See-Through Head-up Display of In-Vehicle Information Systems for Vision Enhancement

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Abstract: This paper argues that laser-based, see-through, head-up displays of in-vehicle information systems (IVIS) enhance driver safety. This study estimates the demand on the driver when a secondary task is being performed and covers various aspects of a driver's performance, such as processing information from displays in different locations and maintaining lane position. A fixed-base driving simulator was used to examine the distracting effects of IVIS on a secondary task. This research has clearly shown that drivers are able to detect more events in the forward environment with a HUD. Drivers who are given a visual speeding alert from head-up displays reduced the amount of time to reach the speed limit by 29% compared to head-down displays. Results from the tests indicated that a head-up display increases time spent watching the road versus the head-down display. In addition, this approach is one of the most effective methods of improving driver safety in hazardous situations.

Key words: Human Computer Interactive, Respond Time, Head-Up Display, In-Vehicle Information System, Driver Distraction

1. Introduction

Complete alertness is important when driving an automobile. To maximize safety, the driver must have instant access to important vehicle information without compromising attention to road conditions. The integrated head-up, see-through display of in-vehicle information systems developed active safety systems and information to reduce driver distraction. However, the effectiveness of a head-up display in the in-vehicle information systems context still remains relatively unexplained. This question is addressed here to improve our understanding of the safety benefits and risks associated with in-vehicle information systems, such as the development of procedures and criteria for the evaluation of the safety of in-vehicle information systems.

Head-up displays are common in airplane cockpits, and this developed display technology is now entering automotive applications. The benefits of a head-up display for the driver consists in keeping his attention on the traffic scene ahead while reading important operation parameters in the same line of sight. With no need to look down to the dashboard or elsewhere, there is no focal adjustment of the eye required. Safety is the most significant gain in using a HUD. The Technology Watch investigative report concentrates on the present state and future development of technologies for projecting traffic-relevant images or information onto the windshield [10]. The technologies analyzed are:
- LCD image generation and projection onto the windshield.
- Laser scanning of an image with micromirrors on the windshield.
- Holographic image combiners.
- Light out-coupling from a wave-guide co-laminated into the windshield.
- OLEDs incorporated into the windshield.

In support of the assertion that contrast and brightness are critical HUD features for daylight readability, the NHTSA reported summer-time drivers frequently use a HUD's variable brightness control [8,9]. This particular government study was conducted in Michigan. In other parts of the country, such as California or Texas where the sun may appear brighter, an important capability for HUD is to overcome daytime light. Scanned laser-based HUDs achieve this most effectively. Comfortable HUD virtual image viewing distances are between 2 and 4 m from the driver's eyes, reducing visual re-accommodation demands for drivers to view critical automotive information. Studies indicate that older drivers benefit most from this aspect of a HUD, maintaining larger headways and reducing their speed in the presence of the S-IVIS tasks [16]. Furthermore, Liu and Wen found that truck drivers in simulators were able to control their speed better with speed information from a HUD than a HDD (heads-down display). The study had shown that a savings of 0.8s to 1.0s in driver reaction time can be achieved with the use of HUDs to display warning information over conventional heads-down-displays [29].

In-vehicle information systems (IVIS) are already available with automobiles in many countries, and these will soon be affordable to the mass market. The challenge is to provide the information in a manner that drivers can easily recognize but that does not interfere with driving. It is widely acknowledged that a single IVIS design does not fit everyone. It's better for users to have different interface and content preferences. These preferences are often related to age, gender, experience, and other demographics such as social and psychological characteristics. IVIS need to be capable of adapting to the context. This paper reviews adaptation techniques found in user-adaptive systems and develops an interface between adaptation techniques and the characteristics of the system being modified. This interface is then used to show that adaptation techniques for user-adaptive systems can be applied to the design of IVIS on a HUD.

In order to develop the IVIS assessment protocol, it is important to first explore the relationship between secondary task modality, secondary task complexity, primary task complexity and driving environment at a fundamental level. Though the studies noted provide useful insight, there is an absence of published work using safety margins to examine the systematic relationship between primary and IVIS on HUD task complexity for a specific task modality in a simulated driving environment. The current study attempts to address the nature of these relationships when driver distraction and human error are often linked with vehicle accidents. At the turn of the last millennium, distraction was linked to as much as 50% of the motor-vehicle accidents on U.S. highways [24], and in Japan it accounted for 25% [13]. Furthermore, as argued by Haigney and Westerman [12], this figure is likely to be lower than the actual percentage since it is based on self-reports and is potentially biased by under-reporting due to fears of legal ramifications. Developments in in-vehicle technology, such as navigation displays, telephones and entertainment system certainly offer drivers real benefits [5]. However, driving is a safety-critical task. When drivers choose to multi-task, there is an associated increase in accident risk [21, 22]. There are at least two well-accepted theories to explain this: Multiple Resource models of divided attention [26, 27] and Working Memory [1, 2].

