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Reducing Driver's Cognitive Load with the Use of Artificial Intelligence and Augmented Reality

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Abstract. Multiple infotainment sources can significantly overload the driver's cognitive load and increase the collision probabilities. Current solutions provided have attempted to alleviate this issue with the centralization of infotainment devices to single touchscreen devices in the dashboard area. Yet this solution still requires the driver to take the eyes from the road and concentrate on operating the secondary tasks unrelated to the driving process. The paper presents a prototype Augmented Reality Head-Up Display (AR HUD) system that superimposes a selected number of infotainment data on the vehicle's windshield only when this is safe for the driver. The selection of infotainment data and projection timing is calculated by a prototype Artificial Intelligence (AI) Co-Driver that aims to reduce the driver's cognitive load. The proposed system was evaluated by 50 users against a typical touchscreen dashboard system. This work presents and discusses the subjective feedback related to the cognitive load that the users perceived during the trials. The paper concludes with a future plan for improving both the AI and AR HUD elements to perform in an urban environment.

Keywords: Cognitive Load, Augmented Reality, Virtual Reality, Driver Distraction, Head-Up Display, Artificial Intelligence, Simulation

1 Introduction

Driving distraction has been extensively studied and analysed to define the reasons that cause this problem aiming to provide viable solutions [1]. In a nutshell, the driver distraction could be attributed to the driver's temporary focus on an irrelevant to the driving, object or event. If these objects or events are external to the vehicle environment they are limited solutions that could be applied to maintain the driver's focus on the primary objective. However, in-vehicle distractions such as infotainment systems, present the highest hazard of distraction and potential collision [2, 3].

The automotive industry responded to this issue by centralising the infotainment systems to a single interactive screen. Yet the screen is located again in the lower - central section of the dashboard/Head -Down Display (HUD), which requires the driver to take the eyes of the road and focus towards the lower section of the vehicle's cabin.

To alleviate this issue, contemporary studies have focused mainly either on the presentation of this data and interaction with various touch-screens, and vehicles sensor capabilities [2, 4]. The transient state of the continuously changing traffic conditions, however, and the sheer volume of infotainment data provided, require a more agile solution that does not rely only upon the software and hardware provision from each vehicle.

To this end, the augmentation of human responses with the use of emerging technologies such as Augmented Reality (AR) and Artificial Intelligence (AI) aims to enhance the user's spatial and situational awareness [5].

Additionally, Head-Up Displays (HUDs) have become a focal point of research in the automotive industry, bearing the promise of augmenting spatial awareness and reducing the driver's reaction times [2-4]. Recent developments in vehicular electronics have identified HUD interfaces as an increasingly feasible alternative to dashboard-bound touchscreens and other HDD devices, as they manage to maintain the driver's gaze on the road [2-4].

Such systems would not only require the deployment of sensory equipment on the vehicle itself but would be benefited by inter-vehicle communication facilities to enable a bird's-eye view of road traffic conditions. Our previous research in Human-Machine Interaction regarding AR HUD systems has proved that such interfaces significantly enhance driver's spatial and situational awareness resulting in faster responses and collision avoidance [2-4].

In this work, we present a custom AR/AI HUD interface that aims to augment human senses and improve driver responses in challenging collision scenarios. The latter are designed based on information provided by the local traffic authorities and simulated in the Virtual Reality Driving Simulator (VRDS) which entails a real-life vehicle, full surround 3D stereoscopic projection CAVE environment, surround audio and vibrotactile devices to increase driver's immersion. To evaluate the augmentation of human senses and responses, the proposed AR/AI HUD system has been contrasted to a typical HDD and evaluated by 50 users. Finally, the paper presents and discusses the results of users' mental and physical workload as well as their collision avoidance performance through the comparative study.

2 Driver Distractions & Cognitive Load

During driving, various vehicular systems, and external stimuli could contribute to driver distraction [6]. Multiple attempts to categorise the source and intensity of these distractions have formulated several models [7-11]. Typically the distraction is attributed to (a) visual/audio, (b) manual and (c) cognitive elements.

The Cognitive Load Theory (CLT) attempts to quantify the driver distraction issue based on the principle that the human cognitive load capacity is limited and as such should be utilised for the main task rather than being segmented in multiple secondary or parallel tasks [7]. In particular, during driving or other similar complex activities, human attention and mental resources must be concentrated on the main task to avoid increased collision probability as illustrated in Figure 1.

Fig. 1. Diagram depicting the human attention and mental resources that affect cognitive load, distraction and collision probability; adaptation from [12].

The contemporary vehicular infotainment systems require driver's attention through visual, audio, manual and cognitive means reducing significantly the remaining cognitive load capacity that is not adequate to perform the driving task. As such the collision probabilities are increased particularly under challenging traffic flow and weather conditions [4, 13-15]. Additional distractions that could further burden the cognitive load are the internal communications between driver and passengers [16-18]. This particular work is concerned with the provision of infotainment in a fashion that is timely presented to the driver. This was deemed essential to optimally exploit the human mental resources for the driving task whilst avoiding the driver's isolation from the typical infotainment interactions that he/she is accustomed to. The latter observation and required connectivity necessities are described in detail in the following section.

