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Published in:
IEEE Consumer Electronics Magazine

DOI:
10.1109/MCE.2019.2923896

Publication date:
2019

Document Version
Peer reviewed version

Citation for published version (Harvard):
Lagoo, R, Charissis, V & Harrison, DK 2019, 'Mitigating driver’s distraction: automotive head-up display and gesture recognition system', *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 79-85. https://doi.org/10.1109/MCE.2019.2923896

Mitigating Driver's Distraction: Automotive Head-Up Display and Gesture Recognition System

By R. Lagoo, V. Charissis, and D. K. Harrison

***Abstract* — Dashboards in modern vehicular interiors, accommodate multiple infotainment systems that allow continuous flow of non-essential information in order to maintain driver connectivity. This results in distraction of the driver's attention from the primary task of driving, leading to a higher probability of collisions. This paper presents a novel Head-Up Display (HUD) system which utilizes gesture recognition for direct manipulation of the visual interface. The HUD is evaluated in contrast to a typical Head-Down Display (HDD) system by 20 users in a high-fidelity Virtual Reality driving simulator. The preliminary results from a rear collision simulation scenario indicate a reduction in collision occurrences of 45% with the use of HUD. The paper overall presents the system design challenges and user evaluation results.**

I. Introduction

The issue of driver distraction in cognitively challenging environments, like vehicle interiors, is a major issue and is further aggravated by the existence of multiple infotainment conduits within the vehicular space [1 - 3]. Furthermore, the inability of aptly distilled and coordinated information during driving can increase the collision occurrences and decrease the safety of the vehicle occupants. The phenomenon is further enhanced by the concurrent infotainment systems which are enriched with various capabilities and provide the driver directly with an abundance of information such as mobile communication, GPS navigation, Internet and audio-visual features embedded in the vehicular environment and controls [3]. The positioning of the particular infotainment devices is accommodated primarily in the middle-lower section of a car dashboard namely Head-Down Display (HDD) section which inherently requires the driver to redivert the visual focus from the external environment to the vehicle's interior.

In addition, the constantly updating stream of information requires from the driver to disengage from the driving (primary task) in order to perform the actions required by the infotainment systems (secondary tasks). resulting in misjudgment of traffic conditions and potential collision [2].

This work is predominantly concerned with two types of information namely text messaging and navigational route updates [3]. Additionally, the paper investigates the usability of a gesture recognition interface that could improve further the driver responses and reduce the time allocated to the infotainment system manipulation.

II. Driver's Distraction

Interactive displays are increasingly becoming part of automobiles as touchscreen technology develops and users demand a constant stream of information [4]. The multiple infotainment functions embedded on the small touchscreen estate increases driver's cognitive load but their wider user acceptance due to, mainly, familiarity, renders them an enticing marketing tool irrespectively to the negative impact they pose to driver's attention.

As stated above the HDD position, although ideal for dual use, from both driver and co-driver, forces the driver to perform long gazes at the display and thus dangerously increase the eyes off the road time [4], [5]. Despite that, the infobesity addiction of the majority of contemporary users, entices them to access their streaming data directly from their mobile phones. Notably, text messaging has been recognized as the second most hazardous secondary task undertaken by the drivers [6]. As such, the risk of collision rises by 2.8-5 times, a risk ratio comparable to that of drink driving [7]. In addition, navigation systems, although inherently not excessively tolling on the driver's cognitive capacity, interactions required during a journey, such attempting to reset the predetermined route, exponentially increase cognitive load and the collision propensity [8].

An attempt to tackle this phenomenon is currently pursued by law-instigated penalty/points punitive approaches. The prohibition of technology use, although a correct interim measure, would be inadequate and merely ineffective in the long term. The proposed direct manipulation HUD system investigates an alternative route in which the user/driver could still be interconnected with the environment, yet safely enabled to concentrate to the complex psychomotor activity of driving.

III. Current Commercial Solutions

Current state of the art applications have been employed by a number of automotive manufacturers in the form of small-sized HUDs *or* gesture recognition systems. The initial category of HUDs has been utilized to provide existing vehicle information and navigation data typically presented on the dashboard of a vehicle. This improved the driver's attention to the road yet it didn't resolve the main issue of infotainment distraction.