Furthermore, Lui demonstrated faster response times and more accurate performance with either auditory or audio–visual presentations of information, compared to a purely visual presentation of the same information [15]. Working Memory models a system that is responsible for the processing and maintenance of information for short durations [2]. Lately, Baddeley gave the central executive the added functions of selecting and rejecting incoming information as well as selecting and manipulating information from long-term memory. When dual tasks are performed, the working memory model suggests that if those two tasks share the same working memory resource, performance in one or both declines when tasks are performed concurrently as opposed to independently [1]. Further work has involved complexity levels of both primary and secondary tasks, mainly visual/manual and auditory systems, but separately. During an on-road study, Verwey showed an increasing number of hazardous situations occurring as the difficulty of interaction with an in-vehicle information system. The objectives were to explore whether driver reaction and performance is affected by a see-through, head-up display under different driving load or information complexity conditions, and to investigate whether differently aged drivers have different performances when operating different in-vehicle displays [28].

These theories, along with the accident statistics mentioned above, provide a basis for current concerns over a driver's ability to successfully interact with in-vehicle information systems (IVIS) when driving [13, 21, 25]. Presently, various methods of assessment are available to assist designers in achieving minimum distraction with their systems. These include: the EU Statement of Principles [6], In-Vehicle Information: Design of Driver Interfaces for Route Guidance [18], Suggested Human Factors Design Guidelines for Driver Information Systems [19] and the 15s rule [11, 20]. When these checklist methods provide a tool in identifying potential design problems with IVIS, authorities lack useful methods of assessing their actual safety impact. Furthermore, some of the current methods have come under some criticism, particularly the 15s rule [17] and the occlusion method used to enforce it during testing [14]. Several studies have examined the effect on driving and task performance of the both visual and auditory in-vehicle secondary tasks. Findings indicated that drivers suffered reduced primary (driving) task performance when interacting with the visual rather than the auditory task [15]. In order to measure the visual effect of a HUD in this paper, the experiment only focused on the visual presentation of information, and only compared it to a visual presentation of the same information.

2. METHOD

2.1 *Subjects*

12 drivers (6 male, 6 female) were simultaneously shown a VR scene of changing speed limits (a 3D graphical scene from the driver's viewpoint) on a display. Drivers indicated whether the three speed limits either presented on a head-down display or superimposed on the road scene, simulating a head-up display (HUD). All subjects had a valid driver's license, drove at least twice per week, and reported not being prone to motion sickness. Each test was approximately 20 minutes of research time. To determine subjects' driving experience, data was collected on the following: gender (male, $M = 6$; female, $M = 6$), years as a licensed driver (male, $M = 6$; female, $M = 8$).

2.2 Apparatus

The fixed-base driving simulator developed by Tatung University (Fig. 1) was used for the study. A real-time, fully-textured and anti-aliased 3-D graphical scene of the virtual world was projected at a resolution of 1024×768 pixels by NEC LT380 on a single 304.8 cm (120 inch) screen in front of the driver. The total horizontal field of view was 60 degrees. The vertical field of view was 46.8 degrees. The frame rate was constant at 60 Hz. Five PCs equipped with Core 2 Duo E7300 processors and 9400GT graphic display cards were used to generate the virtual scene, to control the time sequence of events, to record the vehicle dynamic data, to generate the stimuli, and to record the subjects' response times for the stimuli. To achieve synchronization, the five PCs were connected through an intranet network. In addition, eye and hand movements were recorded by one camera mounted behind the steering wheel and one camera mounted at the right rear of the driver's seat, respectively. Although the simulator was fixed-base, torque feedback at the steering wheel was provided via a spring mechanism fixed at the end of the steering column, and a spring mechanism provided brake pedal booster assistance. A NI USB-6221 data acquisition device collected the vehicle dynamic data at 250 kS/s. The virtual road was a roadway about 4000m with a 60, 80 and 100-km/h posted speed limit and a central divider. There were three 3.5m-wide lanes with a shoulder in the driving direction. The surrounding virtual environment mimicked a roadway layout with low-density traffic. A lead car was introduced at the start of the experiment and was controlled such that it maintained a headway of 3s in front of the simulator vehicle during the experiment. The participant drivers were instructed to maintain a speed of nearly 100 km/h and to stay in the middle lane.