3 Current Solutions

Current solutions provided by automotive manufacturers incorporated the vast majority of the infotainment systems in a homogenous interface ecosystem and positioned in one specific place within the vehicle cockpit which is typically located in different heights in the middle of the dashboard.

Although this provided an overall control of these devices the amount of incoming information increased exponentially through the years resulting in a highly attention-demanding environment that could increase significantly the cognitive workload of the driver [2, 3]. Previous studies have identified these User Interfaces (UI) as one of the most prominent reasons for driver distraction [19,20]. Further user familiarization with these interfaces could arguably reduce the distraction effects for some drivers, yet interfaces that serve secondary tasks should be discreet and simple to use particularly whilst the vehicle is in motion.

An alternative simple solution would be to remove the elements that could cause distractions, either physically or ban their use through legislation. Yet, this could deprive contemporary drivers of a plethora of systems that they are accustomed to continuously using.

This lack of in-vehicle connectivity could consequently create several issues with the acceptability and usability of current and future vehicle models. Legislative attempts are either circumvented or ignored by a large number of users [2]. In addition, drivers result in improvising solutions to transfer such infotainment technologies within their vehicles which would be incompatible with the driving process. This has occurred in the early stages of introducing mobile phone and navigation devices retrospectively in older vehicle models with detrimental effects [2].

Various other applications and operating systems have been introduced to block, or mute external communications and send automated responses whilst driving [21,22]. The isolation of the driver from external influences might enhance temporarily the driver's attention yet on multiple occasions this could upsurge the driver's anxiety, feeling disconnected and deprived of potentially crucial information [9,23].

In addition, contemporary drivers are accustomed to deciding each application's activities and as such prohibitive or predetermined systems are not favourable. As such, the automotive manufacturers are inclined to maintain or in some cases increase the infotainment applications and activities with the caveat of introduction pages that present the potential issues and request from the driver/user to read and accept the conditions under which will use the infotainment system. While these applications mitigate the direct use of mobile phones and other infotainment devices, they still pose a major distraction issue [24,25].

4 Proposed Solution

The proposed system couples a prototype AR HUD with direct manipulation, gesture-recognition interface and auditory signals enabling the driver to interact efficiently and timely with the incoming information released by the system in appropriate intervals. An embedded AI system identifies the urgency of the information and time to read/respond to the driver. Additionally, it operates as a filtering mechanism and through interrupt strategies regulates the pace of information released to the driver, when it is deemed safe. The information is superimposed in the vehicle's windscreen through the AR HUD projection.

The AR HUD solution was deemed essential to minimise the time required off-the-road, for the driver to visually inspect and interact with the infotainment system on the vehicle's dashboard. The proposed UI enables the driver to interact with the information through the proposed multimodal gesture recognition interface in safely provided intervals as illustrated in Figure 2.

Fig. 2. Driver's AI/AR HUD and gesture recognition for controlling infotainment sources.

The proposed UI is designed to receive, contain, distil and release infotainment data in appropriate time intervals aiming to minimise the driver distraction and reduce the cognitive load imposed by these attention-seeking applications. Previous work on direct manipulation and adaptive UI was employed to support the development of the presented prototype system [24-27].

As such the interface was limited to only three main symbols namely (a) home, (b) navigation and (c) mobile phone communication which includes both phone calls and text messages as illustrated in Figure 2.

The selection of data and their release to the driver has been tasked to an Artificial Intelligence (AI) agent which is currently under development and adaptation for different AR HUD systems [27-29]. The particular AI system plays the role of an artificial co-driver which is concerned with the collection, prioritisation and distribution of information to the driver only when this complies with the safety rules and reduced collision probabilities. Adhering to the human-machine collaboration concept, this hybrid approach utilises the AI co-driver to support the driver and minimise the unnecessary intrusion caused by the multiple infotainment sources [4, 30-32].

During the simulation, the driver is intentionally distracted by the infotainment system which attempts to create a cognitive overload, reducing his /her capacity to efficiently and timely respond to the collision challenges

5 Experiment Requirements

The proposed AI/AR HUD system was evaluated against a typical HDD touch screen in the in-house VR Driving Simulator laboratory. The provision of information in different intervals during driving in a local motorway (M8) and moderate traffic flow was designed to test the driver's attention and gradually result in a cognitive overload scenario.

5.1 Driving and Accident Scenario Design

Following previous driving scenarios that emulate rear collision accident situations, the lead vehicles brakes abruptly challenging the driver to respond swiftly and either stop the vehicle or perform an avoidance manoeuvre [2,4,13]. Just before the abrupt braking event, the driver receives a mobile text message regarding a hypothetical meeting that changed location. In addition, the navigation systems present fresh information related to traffic ahead and alternative routes that the driver might consider to avoid a traffic jam.