The second type of current applications namely gesture recognition is in its infancy. This type of systems aims to enable the driver to command and manipulate the infotainment systems by the use of gestures and avoiding any visual and tactile interaction with the dashboard instrumentation. This technology is currently offered by a number of major manufacturers and is primarily based on camera-tracking of driver's hand gesture above the gear-lever and central dashboard area [9]. All the current early examples of introducing this technology to the consumers are still concerned with the existing dashboard area which falls within the HDD vehicle estate and inheritably requires the driver's attention and brief gaze to operate [9]. As such the benefits harnessed by reducing the buttons and knobs of the dashboard is contracted by the physical position of the infotainment systems and the gestures' complexity to operate them. Notably, the number of hand gestures required for the different functions demand from the driver to operate with extended/partially extended arm the different gestures. As such the gesture recognition aiming process contributes gradually to arm fatigue.

In contrast the proposed system does not require from the driver to operate on the middle dashboard region as it combines the benefits of the gesture recognition to the HUD positioning. To this end, the proposed HUD interface could be operated with only one gesture (i.e. pointing) activating the Augmented Reality icon without lifting the hands from the steering wheel or with minimum movement from the steering wheel. This is not an option with the existing state of the art systems.

Secondly the direct manipulation interaction with the proposed HUD is simple and does not involve multiple gestures that might confuse and/or annoy the users.

Finally, the aforementioned commercial systems could not be applied to different vehicles retrospectively.

IV. System Design Considerations

A. Selection of HUD System

The provision of multiple information related to primary and secondary-driving tasks from a single section, positioned typically below the driver's field of view, present an ergonomic challenge and potential hazard. To this end, employing the ample windshield estate for projection of selected data could alleviate the pressure from existing HDD systems [2], [10], [11].

B. Incoming Infotainment Data Distilling

The driver may be overwhelmed if presented with too many warning cues at one time and hence, information must be presented to the interface displays either aggregated or in carefully prioritized sequence, as appropriate. Incoming data must first be cast into a standard format and then prioritized via urgency criteria so that the driver is always notified immediately of high importance events, while less critical cues are delivered as and when appropriate. In the latter case, the data could be released to the driver in a similar manner to the start and stop function of a vehicle engine. The two functions could be potentially connected in order to improve the interaction and data provision. Furthermore, the road-network infrastructure could assist the timing of data provision by communicating the remaining time in a traffic light or in a highly congested traffic.

C. Retrospective Incorporation to Vehicles

The design approach of the proposed HUD and the simplistic interaction through limited number of gestures aims to enable the system operation by younger and senior users alike. Furthermore, the selection of off-the-shelf components facilitates the need of retrospective incorporation of the system in older vehicles. The latter was a primary objective during the design and implementation of the prototype as the majority of the vehicles in the market falls under the used/previous models' category, which tend to be approximately two thirds of the market in Europe and USA [12].

The proposed HUD system could be positioned in an adaptable manner, as it comprises different components, which could be connected either by wire or wirelessly as presented in the block diagram below in Figure 1.

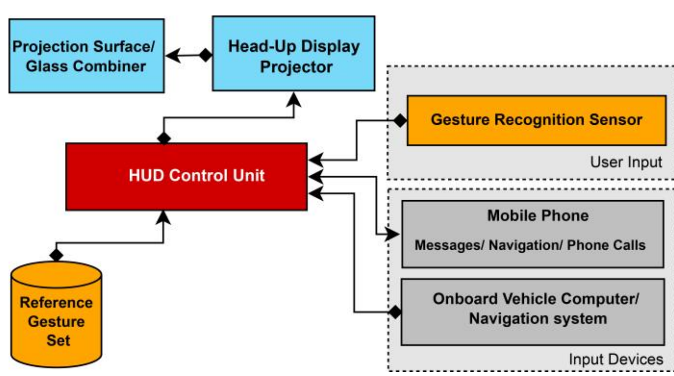

Fig. 1. Explanatory block diagram of the system.

Therefore, the experimental combination of hardware and software presented on this paper is designed to be retrofitted to the majority of used/older vehicles. The prototype version of the system, which facilitated the evaluation process, has been installed in the VR Driving Simulator's vehicle that is a Mercedes A-Class 2003 model. Nevertheless, the system could be also incorporated on the new models under production due to the customization simplicity of hardware and software.