2.3 Tasks and Procedure

In order to measure the visual effect of a HUD, this experiment only focused on the visual presentation of information, and only compared it to a visual presentation of the same information. According to the conceptual framework, the experimental procedures are detailed in Figure 1. Each participant completed the entire experiment in about one hour according to the following procedures:

Driving task: All participants were required to complete the simulated driving route as usual and were asked to obey all traffic rules. They were also requested to increase the vehicle speed to nearly 100 km/h and to stay in the middle lane.

Secondary task: As subjects drove through the simulation, speed-related messages were presented on the display of IVIS. There were three visual messages: speed limits of 60, 80, and 100 km/h on the four display locations. To draw attention to the road, subjects responded to control the speed when speed limit information was displayed on a display. To reach for the desired test duration, highly similar roads were presented. After a training session, baseline road events and HUD data were collected. Subsequently, the subject filled out a questionnaire to evaluate the HUD and tasks used in the experiment.

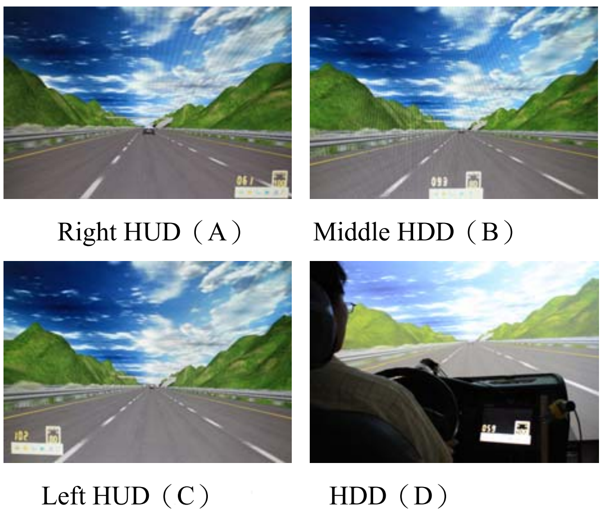

Figure 1: Speed-limit messages on the display of IVIS

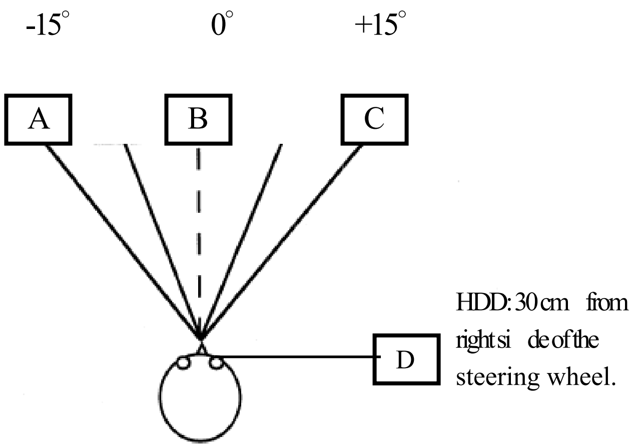

Figure 2: The locations of the displays

2.4 Measurements and Statistical Analysis

The response time (RT) of the IVIS control task was measured as the interval from the appearance of the speed limit on the display. Computers recorded response times to the speed limits, and any response after the speed limit was shown for 5 seconds was registered as a miss. Comparisons of performances of the RT and IVIS control tasks were examined using the mean RT, the miss rate, and the time of response. The mean RT was analyzed by carrying out a series of repeated-measure analyses of variance with type and driving demand (i.e., driving and non-driving scenarios) as within-subject factors.

3. Results

In order to reduce the numerous effects of distractions within the car, it is imperative to put critical information where the driver can use it without affecting focus on the road ahead. Audible alarms are useful supplements when used in conjunction with visual displays, but driving is an overwhelmingly visual task. In order to measure the visual effect of a HUD, this experiment only focused on visual presentation of information, and compared to purely visual presentation of the same information. The driver needs a visual interface that focuses the attention on the road ahead; one such solution is a head-up display (HUD). Several authors have expressed the view that the usability of a vehicle information system is one of the most important aspects of its design [2,3,4]. These technologies are arguably the most sophisticated that drivers have had to interact with in vehicles, and much of the system functionality is of potential use when the vehicle is in motion. Lack of attention to the road and distractions are already major contributing factors in many road accidents [25], so systems that have the potential to add to this problem must be carefully designed.

