Basic Study on the Influence of Cabin Vibration on the Driver's Depth Perception and Subjective Conviction when Using an Automotive Three-dimensional Head-Up Display based on the Relationship between the Degree of Correction and Driver's Recognition

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ABSTRACT

This study discusses the driver's depth perception and subjective conviction to be corrected for in the display contents of an automotive three-dimensional head-up display, such as navigation arrows, based on the levels of the basic correction method used to reduce the effect of car vibration generated by various road surfaces.

1 INTRODUCTION

An augmented reality (AR) head-up display (HUD) has been investigated in automobile-related industries. The virtual image of a conventional AR-HUD is displayed perpendicular to the ground and the focal depth of the virtual image is fixed at a single distance. Such AR-HUDs therefore face problems in terms of human perception; e.g., one problem is a double image and another is the accuracy of the human depth perception. To solve these problems, we propose and research a three-dimensional (3D) HUD as a new type of AR-HUD.

Previous research has reported that the accuracy of depth recognition when using a monocular HMD can be maintained by temporarily hiding display contents when detecting large vibration with an acceleration sensor. However, the driver's depth perception while a car vibrates has not been evaluated.

The present paper investigates the effect of car vibration on the driver's depth perception and subjective conviction when using the proposed 3D-HUD and discusses how such driver recognition is improved by controlling the position change of the display content corresponding to car vibration.

2 FIRST EXPERIMENT

The first experiment extracted the characteristics of vehicle vibration that affect the driver's depth perception.

2.1 Equipment

2.2.1 HUD apparatus

Figure 1 shows the HUD apparatus. The apparatus was constructed using a projection optical system, windshield, and holding case. A button device was installed in the holding case to measure the timing of the participant's responses. Both the HUD apparatus and the button device were connected to a personal computer to measure the time from the presentation of the visual image via the HUD apparatus until the participant pushed the button.

Figure 2 illustrates the optical projection system. The system was constructed using a liquid crystal display (LCD), system for changing the focal depth, and two mirrors. An image displayed on the LCD was reflected and enlarged by the two mirrors and windshield. Drivers therefore perceived the image as a virtual image placed ahead of the windshield via the HUD apparatus. The system was able to change distances from the LCD to the first mirror using the system for changing the focal depth.

