Development of Head-Up Display for Motorcycle Navigation System

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Abstract. This paper proposes a new type of navigation system using head-up display technology for motorcycle. We developed a navigation system using laser projector technology to construct the head-up display system representing information provided with images in high contrast and brightness. We assume this projection technology makes the navigation system suitable for motorcycles using the head-up display compatible with the windshield. The contrast and brightness supports to build up the navigation system for motorcycles so that the rider can obtain information even while running on public road during day or night. To confirm the usage of this system, we conducted an experiment using the motorcycle simulator in the immersive CAVE environment. The motorcycle simulator designed as a full-scale scooter type motorcycle operated in a virtual test course based on a real town in Japan visualized through the immersive CAVE environment. This made it capable for the subject to operate the motorcycle as if they were driving an actual motorcycle in the real world. By measuring the rider's viewpoint in the motorcycle simulator, we concluded that the navigation system using the head-up display could potentially provide navigation information while keeping the rider's viewpoint on the road surface. We indexed the stationary time and the reaction time against the provided information in 9 positions on the windshield to observe how the motorcycle rider will react in each position. From the results of the experiment, we found out that displaying information at the lower right or lower left positions are significantly effective, indicating that these two positions can potentially navigate drivers while the driver does not need to take their viewpoints off the road surface.

INTRODUCTION

A system for navigating in a four-wheel vehicle, formally known as a car navigation system, has been developed and released for more than twenty years and many successful products have been made to satisfy driver needs. On the other hand, navigation systems for motorcycle drivers have not yet been successful in fulfilling driver needs. Most products made were a type that attached a liquid-crystal display (LCD) to the body of the vehicle, which was barely legible under sunlight. In addition, since the attached monitor was at a very low position compared to where the driver looks while driving, it was almost impossible to obtain the displayed information while safely driving the motorcycle. Like driving the four-wheel car equipped with a navigation system, many motorcycle drivers think that it would be much more comfortable driving a motorcycle equipped with a suitable navigation system "(JSDC 2006)". The most important and obvious problem was glare from sunlight, moreover the luminosity that changes during time and even just driving through the city, strongly affects the legibility of the display. The second problem was with the position of the display, which needs to be somewhere where the driver can look for a short length of time while driving the vehicle. The usage of audio augmentation has always been alternative solution to solve in four-wheel vehicles, but for motorcycles, it is hard to listen in open environment during driving. Therefore, it is important to inform the driver using information display, rather than just only audio information.

HEAD-UP DISPLAY

Head-up Display Usage in Driving Vehicles

A head-up display is a type of a display, which has the characteristic of showing the displayed object and the opposite side of the display at the same time. The projected object itself is displayed on the half-mirror but shown like if it is actually floating in the see-through real world. This phenomenon is named, augmented reality (AR)" (Milgram 1994)". To realize this, typical system uses a half-mirror and a projector to display the object. Using this methodology, we can easily presage the capability of usage in driving a vehicle; also can be seen in earlier study" (Yasuhiro et al. 1991)". In fact, some combat aircrafts and airplanes are already equipped with a head-up display for showing flight information to the pilot. The main problem to use this in daily life was mainly about the brightness of the object that the projector can display. Another problem is how to control the displayed object to augment the real world correctly. Since the relative position of the object in real world depends to the position and the angle of the observer, showing the object correctly at the absolute position in the real world is very difficult. As motorcycle drivers move their head during driving, this must also be taken into consideration. This is why we chose to use the head-up display rather than the head-mounted display, which is a similar approach to show information to the driver. The head-mounted display augments the real world based on the screen attached to their head, augmenting only the space in their eyesight"(Livemap 2013)". In order to drive safely, it is common sense to keep attention to not only the direction to drive but to all conditions of the surrounding environment. Therefore, the augmentation against the space of the driver's eyesight is not that ratiocinative in occasions of showing navigation information, which shall augment in the field of real world. Although there are problems, it is clear that the usage of a head-up display meets the motorcycle driver's needs. When adapting this navigation system in the real world, the head-up display will be integrated to the windshield.