5.2 Participants

The participants for the evaluation experiment were 50 volunteers with valid driving licences. The sample was composed of users spanning a variety of ages, professions and genders. On the latter, the distribution was 41 male and 9 female.

5.3 VR Driving Simulation

The experiment took place in the built for purpose Virtual Reality Driving Simulation (VRDS) laboratory that utilises a real-life vehicle (Mercedes A-Class 2003 model) and a fully immersive CAVE environment as illustrated in Figure 3. The latter employs a 5.1 surround audio system connected to vibrotactile devices that simulate the road imperfections and the vehicle engine, gearbox and tyres' vibrations.

The simulation software is also custom-built offering a photorealistic representation of the local motorways' network between Glasgow, Edinburgh and Stirling in Scotland.

The VR environment was developed as a closed circuit (the motorway exits were blocked from construction activities) to avoid having users driving in random directions within the large area of the simulation which was 28 miles of motorway roads.

Fig. 3. The Virtual Reality Driving Simulator laboratory (VRDS Lab) in action.

Fig. 4. Schematic of the Virtual Reality Driving Simulator laboratory (VRDS Lab) and the relevant equipment used for the experiment.

6 Evaluation & Results

6.1 Task Load Index AR/AI HUD vs HDD

A customized version of Hart and Staveland's NASA Task Load Index (TLX) method was used to assess the AI/AR HUD with contactless gestures perceived in 7-point scales namely; mental demand, physical demand, temporal demand, performance, effort, and annoyance [33]. The TLX used, assesses the user's workload on five gradations in increments of very high, high, medium, low and very low. The task load index was scored lower on all scales by the vast majority of the users as presented in Figure 5.

Table 1. Task Load Index for User Experience and Cognitive Load

7 -point scale Questions		
A.	Mental Demand	How mentally demanding was the task?
B.	Physical Demand	How physically demanding was the task?
C.	Temporal Demand	How hurried or rushed was the pace of the task?
D.	Performance	How successful were you in accomplishing what you were asked to do?
E.	Effort Expended	How hard did you have to work to accomplish your level of performance?
F.	Annoyance Experienced	How insecure, discouraged, irritated, stressed, and annoyed were you?
G.	Overall Preference	Please rate your preference comparing the HUD to the HDD interface.

Fig. 5. Task Load Index results of 50 users.

The evaluation presented that the *mental demand* perceived by the users was very low by 22% and low by 54%. The 12% of the users that responded that the system required a medium mental effort to operate suggested that further familiarization could have probably alleviated this issue.

In turn, the *physical demand* to operate the system was rated as 12% very low and 42% low. Yet, 46% of the users found the physical effort to be medium (38%), high (6%) and very high (2%). This result could be largely attributed to the actual driving simulator hardware which for this experiment had to be composed of existing off-the-shelf components (i.e. Leap Motion) and other peripherals which were not originally designed for in-vehicle interaction with custom UIs, which was confirmed by the majority as an issue in the debriefing session after the simulations.

The temporal demand required was rated as 22% very low and 52% low respectively. The AR projection of the information promptly by the AI co-driver, provided additional time to respond and maintain the eyes on the road, resulting in better collision avoidance manoeuvres.

This was also confirmed by the user-perceived performance which was assessed as high and very high by 64% of the users whilst using the HUD with contactless gestures.

In terms of minimising the stress, 59.18% accepted that HUD was very useful in reducing stress for interaction with infotainment while driving as illustrated in Figure 5. In total 90% of the users responded that they preferred the AR HUD system to the typical HDD.

7 Conclusions

This work presented the current issues of driver distraction and cognitive load occurred by the contemporary attention-demanding infotainment systems. The latter contributes to the increased collisions and fatality rates. Adhering to the above observations the paper describes the development rationale of a prototype system that employs AI and AR HUD technologies aiming to curb driver distraction by controlling the incoming infotainment data.

In contrast to previous attempts, the particular system doesn't deflect completely the incoming information, but distils, prioritises and presents the main information to the driver when it is considered safe by a dedicated AI Co-driver designed in conjunction with the AR HUD system. The released information is superimposed on the vehicle's windshield maintaining the driver's eyes on the road. The information is concentrated in the simplified AR UI which the driver could operate through a gesture recognition interface. The cognitive load to operate the system was evaluated in contrast to an existing HDD touchscreen, by 50 users.

The evaluation was performed in the VRDS laboratory. The results were promising and offered an indicative appraisal of the system's functionality and future. A tentative plan for future work would entail the further development and tuning of the AI and AR HUD parts of the proposed system, to perform in an urban environment and facilitate additional interrupt strategies and timely provision of infotainment data.

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