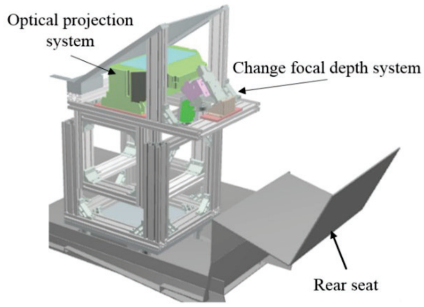

Fig. 1 HUD apparatus

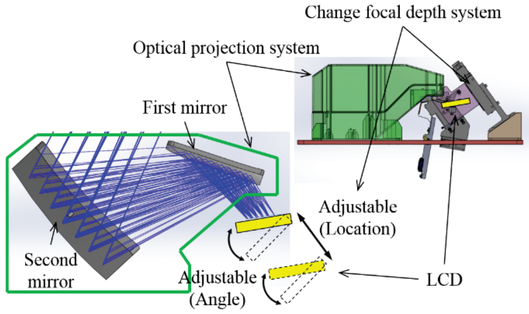

Fig. 2 Illustration of the projection optical system

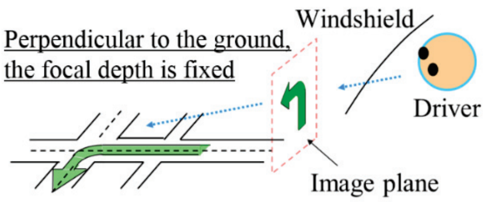

Fig. 3 Illustration of the AR-HUD

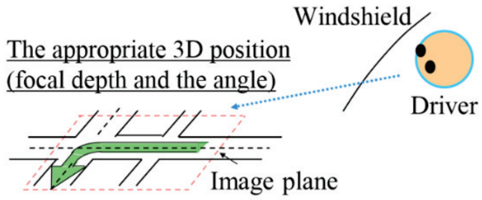

Fig. 4 Illustration of the proposed 3D-HUD

The angle of the LCD could be changed manually. This operation allowed us to change the focal depth of the virtual image and angle of the image plane. The HUD apparatus was able to play the role of both the AR-HUD and 3D-HUD. Figure 3 illustrates how the HUD apparatus was used as an AR-HUD. In the AR-HUD, the image plane was perpendicular to the ground and the focal depth of the virtual image was fixed at a single distance. Figure 4 illustrates how the HUD apparatus was used as a 3D-HUD. In the 3D-HUD, virtual images were placed at an appropriate 3D position. In particular, the image plane was perpendicular to the ground and the focal depth of the virtual image was set at the target distance in the case of the vertical target. In contrast, the image plane was horizontal to the ground and the focal depth of the virtual image could be set to any distance to match the image plane of the ground in the case of the ground target.

2.2.2 Experimental car

An experimental car was equipped with an HUD apparatus, cruise control system, and accelerometer for measurement of car vibration. The car passed a structural change inspection.

2.2 Participants

Two male drivers aged 21 and 22 years participated in the experiment. Each participant had corrected-to-normal vision and normal hearing ability, a driver's license, and sufficient driving experience.

2.3 Procedure

Informed consent was obtained from all participants at the beginning of the experiment. Each participant then sat in the back seat and his viewpoint was fixed in position. The participants were instructed to observe the relationship between the front scene and the information content while using the 3D-HUD in the traveling car. Moreover, they were instructed to press a switch button when they felt uncomfortable or they felt that the relationship between the front scene and the HUD content was unacceptable, to extract the characteristics of car vibration that affect a driver's depth perception.

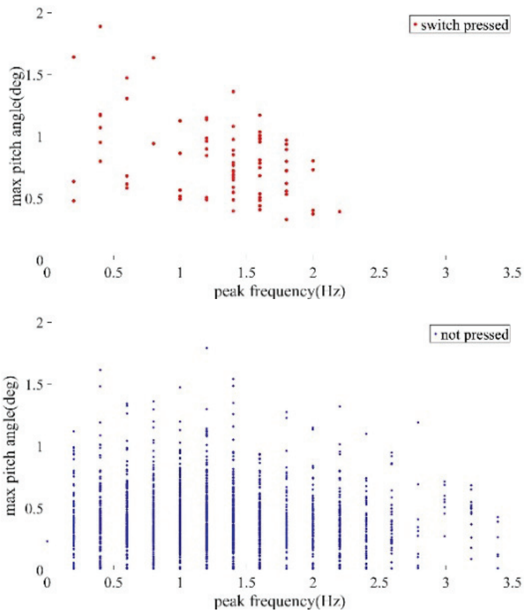

Fig. 5 Relationship between the peak frequency and maximum pitch angle

2.4 Results

Focusing only on the pitch angle data, the drift and trend components were removed. Next, data from 3 seconds before the switch was pressed to 2 seconds after were cut out as a 5-second window and used as data for the time that the switch pressed. A continuous section excluding the time that the switch was pressed was then cut out as a 5-second time window and used as data for the time that the switch was not pressed.

Figure 5 shows the maximum pitch angle (amplitude) and peak frequency of the car vibration observed in the experiment. It is seen that the car vibration that made the participants feel uncomfortable tended to have a large maximum pitch angle and a frequency range from 1.4 to 1.6 Hz. The 90th percentile of the maximum pitch angle was 1.2 degrees, and we adopted this value as a guide for the amplitude of car vibration.

3 SECOND EXPERIMENT

The second experiment evaluated the driver's depth perception of a navigation arrow on the HUD under specific vehicle vibrations.

3.1 Environment and equipment

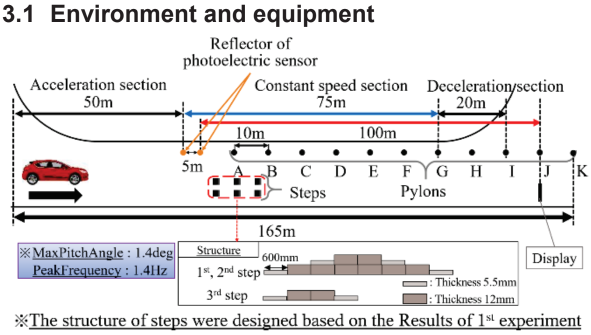

Fig. 6 Experimental environment

The experiment was conducted in a closed area that included a straight road exceeding 160 meters in length. Materials such as pylons, steps, and reflectors of a photoelectric sensor were used on the straight road as shown in Figure 6. The experimental car and HUD apparatus were the same as those used in section 1.