Prototyping

To confirm the usage of head-up display we developed a prototype of head-up display suitable for motorcycles shown as Figure 1. This prototype uses an acrylic board as a half-mirror that has a 92.6% transparency meaning it has 7.4% reflectance. The projection system uses a laser projector projected through a non-spherical lens. Without the lens, the virtual object projected will only be shown in the distance same with the distance from the half-mirror. As we are aware that the projected virtual object shall augment the real world, we need to configure the object to a distance that the driver can look naturally regarding the distance they are actually looking while driving. The non-spherical lens customizes the focal point for the projected virtual object, which depends on the focal distance of the lens.

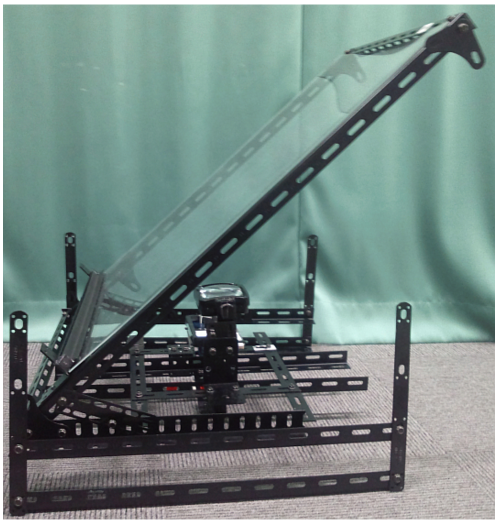


Figure 1. Head-up Display Prototype

Laser Projector

For the projector, we used a laser projector (Microvision, Laser Pico Projector SHOWWX+) that has a unique different characteristic compared to other handy type LCD projector. The traditional LCD projectors were not suitable enough because of the contrast and brightness using outdoors. On the other hand, the laser projector managed to actualize high contrast and high brightness even with the same lux with the LCD projector. This made it capable to use the projector in outdoors, and we confirmed that actually displaying it to the head-up display on a sunny day (6470 lux) showing a green arrow shown in Figure 2.

Figure 2. Laser projector displayed through head-up display

Virtual Object's Focal Point

We decided to set the focal point of the virtual object around 3 meters regarding the estimated distance the driver is looking during driving in an urban city. Our estimation has fortunately become almost the same to a specific product of navigation system for four wheels automobile (Yamashita, 2012 described). For the prototype, we used the lens (Eschenbach Magnifier 3.8x) that has focal length of 90.90mm. With this lens's focal length and the focal distance of the virtual image, we calculated the distance of the actual object using the lens formula. Figure 3 is the picture of the lens usage with the laser projector.

