Enhancing Driver's Vision with the use of Prototype Automotive Head-Up Display Interface

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Abstract
Driving is a complex task largely dependent on vision as the predominant channel of information. Considering the wealth of visual cues available in a vehicle, it becomes crucial to manage the frequency of information provided to the driver. Notably, the significance of the quality and quantity of incoming information increases substantially under adverse weather conditions or in heavy traffic situations. The purpose of this study is two-fold. Firstly, our intent is to investigate avenues for enhancing the driver's spatial awareness under low visibility conditions and secondly to direct additional information from vehicle sensors in a way that improves human response times and reduces the possibility of collision. We designed a full-windshield Head-Up Display (HUD) interface based on a survey which recorded drivers' attitudes, preferences and requirements. The prototype HUD interface was tested in a car-following driving scenario, on a driving simulator. This paper provides an overview of the interface design process; describes the user trials and presents our conclusions and future work.

1. Introduction

Contemporary driving and navigation interfaces are inescapably bound up with various and numerous gauges, buttons and occasionally screens, hosted in the dashboard compartment. Inevitably, the wealth of information provided regarding the vehicle's functions and mobility status can result in the driver's distraction (Phaal, 2002). Information filtering, analogous to the situation should be applied in cases that demand extensive driver's attention (i.e. contrary weather conditions) (Salvucci, 2001). Automotive research has suggested that superimposing a limited number of information on the windshield of the vehicle, could result in decreased response times and more stable driving reactions when compared to information provided through traditional Head-Down Displays (HDDs) (Green, 1993; Steinfeld and Green. 1995; Horrey et al. 2003).
This study proposes to combine the information received from the existing navigation systems and the vehicle's exterior sensors in an efficient and prompt-alert Head-Up Display (HUD) interface. The main objective of this guiding interface is to minimise the mental workload of the driver in high risk situations by presenting only the necessary information for successful navigation. By adhering to the guidelines for in-vehicle information systems set by standardisation organisations (BSi, 1999; 2003) we developed a system that can be utilised when low-visibility conditions occur in a motorway environment.
The rest of the paper is organised as follows. Initially, we touch upon the safety issues arising from car-following scenarios, under specific traffic and weather conditions. After the overview of contemporary navigation and HDD systems, we provide the

rationale for the proposed HUD interface design and the decision to opt for guiding-symbolic information rather than traditional map-direction representations. The elements of the interface are presented briefly in the subsequent sections. Further on, we give a description of the driving simulator that was used in the experimental evaluation of the system and discuss the research results. Finally, we present our conclusions and a provisional plan for future work.

2. Traffic and Weather Conditions

2.1 Traffic Conditions

The motorway traffic accidents investigated for the purposes of this study engage two categories of car-following scenarios. In the first category a rear collision event usually occurs when the lead vehicle brakes abruptly (Smith et al. 2003). The second category examines rear collisions caused by traffic-congestion (Daganzo, 1999). In the recent years, the frequency and effects of such accidents have raised major concerns thus further investigation and development of collision warning/avoidance systems is encouraged by governmental bodies.

2.2 Low Visibility and Related Accidents

Low visibility is a phenomenon created by a number of different factors and can considerably decrease the driver's situation and spatial awareness. In this study we are particularly interested in thick fog (visibility<100m). The combination of fog and high speeds on motorways can be a major cause of car-following related accidents, as the statistics of the Strathclyde Police Department, in Scotland have shown (SPD, 2004). Previous research indicated that a combination of visual, haptic and auditory collision warning systems can assist the driver in such conditions (Lee et al. 2004). Capitalising in these initiatives we have focused our research on visual cues as driving is primarily a visual task.

3. Contemporary Navigation Systems

3.1 Overview of Navigation systems

Two categories of displays can be identified with regard to the amount and type of navigational information given to the driver; the map-navigation and guidance-navigation. The former embraces the vast majority of commercially available navigation systems that present information regarding various roads on a 2D or 3D map, typically by using a Global Positioning System (GPS). Existing GPS based navigation systems inform the driver about the position of the vehicle on a 2D map and may suggest possible routes by taking into account distance or traffic congestion. The information is often presented as visuals on hierarchical displays positioned in the middle of the dashboard, these in turn contribute to visual cluttering and driver distraction.