V. PROPOSED HUD SYSTEM

The design mantra of the proposed HUD system adheres to previous work related to HUD interfaces and the reduction of driver distraction [1], [2], [13]. The system under consideration informs the driver with regards to incoming mobile messages and navigation updates. Yet it doesn't reveal any of the above, unless the vehicle is immobile or in acceptable driving conditions that are appropriate for accessing secondary task data. The provision of visual and gesture recognition interface elements enables the driver to access the information in a timely fashion and without losing contact with the external surroundings.

A. Visual Interface

The design of the visual interface followed a minimalist approach. The icons superimposed on the HUD section are simplified and present distinctively the functions and different activity states.

Fig. 2. The selected three HUD interface entailing the following icons namely: (a) Home icon, (b) Navigation/Map Icon and (c) Text Message Icon

Initially the interface was equipped with six icons namely Home, Settings, Internet, Text Message, Phone Call and Map/Navigation. Yet it was deemed useful to maintain only three icons (Home, Text Messaging and Map/Navigation) through an elimination process by focus group trials as presented in Figure 2. The Home icon serves as a return to the original state of the HUD interface command, whilst the two other icons denote the incoming information with a red-sphere which encapsulates the number of messages or navigation updates received as illustrated in Figure 3. The red sphere appears on the upper right corner of the main icons offering an indication with minimum distraction due to the position and size of the inlay icon.

Fig. 3. Final HUD interface with 3 icons in action during simulation.

The preliminary focus group trials revealed that a larger number than three icons increases exponentially the effort to activate a selected icon with the point and push gesture resulting in 60% probability of activating successfully the correct icon. The latter required intensive targeting and precise gesture motion from the users in order to not activate the neighboring icons accidentally. This additional functionality issue of the proposed system solidified the choice to maintain only three icons in the driver's field of view as presented in Figure 3. The use of only 3 icons provided double space for the enlargement of the icons and expansion of the space in-between them, which enabled the user to achieve a 90% success rate of selecting and clicking the icon with the use of a gesture.

B. Gesture Recognition Interface

The gesture recognition interface was programmed to utilize a simple movement, which entails point and "air-click" of the selected AR icon. Regarding the gesture recognition algorithm, we utilized the existing off-the-shelf Leap Motion algorithm provided by the Software Development Kit (SDK) and customized it for the space and distance to the driver and the vehicle interior limitations. The icon images were projected on a virtual grid within the cone of interaction of the Leap Motion device. The "air-clicking" gesture performed by the user's finger was crossing through the virtual grid (selection of the icon) and when the finger was retracted from the grid was activating the icon's action.

The simple, one move, was approved unanimously by the focus group and was understandable by users of different age, gender and professional background. The compilation of visuals and gestures for the system followed the direct manipulation interface design methodology, which is being used at large and successfully, on other systems.

VI. EVALUATION METHOD

Each user-trial involves three distinctive evaluation stages. The first one is a pre-test questionnaire aiming to gather information regarding driving experience, mobile and computer technologies, as well as driving habits.

The second stage entails the actual driving simulation with and without HUD system. To this end, the evaluation method explores both the driver's responses through numerical values as well as their subjective feedback. The first is provided by the VR driving simulation comparative study between a typical HDD touch screen system and the proposed HUD and gesture recognition system. The acquired information presents the collision occurrences, the speed of the vehicle, lane changes, driver's Response Time (RT), and headway (HW) maintained between the driver's vehicle and the lead computer-controlled vehicles [2], [10].

The sequence of testing of the two different systems is random in order to avoid any evaluation results' bias. The third and final stage concludes with a post-test questionnaire to receive users' subjective feedback and suggestions regarding the usability of the proposed system. Additionally, this last stage offers the user with an opportunity to offer additional comments.

This paper presents the results from the first twenty users, their collision occurrences and their subjective feedback based on the post-trial questionnaire.