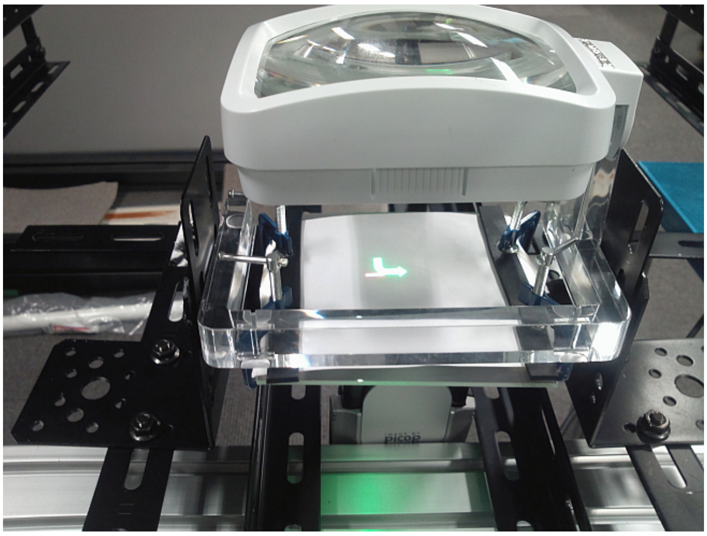


Figure 3. Lens usage with the laser projector

SIMULATION

Motorcycle Simulator

We used a scooter-type motorcycle simulator shown in Figure 4 to conduct the following experiment. This motorcycle simulator uses a digital signal processor to configure and monitor the system. Figure 5 is this system configuration diagram, showing how we observe the driver's actions. We measured the steering, acceleration, and the break using the potentiometer converted into digital signal by the digital signal processor (DSP). In the DSP, we calculate the planar position from the data of steering angle, acceleration amount, and brake amount. The calculated position is send to the driving simulator through UDP using the Ethernet.

Figure 4. Scooter-type motorcycle simulator

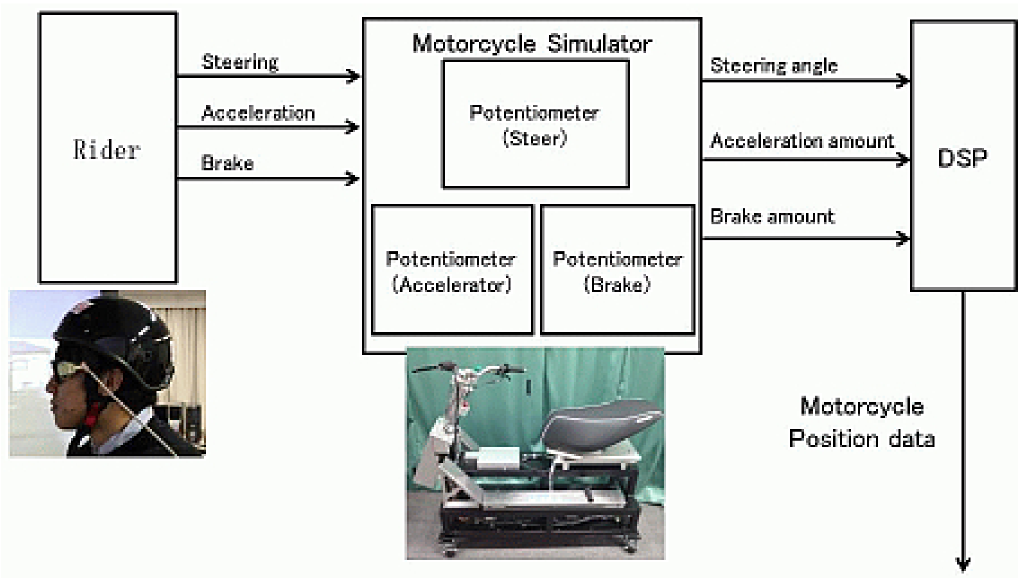


Figure 5. System configuration diagram (Motorcycle)

Driving Simulator

We used a real world based driving simulator for automobile in the cave automatic virtual environment (CAVE) which provides immersive virtual reality environment"(Tateyama 2009)". We adapted the system for motorcycle to conduct the experiment.

Immersive CAVE Environment

The immersive CAVE environment provides visual surroundings giving full-simulated eyesight to the driver. The electromagnetic sensor (Flock of Birds) tracking the user's head position provides the 3D images so the driver can see the real-time rendered three-dimensional stereo image perfectly wearing the3D glasses. Figure 6 shows the system configuration of the immersive CAVE environment combined with the motorcycle simulator and the head-up display. In the experiment we conducted, the conductor operated the navigation render computer manually to generate the head-up display image based on the motorcycle position. This operation will be processed automatically in the near future for further experiments, described as a dot line in the figure.