The timing of the presentation of the navigation arrow on the HUD was controlled considering the time elapsing from the moment of passing the first reflector to the moment of passing the second reflector. The second reflector was used as a start point, and the position of the steps was adjusted so that the front wheel of the experimental car climbed the steps when the car reached the start point.

3.2 Experimental tasks

Participants were instructed to perform two tasks simultaneously: a visual task and depth judgement task. The visual task was designed as the primary task and the depth judgement task as the secondary task. The tasks are described as follows.

3.2.1 Visual task

The purpose of the visual task was to simulate the driver's visual behavior while driving. Participants were instructed to watch a Landolt ring presented on the display and requested to report the direction of the Landolt ring when a beep sound was presented. The Landolt ring changed every 1 second.

3.2.2 Depth judgement task

The purpose of the depth judgement task was to simulate an HUD application that assists the driver to identify intersections at which the driver should turn left. Participants were instructed to judge which pylon was indicated by the navigation arrow. Participants were required to tell the experimenter which pylon they chose after pushing the button. Participants were instructed to give priority to speed over accuracy when performing the depth judgement task.

3.3 Experimental conditions

A navigation arrow indicated three target distances (50, 70, and 90 m) for the two types of HUD (i.e., AR-HUD and 3D-HUD). The navigation arrow was controlled adopting three types of initial basic method to decrease the amplitude of the position change of the navigation arrow using the pitch angle while the car vibrated. This paper defines the deviation in the pitch angle of the navigation arrow as the error angle. We controlled this error angle in three steps; i.e., the error angle was 0, 0.3, and 0.6 degrees in reduction methods 1, 2, and 3, respectively. In the case of reduction method 3, the amplitude of the deviation in the pitch direction of the navigation arrow was 1.2 degrees, which was almost the same as when no reduction method was used.

The experimental conditions were thus combinations of the HUD type, indicated distance, and reduction intensity.

3.4 Evaluation items

The following items were set to analyze and evaluate the performance of depth perception based on route guidance arrows.

3.4.1 Reaction time

The reaction time was defined as the time required to judge which pylon was indicated by the navigation arrow presented on the HUD apparatus.

3.4.2 Absolute judgement error

The pylon position indicated by the navigation arrow presented on the HUD apparatus was assigned as the presentation position. The pylon position that the participant indicated was measured as the recognition position. The absolute value of the difference between the recognition position and the presentation position was defined as the absolute judgement error.

3.4.3 Subjective evaluation

We measured the degree of subjective confidence when participants completed the depth judgment task using a visual analog scale.

3.5 Participants

Participants were 10 men who were between the ages of 21 and 24 years (average age: 21.9 years, standard deviation: 0.88 years) and had normal vision and hearing and drove about once a week.

3.6 Procedure

Informed consent was obtained from each participant at the beginning of the experiment. The experimenter drove the experimental car and each participant sat in the back seat and had his viewpoint fixed in position. Prior to measurements, each participant undertook practice trials to grow accustomed to the task procedures. After practice, each participant continued the visual task in the measurement experiment. When a beep sound was presented, participants were required to complete the visual task and depth judgement task. Each set of conditions was repeated five times in random order.

3.7 Results and discussions

Figure 7 shows the relationship between the participant's reaction time and indicated distance for each type of HUD when using three levels of correction. The participant's reaction time was about 1.0 second on average, regardless of the conditions. This is a result of giving priority to speed when participants performed the

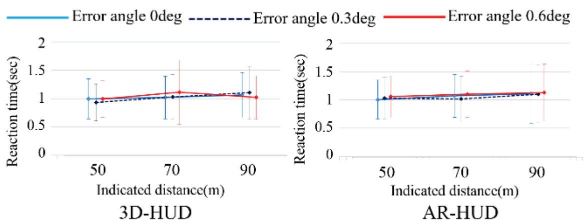

Fig. 7 Relationship between the participant's reaction time and indicated distance