VII. SIMULATION REQUIREMENTS

A. Evaluation Scenario

In order to evaluate the effectiveness of the proposed HUD interface the system was tested with the use of the in-house VR Driving Simulator (VRDS) Laboratory. The 4th and latest generation of the simulator utilizes a full-scale Mercedes A-Class vehicle, positioned in a Cave Automatic Virtual Environment (CAVE) room. The CAVE is comprised by full enclosure and surround projection, which increases the immersion sensation. The driving simulation settings followed closely the accident scenarios previously used for the evaluation of other in-vehicle systems and were based on crucial information provided by the Strathclyde Police Department [1], [2]. The HDD was positioned in the existing screen-space which is located in the middle-lower section of the dashboard which is approximately 720mm-880mm from the driver's eyes, depending on the driver's height. Similarly, the HUD is positioned 850mm-990mm, again depending on the driver's height. The HUD is projecting the image in front of the driver's field of view on the windshield, just above the steering wheel. The projected AR image of the HUD icons appears at 2m ahead, which is approximately in front of the car's bonnet as an ideal projection space as highlighted by previous studies. The gesture recognition system device is positioned on the top of the instrument's dome just behind the steering wheel approximately 500mm-650mm from driver's head.

For this evaluation only one scenario was employed, namely *rear-collision accident scenar*io. In this scenario the lead and neighboring vehicles were creating seamlessly the circumstances for a rear-collision incident at multiple points within the simulation. This scenario was repeated once for the HUD and once for he HDD system. Prior to the evaluation each driver was offered approximately 15 minutes to drive on an uneventful simulation as part of the familiarization run, in order to get used to the controls and systems of the vehicle. After the familiarization run, each participant drove on average 12 minutes per simulation, one for each system. During the evaluation the driver receives 4 different snippets of information related to mobile phone text messages from a virtual friend and navigation warnings respectively. The timing of the messages coexists with the maximum probability of a collision gradually built up by the Artificial Intelligence (AI) of the computer controlled neighboring vehicles. As such the driver is momentarily distracted and enticed to check the incoming information. Whilst the accident scenario unfolds, the driver is challenged to brake abruptly behind the lead vehicles.

B. Participants

The evaluation was performed by twenty users (7 female, 13 male), which held a valid driving licence, and they were aged between 20 and 55. The participants were asked prior to the experiment, to follow the limits and driving rules set by the British Highway Code.

VIII. EVALUATION RESULTS

The evaluation results presented encouraging information with regards to the collision occurrences with and without the HUD interface as presented in Figure 4. The statistical significance of results was extrapolated from the sample of the study (20 subjects) to the overall population of drivers (large sample confidence interval for the population mean). This was calculated with the traditional large sample confidence interval (CI) statistical analysis method. The collision occurrences results were calculated with confidence of

95%, which suggests a margin of 5% of potential error that is acceptable for the nature of this evaluation. Evidently the analysis highlighted that drivers have a probability of average 80% (0.99-0.61) to collide when they use the HDD as an infotainment source in normal driving conditions. The above number was decreased to 35% (0.58- 0.12) when the proposed HUD interface was utilized. This resulted in sharp decrease of 45% of collision's occurrences with the use of the prototype, gesture recognition HUD system.

This occurred due to fact that the AR HUD interface in conjunction to the gesture recognition interface enabled the drivers to maintain the eye gaze on the road and their hands on the steering wheel at all times.

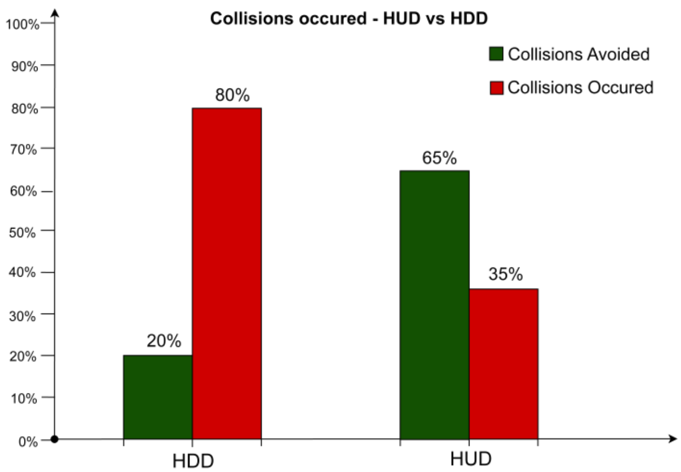

Fig. 4. Number of collisions recorded with HDD vs HUD interface

The driver's collision avoidance performance was also reflected by their subjective feedback, which is essential for any application of consumer electronics.

