The impact of AR-HUD intelligent driving on the allocation of cognitive resources under the breakthrough of 5G technology

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Abstract. This paper focuses on the establishment of an AR-HUD assisted driving test system based on a VR platform, which has the advantages of high security and immersion, repeatable experiments and the ability to perform eye-movement analysis. This paper first defines and designs the vehicle driving safety icons based on human-computer interaction principles and engineering psychology, supplemented by PS to define and design the AR-HUD interface while combining mental load and other factors, then uses 3Dsmax software to build the 3D model material required for driving, then builds the driving environment and designs various driving emergencies in Unity based on featured technologies such as multi-channel rendering and global illumination, and then combines HTC VIVE Pro eye display. Thirty drivers were then tested on a distraction task. Analysis of the subjects’ eye-movement data revealed that the AR-HUD system improved the cognitive efficiency of the drivers compared to the traditional driving method while allocating cognitive resources to the central driving area, speed module, navigation information, and hazard warnings in a balanced manner, thus improving the ability to react to unexpected driving events.

Keywords: immersive technology, human-computer interaction, cognitive resources, safe driving, AR-HUD interface design

1. Introduction

In recent years, with the breakthrough of 5G technology, more and more applications based on 5G technology have been better implemented, bringing great convenience to our production and life, such as for providing medical services [1], deploying smart grid [2], improving agricultural production [3], and promoting the development of augmented reality (AR) technology [4]. This has led to a greater use of augmented reality (AR) technology, which is widely used in medicine [5], [6], education [7], [8], archaeology [9], [10], gaming [11] and, more recently, in combination with HUDs [12]. In the normal viewing direction and within the field of view, the driver can see the data on the dashboard without shifting their eyes, thus making the driving process easier and safer [13]. With the development of AR technology, the integration of AR technology into the HUD has allowed the technology to break through the original bottleneck and has received increasing attention from drivers. In the specific implementation of this technology, Park H S [14] et al. designed an in-vehicle AR-HUD system that could identify driving safety information and project it into the driver’s field of view; Bark K [15] et al. mentioned that
by experimentally comparing the driver’s reaction time to information in two different contexts, with and without AR, they proved that the AR-HUD navigation system could help drivers react faster to turning positions; Kim, Hyungil [16] et al. proposed a new method to evaluate AR-HUDs in a way of assessing driver gaze behaviour, situational awareness, confidence and workload. And experiments found that only one of two tested AR interfaces could improve driver awareness of pedestrians without visually and cognitively distracting drivers from other road elements that were not augmented but still critical for safe driving [17]; Zhou [18] used a qualitative research method based on actual car-following research and an interview method to study the driving situations of typical users, dug deeper into the user requirements of AR-HUD assisted driving systems and completed the interface design of the system accordingly.

All of these studies focus on the implementation of specific technologies, but to some extent, they neglect the user’s experience. As mentioned above, 5G technology has already made significant breakthroughs and in line with today’s ‘smart driving’ era, it is feasible to use 5G technology to further improve AR-HUD and accelerate the implementation of this technology. In order to achieve this goal, it is necessary to further improve the interaction between the driving system and the ‘human’ [19], which means the presentation of the interface is one of the most important aspects of the user’s experience and the interaction between the user and the driving system. The impact of the head-up display layout on the user’s driving experience has not been tested by using virtual driving. In this paper, the focus is to improve the user experience by focusing on interface design issues.

2. System overview

2.1. Experimental Equipment
This experiment uses the HTC VIVE Pro eye, a headmounted display device with a good immersive experience. The main body is a high-performance desktop computer, and the steering wheel, foot pedals and gears are also connected to the computer via relevant ports for overall connectivity. The VIVE comes with an eye-tracking function and each tester needs to have their eyes calibrated at the beginning to allow the eye-tracking device to work properly.

2.2. Driving Surroundings
In order to have a good fidelity driving experience and at the same time let the test subjects have a good interactive experience when using the AR-HUD assisted driving system, a city system with pedestrians, vehicles, street lights, flowers and other driving peripheral entities was designed and built in Unity, which also includes climates such as sunny days, dusk, rainstorms, thunder, light snow and dust storms. The vehicle’s action logic code is written to avoid blockages, mould penetration, etc.; data relating to driving operations such as friction between the vehicle and the substrate, vehicle acceleration, maximum vehicle speed, deceleration when braking, etc. are determined to ensure a good driving experience.

2.3. AR-HUD interface design
As shown in Fig. 1, according to the design principles, the information layout of an actual driving system which should be the most conspicuous position and the centre of the area in the driving process is the main visual area for the driver to obtain information about the driving status ahead. This part of the area is not laid out with AR-HUD driving information, but in the two relatively minor upper left and upper right corners are placed the vehicle speed and the forward driving guidance, respectively. The vehicle speed is the most important longitudinal parameter in the driving process, so large circles are used to wrap the figures for easy observation. In the top right corner, navigation information is presented for the current route and the nearest road only so that the driver can find the current position and the driving trend more quickly and precisely, and get the most urgent driving needs without wasting too many sensory resources. At the same time, the driver is psychologically and physically prepared for the driving manoeuvres to be performed. What is placed directly above is the lane information. To the right, the distance that driving for specific forward, left or right turns needs is presented. In the lower centre, to
the right, the fuel consumption and the remaining fuel are shown. Important buildings such as schools, government offices, stadiums and bridges are also shown according to the needs of the driver. Two main colour modules, blue and green, have been developed for the operator to choose. The maximum number of symbols containing information that can appear at the same time is set at 8. All driving information is brought closer to the middle as the speed of the vehicle increases, with information within 85° of the binocular view for speeds less than 75 km/h, within 65% of the binocular view for speeds between 75 km/h and 100 km/h and 40° of the binocular view for speeds above 100 km/h.

