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

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**Abstract:** *Dashboards in modern vehicular interiors, house multiple infotainment systems that allow a continuous flow of non-essential information maintaining 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

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], [2]. The positioning of the particular infotainment devices is accommodated primarily in the middle-lower section of a car dashboard (HDD section), which inherently requires the driver to redivert the visual focus from the external environment to the vehicle's interior. This can increase collision occurrence and decrease the safety of the vehicle occupants [3].

In addition, the constantly updating stream of information requires 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 such 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. As such the proposed system builds upon previous consumer electronics' studies that highlighted the need for Human-Machine Interaction (HMI) systems that could improve the car occupants' safety, for both contemporary human-driven and future autonomous vehicles [4-6]. The proposed system is aiming to transcend the limitations of current infotainment and HMI systems offering a unique approach to the provision of information in the vehicular environment.

## II. Driver's Distraction

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 on driver's attention [7].

The HDD position further forces the driver to perform long gazes at the display and thus dangerously increase the eyes-off-the-road time [7], [8]. Notably, streaming data directly from their mobile phones and text messaging has been recognized as the second most hazardous secondary task undertaken by drivers [8]. As such, the risk of collision rises by 2.8-5 times, a risk ratio comparable to that of drink driving [7].

Similarly, navigation systems may require multiple interactions to operate which exponentially increases cognitive load and the collision propensity [7]. An attempt to tackle this phenomenon is currently pursued by law-instigated penalty/points and other 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

A number of automotive manufacturers have employed applications such as small-sized HUDs and gesture recognition systems. Currently, commercially available 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 [8].

Gesture recognition type of interactions enable the driver to command and manipulate the infotainment devices by the use of gestures and avoiding any visual and tactile interaction with the dashboard instrumentation. Variation of this idea is currently offered by a number of manufacturers based on camera-tracking of driver's hand gesture above the gear-lever and central dashboard area [9]. All the current early examples are still concerned with the existing dashboard area which falls within the HDD vehicle estate and requires the driver's attention and brief gaze to operate [3].

In current systems, the beneficial reduction of buttons and knobs on the dashboard is contradicted by the physical position of the infotainment systems and the gestures' complexity, requiring from the driver to operate with a fully/partially extended arm to perform the different gestures contributes gradually to arm fatigue. In contrast, the proposed system combines the benefits of the gesture recognition to the HUD positioning;

The proposed 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. Additionally, 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 the projection of selected data could alleviate the pressure from existing HDD systems [2], [10].

### 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 interaction and data provision. The road-network infrastructure could assist the timing of data provision by communicating the remaining time in a traffic light or in highly congested traffic.

### C. *Retrospective Incorporation to Vehicles*

The design approach of the proposed HUD and the simplistic interaction of a single gesture aims to enable the system operation by younger and senior users alike.

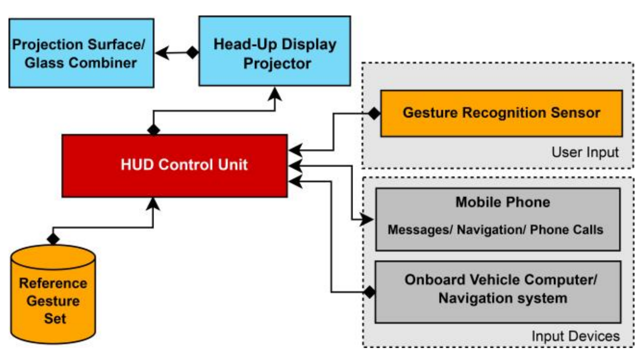


Fig. 1. Explanatory block diagram of the system.

The selection of off-the-shelf components facilitates the need for retrospective incorporation of the system in older vehicles. The latter was a primary objective during the design and implementation of the prototype as two-thirds of the vehicle market in Europe and the USA [11] falls under the used/previous models' category.

The proposed HUD system could be positioned in an adaptable manner, as it comprises different components, with wired or wireless connectivity as presented in the block diagram in Figure 1. Therefore, the experimental combination of hardware and software presented in 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]. 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.

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. The preliminary focus group trials revealed that a larger number than three icons (initial trials included up to six icons) exponentially increases the effort to activate a selected icon with the point and push gesture (resulting in 60% probability of successful icon activation). Ease of targeting and accuracy of icon selection solidified the choice of only three icons in the driver's field of view.

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

This also 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 the 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 the retraction of the finger 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.

## VI. Evaluation Method

User-trials involved 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 the 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], [11].

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 and 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 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 of a 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 the driver's head.

For this evaluation only one scenario was employed, namely *rear-collision accident scenar*io. In this scenario, the lead and neighbouring 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 the 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 simulation's neighbouring 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 data 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 the confidence of 95%, which suggests a margin of 5% of potential error that is acceptable for the nature of this evaluation. The analysis highlighted that drivers have a probability of an average of 80% (0.99-0.61) collision when they use the HDD as an infotainment source in normal driving conditions.

This was decreased to 35% (0.58- 0.12) when the proposed HUD interface was utilized. This resulted in a sharp decrease of 45% of collision's occurrences with the use of the prototype, gesture recognition HUD system. This occurred due to the fact that the AR HUD interface in conjunction with 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.