The dependent measures in this experiment were response time and error rate, as well as preference rankings for the alternative displays. Prior to the analysis of each variable, no steps were taken to filter the data set. Analysis of the error data is described first, followed by the response time data and the preferences. As keys were pressed, responses were coded by the software as (a) within or outside of the time deadlines (both too fast and too slow), and (b) if they were correct or not. Tables 2, 3 and 4 show the coding scheme and Figure 3 shows the biographical statistics of subjects.

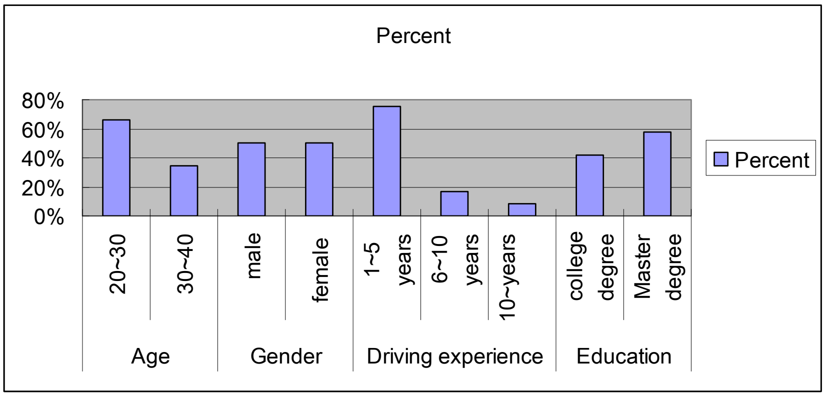

Figure 3: Biographical statistics

Table 1: Questionnaire to evaluate the secondary tasks of HUD and IVIS

	Yes	No
1. Have you ever driven a vehicle with an in-vehicle information or navigation system?	32%	68%
2. Have you ever driven a car with a Head-Up Display (HUD)?	0%	100%
3. Have you ever received a speeding ticket?	18%	82%
4. Does the speed limit warning help?	92%	8%
5. Is the Head-Up Display more effective than the Head-Down Display?	92%	8%
6. Do you consider the HUD a useful and helpful tool?	92%	8%
7. Could you become overly dependent on the IVIS while driving?	59%	41%
8. Do you think IVIS devices compromise safety?	41%	59%
9. Do you think that too much information from IVIS increases cognitive workload?	58%	42%
10. Do you think IVIS on a HUD enhances driving safety?	92%	8%

Table 1 shows 92% think the HUD speed limit warning is helpful, and that the HUD enhances driving safety and time spent watching the road. 58% think drivers felt overconfident using the IVIS. 41% think IVIS devices negatively affect safety. 58% think too much information from the IVIS increases cognitive workload.

Table 2: The response time (RT) of male and female drivers

Subjects	Factors	HDD(D)	HUD-L(C)	HUD-R(A)	HUD-C(B)
Female subjects	Mean Value	1.415	1.166	1.119	0.959
	Standard Deviation	0.186	0.243	0.218	0.106
Male subjects	Mean Value	1.402	0.990	1.062	1.031
	Standard Deviation	0.221	0.116	0.065	0.125
Male and female subjects	Mean Value	1.409	1.064	1.100	0.995
	Standard Deviation	0.214	0.210	0.166	0.128