![Figure 1. The information layout](image)

### 3. Methods

#### 3.1. Participants

The aim of this experiment is to investigate the allocation of cognitive resources under a driving distraction task. Taking advantage of the repeatability of the VR environment, the surrounding pedestrians, vehicles, weather and buildings were set up in exactly the same way for each driving test. The test subjects were 6 vehicle drivers between the ages of 21 and 40 with years of driving experience who had no psychological or physiological reactions to VR driving. They were asked to refrain from consuming alcohol, coffee or other drinks that would affect their driving behaviours. In the lab, they were put through a driving test, completing the same driving distraction task while their eye movement data, vehicle speed, brake usage and steering wheel turn data were recorded.

#### 3.2. Testing Process

- The experiment was preceded by a questionnaire focusing on the perception of VR technology and driving assistance systems.
- Bring the head-mounted display device and check that the horizontal and vertical coordinates of the virtual space you are in fit the driving environment.
- Perform eye-movement adjustments so that the eyetracking device can properly record eye-movement data during driving.
- The overall driving environment and driving emergencies are identical for each driver once they start driving.
- Complete the driving task and fill in the questionnaire. Mainly about the utility of the AR-HUD and the main factors driving the driver to observe the information displayed by the AR-HUD while driving.
3.3. Distracting Task Design
The main driving distractions include chatting, watching videos, listening to the radio, etc. We designed listening to the radio as a simple distraction task, and answering phone calls and intermittently playing videos around the virtual driving environment as complex driving tasks. Both the simple and complex distraction tasks have the same volume and duration, starting fifteen seconds before the dangerous driving scenario and ending fifteen seconds after the completion of that part of the driving operation. The driving material is mainly about intersections ahead, oncoming traffic and construction work ahead.

4. Results

4.1. Visual Search Breadth
The search breadth in the horizontal and vertical directions was then quantified and analysed, as Fig. 2 and Fig. 3 show.

![Standard deviation of vertical viewing angle](image1)

**Figure 2.** Standard deviation of vertical viewing angle

![Standard deviation of horizontal viewing angle](image2)

**Figure 3.** Standard deviation of horizontal viewing angle

The standard deviation of the position coordinates in the vertical and horizontal directions was used as an indicator to evaluate the search breadth and to reflect the discrete degree of the driver’s viewpoint distribution during the driving process. The data was analysed and compared, and the final choice was...
made to use the standard deviation as the evaluation criterion. $p=0.008<0.05$ for the t-test without HUD in the vertical direction, thus indicating that the standard deviation of the viewpoint of HUD is significantly higher than the value without HUD, and also indicating that the driver’s search is wider in the vertical direction with the assistance of HUD; in the horizontal direction, the t-test without HUD t-test result $p=0.0159<0.05$, thus indicating that the standard deviation of the viewing angle of the HUD was significantly higher than the value without the HUD, indicating that the driver’s search range in the horizontal direction was wider with the assistance of the HUD.

4.2. Pupil Diameter
To more accurately reflect the driver’s physiological responses, we then analysed the driver’s physiological characteristics from the eye-movement data, i.e. measuring pupil diameter changes. The driving material is: a sudden vehicle approach at a pre-defined location. By measuring the pupil change of the driver with and without the HUD, the results are shown in Fig. 4.

According to the graph it can be seen that the time of pupil dilation with the help of the AR-HUD assisted driving system or the peak pupil dilation is lower than without the AR-HUD assistance.

![Figure 4. Pupil changes without and with HUD](image)

5. Discussion
A t-test of the standard deviation of the vertical view and the standard deviation of the horizontal view clearly shows that drivers using the AR-HUD assisted driving system have a higher breadth of search while driving. However, considering the fact that the vast majority of people are still in a state of curiosity and exploration with VR devices, therefore, this diversion of attentional resources could be due to the driver’s desire to try something new. On the other hand, this distraction may also be due to the driver’s actual driving needs and the need to divide attention between different pieces of information. In order to investigate whether this more distracted gaze pattern is effective in promoting safe driving, the paper then goes on to analyse the pupil scaling of the driver from a physiological perspective. This is because a person subjected to a sudden driving situation can cause sympathetic excitation, which in turn leads to pupil dilation. The experimental results show that with the AR-HUD system, the driver is able to detect emergency situations earlier in the driving process.

Therefore, driving resources are more evenly distributed with the AR-HUD system than with normal driving. The driver pays balanced attention to areas such as the central driving field of view, vehicle speed, navigation and fuel speed, and perceives the various driving characteristics of the driving process.
in a comprehensive and uninterrupted manner. Because people do not need to look down when perceiving AR-HUD assisted driving information and the information presented on the AR-HUD driving interface is clear and easy to identify, the efficiency of resource acquisition is improved, which allows drivers to better allocate their attention to the various modules during the driving process. This efficient perception mode also improves driver safety and will bring a qualitative change to driving.

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