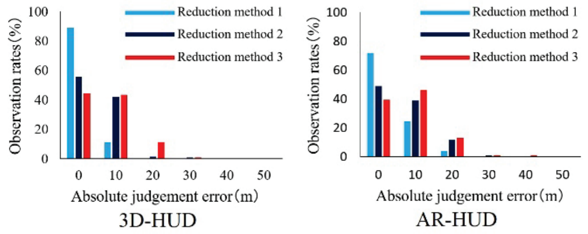

Fig. 8 Relationship between the participant's absolute judgement error and indicated distance

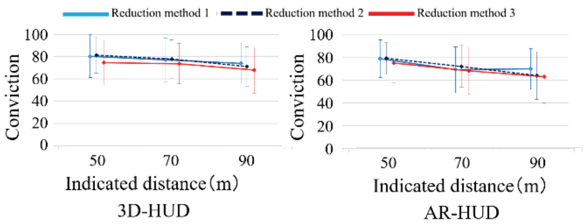

Fig. 9 Relationship between the participant's conviction and indicated distance

Table 1 Results of the statistical test for the independent variables when using each type of HUD

	Reaction time		Absolute judgement error		Conviction	
	3D	AR	3D	AR	3D	AR
Error angle : 0deg	·	·	· **	· †	·	·
Error angle : 0.3deg	·	·	** ·	·	* · **	** · †
Error angle : 0.6deg	·	·	· **	·	·	·

** : 1%, * : 5%, † : 10%

depth judgement task.

Figure 8 shows frequency distributions of the absolute judgement error for each level of the reduction method. Reduction method 1 resulted in a much greater decrease in the absolute judgement error than any other reduction method. This tendency was particularly noticeable when using the 3D-HUD. This implies that the 3D-HUD provides position information more accurately than the AR-HUD when there is car vibration. When the car vibrates, virtual images of both the 3D-HUD and AR-HUD are displayed on the same straight line, but the AR-HUD is affected by movement of the viewer's eye. This is because the virtual image of the AR-HUD is displayed closer to the car than the road surface.

Figure 9 shows the relationship between the participant's subjective conviction and the indicated distance for each level of the reduction method. Reduction method 3 reduced subjective conviction slightly compared with the other reduction methods. In regard to independent variables, such as the HUD type, indicated distance, and reduction intensity, a three-way analysis of variance was applied to the results of subjective conviction. Results show significant main effects of the type of HUD, the indicated distance, and the level of the reduction method ($p = 0.0476$, $p = 0.0119$, $p = 0.0041$). There were no significant interactions among the three variables.

Table 1 gives results of the statistical method for the reaction time, absolute judgement error, and conviction when using each type of HUD. In the case of using the 3D-HUD, there was significant difference between error angles of 0 and 0.3 degrees in the absolute judgement error. Meanwhile, there was no significant difference between error angles of 0 and 0.3 degrees in the subjective conviction. Therefore, when using the reduction method for the display content on the 3D-HUD, there may be different effects on the driver's objective recognition accuracy and subjective conviction.

The above results imply that there was a particular range with lower recognition accuracy despite the higher subjective conviction. A similar tendency was observed when the amplitude of the deviation on the display content was reduced to about 0.3 degrees of pitch angle. Such a relationship between the objective recognition accuracy and the subjective conviction has not been found by other studies, and the results of the present study thus provide a guide to how much deviation of the display contents can be tolerated.

4 CONCLUSION AND FUTURE WORK

We investigated the effect of car vibration on the driver's depth perception and subjective conviction when using a 3D-HUD, based on the degree of correction in the method for reducing its effect. It was thus clarified that the 3D-HUD is able to provide depth information more accurately than the conventional AR-HUD when a car vibrates. The experimental results imply that both the recognition accuracy and subjective evaluation increase when using the correction method for contents of the 3D-HUD at lower levels (0.3–0.6 degrees). It may therefore be possible to increase the accuracy of depth recognition unconsciously when using the correction method at higher levels (0–0.3 degrees).

Future work should investigate the relationship between the degree of correction in the reduction method and the driver's recognition for visual contents in more detail.

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