which concluded in almost identical results, solidifying our initial hypothesis with regard to the potential benefits of such HUD interface. Conversely, these additional notification symbols to the HUD interface increased the system's effectiveness and expanded its usability to other potential collisions. Yet it is perceptible that a fully functional real-life HUD device would require additional research for successful implementation. Such fully functional HUD deployed in an actual vehicle is in our future plans. Finally, parallel development of additional functionalities is essential for offering a holistic approach to driver's navigation, infotainment and other in-vehicle related activities.

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