The drivers' speed perception was also a revealing factor as 70% of the drivers felt that they were driving faster. Yet the speed difference with the non-HUD trial was marginally higher. However, if the drivers' feel that they are driving faster it could dampen the need to increase their speed significantly in order to compensate for the lost time acquired by the manipulation of the typical infotainment systems. Notably, although the users' speed with HUD was increased, their collision occurrences dropped dramatically as it is highlighted in Figure 4. The ease of use responses was further investigated on a Task Load Index of the Physical Demand, which offered overall a 65% of very low and low ratings as illustrated in Figure 5. Yet 25% of the users found that the physical demand required was medium and 10% consider it high. The reason for this is that the seating position could not facilitate perfectly all the users and as a result of this, some of them found difficult the process of successfully "air-clicking" the HUD icons. Similar picture was presented on the Mental Demand workload with marginally better results of 75% consisting of low and very low responses in contrast to 25% of medium and high as depicted in Figure 6. The overall consensus with regards to the system adoption by the users instead of the traditional touch-screen HDD interfaces received a 75% acceptance whilst 25% of the users were undecided.

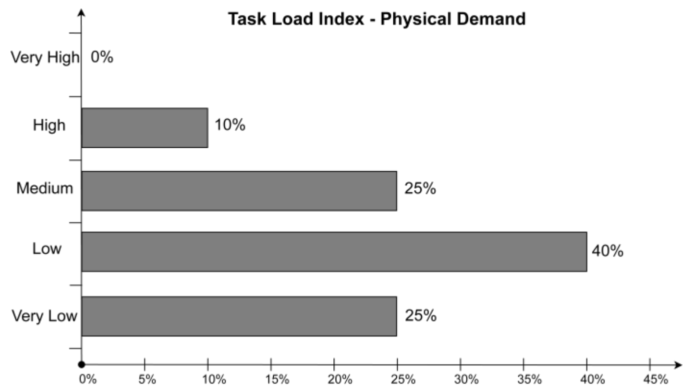

Fig. 5. User Experience results regarding the perceived task load index of physical demand.

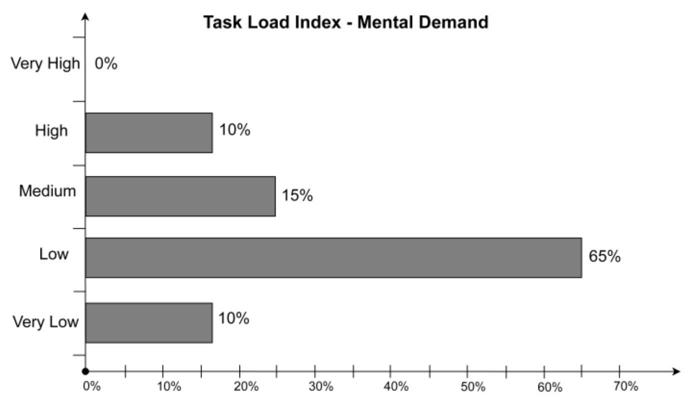

Fig. 6. User Experience results regarding the perceived task load index of mental demand

Notably the small percentage of users that found the system difficult to operate and were undecided regarding the technology acceptance, could be attributed to the fact that the system is a prototype that was designed and built for testing purposes instead of production at this point. Yet the feedback informed the amendments of a second version which the authors endeavor to finalize and test in the near future.

IX. CONCLUSION

This paper presented a prototype gesture recognition HUD interface that was developed with the aim to mitigate driver's distraction typically occurring due to the plethora of incoming information produced by the vehicular infotainment systems. The system focused on two of the main distraction attributes namely mobile phone text messaging and navigation updates. The derived simulation outputs offered promising results, demonstrating 45% improvement in collision avoidance. Additionally, the subjective feedback presented in turn, confirms the users' intention to adopt this technology, which could be either embedded on the new vehicles or retrospectively provided as consumer electronics.

Our future work plan involves the continuation of user-trials in order to increase the user numbers and provide improved data granularity that could be extrapolated in the overall drivers' population. Finally, the future plans entail the provision of additional icons that could engage the co-driver and absorb more of the secondary tasks from the driver.

About The Authors

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