On the other hand, guidance-navigation systems focus on enhancing the driver's spatial awareness, within a short perimeter of the vehicle, by simultaneously offering collision warning as well as other alert cues. These functionalities become extremely important in low visibility conditions where the sense of orientation is reduced. This study falls into the guidance-navigation category as it focuses on augmenting drivers' senses rather than directing them to a specific destination on the map.

3.2 Situation and Spatial awareness

Dividing the driver's attention between the road and the map-navigation or other HDD elements, may present a high risk as "eyes off the road" time increases considerably. International norms and navigation guidelines are prohibiting the usage of navigation systems during driving (SAE, 2000). However, the problem is escalating in parallel to the technological infotainment advances in the automotive sector, thus compromising the safety factor.

Additionally, low visibility conditions are exacerbating the risk by deteriorating substantially the sense of spatial awareness. Often, heavy rain, snowfall or fog minimises the field of view, resulting in a "flattened" image perception of the road lying ahead. Inevitably, the decline of spatial awareness negatively influences the situation awareness, causing the driver's response times to be lengthier.

Too often, contemporary map-navigational systems can be inefficient in assisting navigation in low visibility conditions as the given information cannot match the driver's "flattened" environment view. As close proximity vehicles, lane marks and side barriers become indistinguishable, the driver has to be constantly alert in order to identify and avoid them. In such cases an alternative type of navigation, serving purely guiding purposes, should be utilised. For that reason, the primary function of this proposed interface is to enhance the driver's vision by identifying, in a symbolic form, the external objects that suggest higher risk of involvement in the driver's route. By superimposing the essential information on a HUD system, faster response times can be achieved as has been demonstrated in previous studies (Steinfeld and Green. 1995). In the following section we discuss which symbols have been considered essential for safe guidance in a motorway car-following scenario, under low visibility.

4. Interface Initial Design and Usability

4.1 Symbolic Representation

A variety of information can be conveyed more successfully in a visual, symbolic manner rather than in alphanumeric data. A graphical symbol can transfer the desired information via a more compact display that can be apprehended more rapidly by the user (Dourish, 2004). During the design of the HUD, four pieces of information were initially identified as the most vital for collision avoidance in motorways, namely lane recognition, lead vehicle detection, traffic warning and sharp turn notification. Hence, in order to represent visually this information, four symbols have been designed and integrated in the HUD interface. The design of the symbols has been built around valuable comments and ideas which have been gathered during informal interviews with drivers.

a. Lane Symbol/Pathway: The pathway display concept was initially designed and developed for aviation HUDs. Our simplified version is a composition of converging lines, superimposed on the real road lane markings. The presence of these lines aims to provide information regarding the vehicle's position on the road and eventually prevent the driver from an accidental lane departure. Additionally, through a colour coding sequence, the lane symbol can also act as an obstacle warning system. For instance, a green lane strip indicates absence of a vehicle or obstacle on that side of the vehicle (Figure 1a), whereas a red lane strip serves as a warning signal indicating an object on the side of the vehicle, whether this is another vehicle, the hard shoulder lane or the lane barriers.

b. Lead Vehicles Symbols: The use of a lead vehicle warning system was considered necessary for enhancing the driver's realisation of the surrounding environment and in particular for signifying the distance from the front vehicle. This category of collision warning uses the instantaneous differential separation and differential velocity between the driver's car and the vehicle ahead to continuously compute time-to-collision (Bloomfield et al. 1998). The symbol used for this purpose is a miniature representation of the outline of a car as shown in Figure 1-b1. To further highlight the lead vehicle travelling in the same lane, an inverted triangle has been added to the symbol depicted in Figure 1-b2. These icons are, ideally, superimposed on the first row of leading vehicles and entail four colour states denoting distance/risk levels: blue → green → yellow → red. However, indication of the existence and movement of vehicles which are in close proximity to the driver's vehicle, it would suffice to rely on the colour-changing pathway symbol. Yet, this addition performs as a second safety system and at the same time enhances the peripheral view.