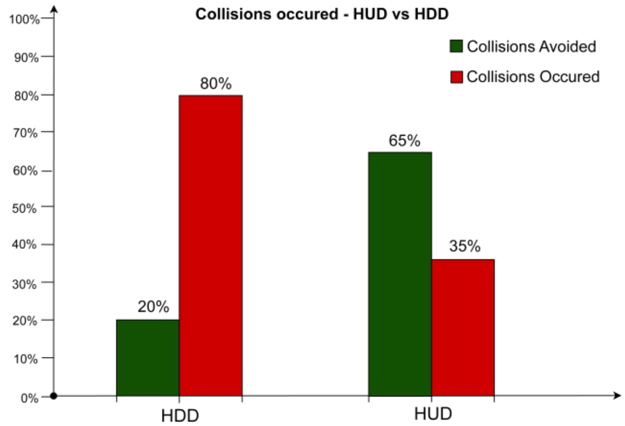


Fig. 4. Number of collisions recorded with HDD vs HUD interface.

The drivers' speed perception was also a revealing factor as 70% of the drivers felt that they were driving faster and objectively speed was marginally higher in the HUD trial. Interestingly, their collision occurrences dropped nevertheless as it is highlighted in Figure 4. The driver's collision avoidance performance was also reflected by their subjective feedback, which is essential for any application of consumer electronics.

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 (left). 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.

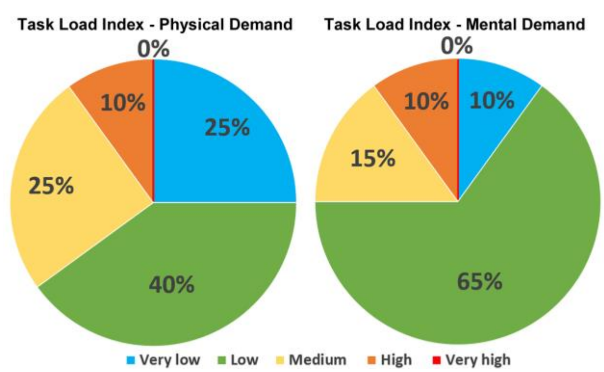


Fig. 5. User Experience results: perceived task load index of physical demand (left) and of mental demand (right).

A 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 5 (right).

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. Yet the feedback informed the amendments of a second version which the authors endeavour 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 occurring due to the plethora of incoming information produced by the vehicular infotainment systems.

The system focused on mobile phone text messaging and navigation updates. The derived simulation outputs offered promising results, demonstrating a 45% improvement in collision avoidance. Additionally, the subjective feedback 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.

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## References

[1] V. Charissis, S. Papanastasiou, W. Chan, and E. Peytchev, "Evolution of a full-windshield HUD designed for current VANET communication standards", *IEEE Intelligent Transportation Systems International Conference*, The Hague, Netherlands, pp. 1637-1643, 2013.

[2] V. Charissis, and S. Papanastasiou, "Human-machine collaboration through vehicle head-up display interface", in *International Journal of Cognition, Technology and Work*, P. C. Cacciabue and E. Hollangel (eds.) Springer London Ltd, vol 12, no. 1, pp 41-50, 2010.

[3] R. Lagoo, V. Charissis, W. Chan, S. Khan and D. Harrison, "Prototype gesture recognition interface for vehicular head-up display system", *IEEE International Conference on Consumer Electronics*, Las Vegas, USA, pp.1-6, Jan. 2018.

[4] S.A. Applin, A. Riener and M.D. Fischer, "Extending Driver-Vehicle Interface Research Into the Mobile Device Commons: Transitioning to (nondriving) passengers and their vehicles", *IEEE Consumer Electronics Magazine*, vol. 4, no. 4, pp. 48-54, 2015.

[5] R. Thakur, "Scanning LIDAR in Advanced Driver Assistance Systems and Beyond: Building a road map for next-generation LIDAR technology", *IEEE Consumer Electronics Magazine*, vol. 5, no. 3, pp. 48-54, 2016.

[6] T. VanGoethem, "Even When They're Not Driving, the Driver Must Come First [Product Reviews]", *IEEE Consumer Electronics Magazine*, vol. 7, no. 2, pp. 115-117, 2018.

[7] A. Morris, S. Reed, R. Welsh, L. Brown and S. Birrell, "Distraction effects of navigation and green-driving systems – results from field operational tests (FOTs) in the UK", *European Transportation Research Review,* Springer Berlin Heidelberg, vol.7, no. 26, 2015.

[8] S.M. Simons, A. Hicks, and J. K. Caird, "Safety-critical event risk associated with cell phone tasks as measured in naturalistic driving studies: A systematic review and meta-analysis", *Accident Analysis and Prevention Journal*, Elsevier, vol. 87, pp. 161-169, 2016.

[9] F. Parada-Loira, E. González-Agulla, J. L. Alba-Castro, "Hand gestures to control infotainment equipment in cars", *Proc. the IEEE Intelligent Vehicle Symposium, (IV '14)*, pp. 1-6, 2014.

[10] H. Okumura, T. Sasaki, A. Hotta, and K. Shinohara, "Monocular hyperrealistic virtual and augmented reality display", *2014 IEEE Fourth International Conference on Consumer Electronics (ICCE-Berlin)*, Berlin, Germany, pp.19 – 23, Sept. 2014.

[11] C. Navarre, A. Kotov, L. Hwang, J. Y. Barbier and M. Jarvin, "Anatomy and physiology of the used car: A global analysis with particular reference to four key markets: U.S., Canada, France, Germany", *CIRP Report*, K. Twidle (ed.), Car Internet Research Program II and Capgemini, 2007.