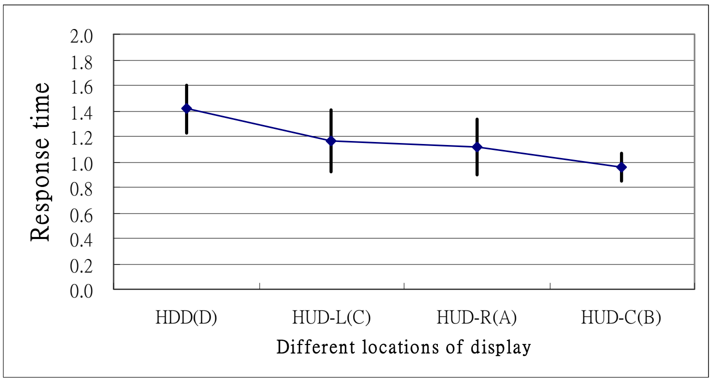

Figure 4: The response time (RT) of female drivers

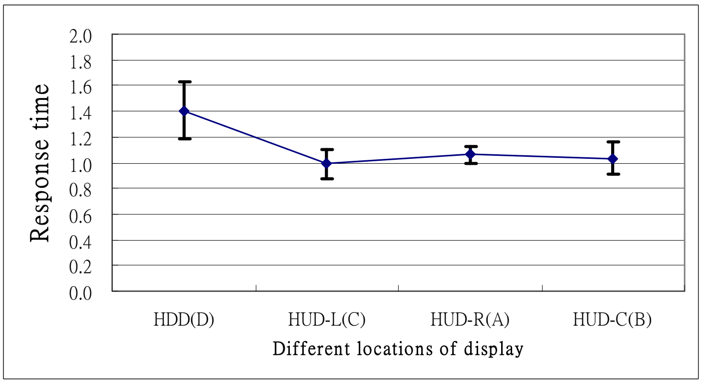

Figure 5: The response time (RT) of male drivers

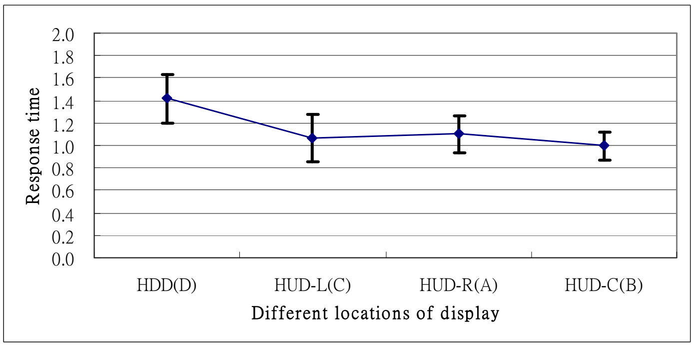

Figure 6: The response time (RT) of male and female drivers

In this experiment the mean responses for the female subjects with HUD（B）on the center of windshield were 0.072s faster than male subjects, who needed 1.031s. This indicates that female subjects got more help from IVIS on HUD. However, female subjects took more response time from IVIS on the HDD than male subjects by

0.013s. The mean response to HUD（A）on the right side of the windshield was 1.1s, HUD（B）on the center of the windshield was 0.995s, HUD（C）on the left side of the windshield was 1.064s, and to the head-down display HDD (D) it was 1.409s. There was a significant effect of type on the mean RTs of the IVIS secondary task on the center of HUD（B）and driving scenarios. The response time to HUD（B）was faster than the head-down display by 0.414s. When the image of the speed limit was presented on HUD（B）, performance also improved (response times decrease, typically by values approaching 29% over the baseline HDD).

4. Conclusion

Today most new vehicles found on the market are already equipped at different levels with various driving assistances which provide drivers with more or less valid information on the conditions on roads ahead, direction indications and many other communications. As has been established in the present Action, driver use and acceptance of this vast range of interactive information varies considerably. The boundaries of the imagination, inventiveness and strong motivation of those who design and develop IVIS devices have few restrictions. Indeed, one tends to experience new ways of informing, which vary between providing information that is totally irrelevant to drivers and giving vital indications which, if not heeded or registered instantly, can lead to unsafe situations or even worse. Vehicle manufacturers install IVIS devices into their interior designs that lead sometimes to the inconsistency of several types of operational modes. As a result, it is necessary to find out the effectiveness of a head-up display in the in-vehicle information systems. The responsible international groups of experts that prepare standards, approval rules and regulations are currently discussing essential criteria for the future design and installation of IVIS devices in vehicles.

In addition to improvements in reaction time, HUDs also improve driver behavior under both low and high mental workloads where the probability of detecting forward roadway events is greatly improved compared to conventional HDDs. This paper investigation of performance tests and user preference ratings, the warning indicator in front of the center HUD proved to be the best for forward collision warning, with almost half a second improvement in average brake reaction times and no missed warnings. In terms of subject preferences, an implementation of the center HUD was the most preferred display. The questionnaire form the subjects completed shows 92% think the speed limit warning is helpful, IVIS on a HUD enhances driving safety and enhances a driver's vision versus a head-down display. 58% think drivers are overconfident with IVIS, and 58% also think too much information from IVIS will increase cognitive workload. Therefore, it would be beneficial to study how to design a better interface of HUD-based IVIS and organize information to decrease cognitive workload and working memory.

The evidence suggests that response times to HUD-based IVIS displays will be significantly less than for similar displays mounted as a head-down display. The warning signs would prove more effective if the speed was also displayed in the driver's field of view. This kind of alert would still have the ability to quickly grab the driver's attention, include information about how much to slow down, and allow the driver to maintain focus on the road. The findings of this experiment do not provide resounding support for see-through HUDs, but the response time data strongly favors developing them. This paper showed that the response time data is intriguing enough and the opportunities for improving the quality of the implementation are sufficient to warrant further human factors studies of the merits of see-through HUDs. Efforts to develop improved, see-through HUDs should emphasize designs that reduce opportunities for driver errors. These results are of potential interest to designers of in-vehicle systems and development of working prototypes should not proceed without favorable results from those experiments.

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