c. Turn Symbols: When visibility is limited, certain parts of the motorway, such as junctions, intersections and hairpin turns, can be particularly tricky to traverse. Projecting a big-scale map in the driver's view span can result in distraction from the driving task; therefore, in the proposed interface we introduced a turn symbol in the form of an arched arrow (Figure 1c). The colour of the symbol is consistent with the other three symbols, as it initially appears in light blue and distinct stripes of green, yellow and red are added depending on the distance from the potentially hazardous road turn. As expected, the arrow points in the direction of the upcoming road turn. Hence, the turn symbol could prevent the driver from panning through the side windows (Harder et al. 2001) by providing information about the distance from the turn, its direction and the vehicle's position in relation to it.

d. Traffic Symbol: A common cause of accidents in motorways is the rapid deceleration of the leading vehicles which is usually the consequence of a response to traffic congestion along the road. Normally, when vehicles approach a congestion event, reduce their speed either gradually or abruptly, depending on their distance from the traffic. This creates a chain reaction of slowing vehicles which is due to affect several links in the traffic flow. Therefore, a traffic notification symbol can be useful, especially when traffic congestion has been formed in areas hidden from view (i.e. around corners, under bridges, low visibility conditions). In our design, the traffic symbol is represented as a miniature of overlapping lead vehicle symbols (Figure 1d).

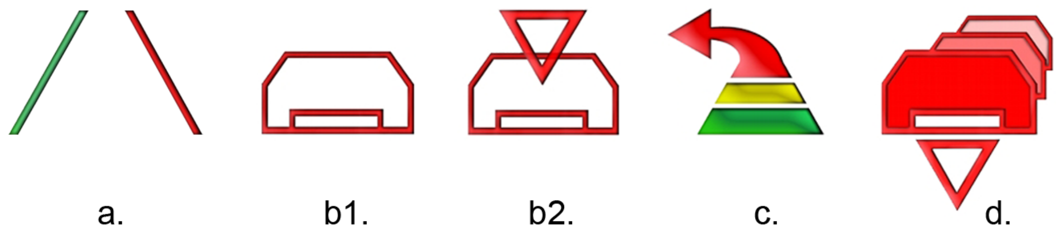

Figure 1. Symbols used in the full-windshield HUD: (a) lane symbol indicating the presence of an obstacle on right side of the vehicle (b1) lead vehicle on a different lane (b2) lead vehicle on the same lane (c) road turn in close proximity (d) traffic congestion

4.2 System Usability

The approach of a simplified interface aims to embrace the needs of the majority of the users, regardless of age, sex, cultural and educational backgrounds. We opted for a minimal symbolic visualisation, which is intended to be understood by the average driver and conveys the essential information in a timely manner. During the development of the interface we created a decision-making subsystem which regulates the incoming sequence of external information. In order to provide the driver with real-time information, interrupt and delay strategies have also been evolved based on a previous study (Kenny et al. 2004). The proposed flow chart of information is depicted in Figure 2.

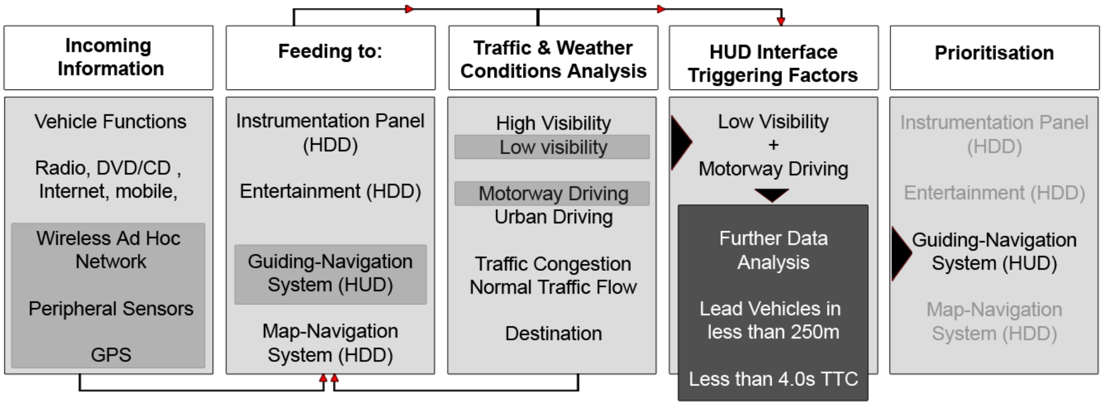

Figure 2. Information analysis and interrupt strategies chart.

5. Interface Evaluation and Discussion

5.1 The Experiment

To evaluate the effectiveness of the proposed HUD system with the existing HDD interfaces, we re-created two car-following scenarios and carried out user trials on a driving simulator. The trials were performed in the eMotion lab at Glasgow Caledonian University with participants of varying driving experience and age. The room was equipped with two video cameras, an eye-tracking device and a pulse measuring system for recording the subject's reactions. The driving simulator setup consisted of driver's chair, a gear stick, a steering-wheel and pedals. A screenshot of the simulator in action is shown in Figure 3. A more analytical description of the driving simulator has been given in previous work (Charissis et al. 2006)

Figure 3. Screenshot of the driving simulator

A preliminary test involving 14 users was conducted in order to identify possible flaws of both the interface and the simulator. Forty users took part in the final trials and each of them drove through six scenarios. For familiarisation purposes, the first two scenarios involved driving under light traffic conditions for approximately 35km. The following two scenarios had been designed to recreate possible accident situations under low visibility conditions. The simulator's dense fog was restricting visibility to below 50m (zero visibility). Both car-following scenarios were played out with and without the HUD interface. Users were instructed to drive as they would normally do under these conditions, respecting the speed limits. The 3D testing track was built to resemble a section of motorway in Scotland.

5.2 Results and Discussion

The trials have provided evidence that these symbolic representations, projected on a HUD environment, can augment the sense of space and give essential guidance information for more stable steering and for preventing collisions with other vehicles or obstacles. Accident occurrences had been reduced substantially when the proposed interface was utilised in contrast to the typical instrumentation panel (Charissis et al. 2006).

The post-test interviews highlighted that the interface elements made the driving task more facile, especially under difficult weather conditions. Visual information is rapidly assimilated by users, which leads to considerably faster reactions. In order to measure the learning curve, ten random drivers had been chosen to perform the trial without receiving any instructions or guidance about the function of the HUD interface. Within the first few minutes of the simulation, they had discovered the utility of each symbol, demonstrating in this way the ability of the interface to be comprehensible without reading an extensive manual beforehand.

According to previous research, the minimum safe time-to-collision is four seconds (Bloomfield et al. 1998). The response times of the first group of participants (10/40) showed that the HUD interface enabled an increase in the time-to-collision to approximately 8 seconds. This outcome can be primarily attributed to the ability of the interface to indicate the lead vehicles in advance (250m approx) which are particularly prone to collision. Furthermore the colour-coding as well as the gradual size-shifting of the symbols create a series of progressive collision-warnings, in contrast to flashing or pop-up visuals that usually distract the user.

Nevertheless, a few concerns had been raised. The initial findings suggested that the use of the HUD interface had slightly increased the drivers' speed despite the low visibility. The addition of a counter-act subsystem, accommodated in mainframe of the interface, could offer a possible solution via monitoring the driver's speed and either automatically setting a limit or passively indicating a proposed speed. This interface was strictly focused on a car-following accident scenario that occurs in dense fog conditions on motorways, therefore the usage of the system and the findings cannot be generalised to different conditions (i.e. urban driving or 100% visibility).

6. Conclusions

This paper has presented the initial design philosophy of a prototype HUD interface for usage in low visibility conditions. This preliminary study, conducted on a driving simulator, has exhibited that the proposed HUD interface can communicate most of the essential information required for driving in the investigated scenarios.

In the future we aim to develop and evaluate variations of the initial interface building upon the data collected so far, as well as the feedback received from the participants. We further intend to evolve our design to a "direct manipulation" interface, taking into account current infotainment systems that are typically incorporated into many HDDs. Finally, we plan to design new visual elements and explore other human machine interaction techniques with the intent of further increasing the driver's safety.

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