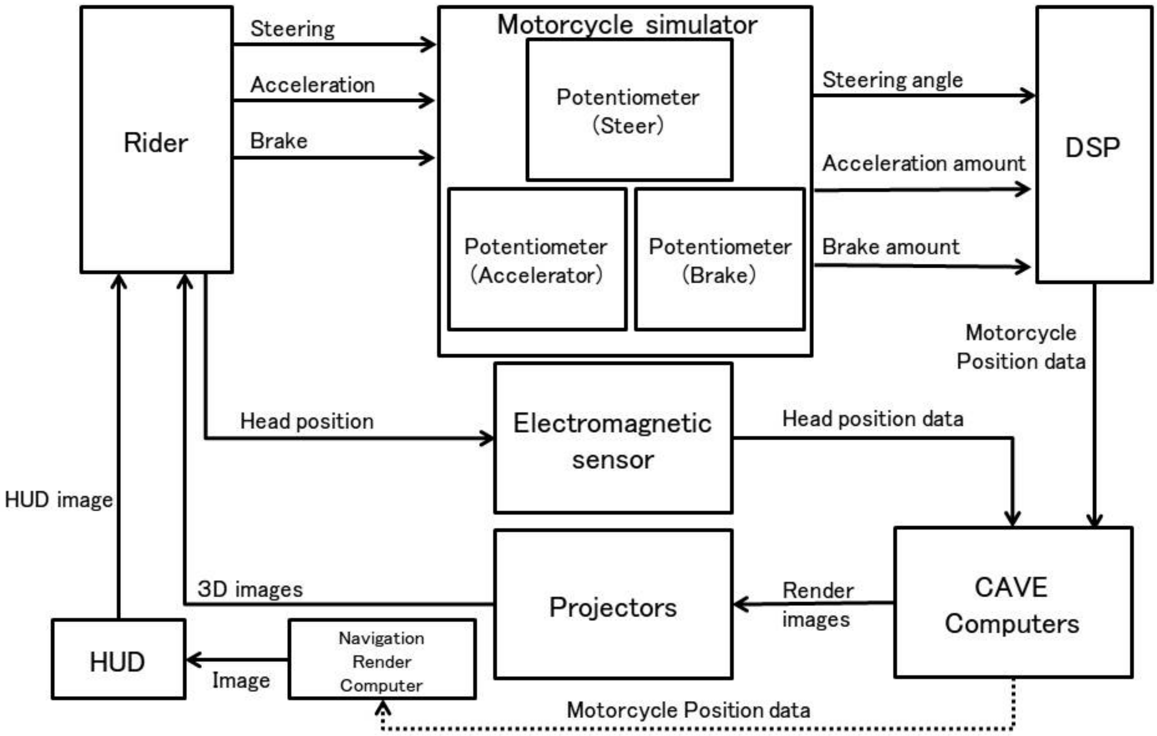


Figure 6. Overall system configuration

EXPERIMENTS

Presenting Information Effective

In order to present information effectively to the driver, we assume that the eye-motion is one of the important factors. This includes the position of the displayed object on the head-up display, and the moment to display the object. It is very important and a premise to be sure that the displayed object shall instruct the driver navigation information without distraction and violating the driver's safety. We assume this leads directly to the effectiveness of the head-up display navigation by considering the amount of extra time spent for looking at the presented object rather than what the driver should have been looking. To investigate the position to display, we measured the motorcycle driver's view direction by conducting an experiment in the real world. Based on the result, we conducted an experiment in the simulator using the head-up display to scrutinize the position to display effective. For each experiment, we used an eye-mark recorder (nac EMR-9) shown in Figure 7.

Figure 7. Eye-mark recorder

Driver's Eyemotion in Real World

We composed an experiment to check where the driver is actually looking while driving in the real world. We conducted this experiment at the Hiyoshi driving school. We performed the experiment by three subjects on a cloudy day using a 400cc motorcycle (Honda CB400SFRevo). From the results, we found out that rider keeps their viewpoint mainly on the road surface, moving their direction vertically rather than horizontally.

Head-up Display Navigation in Simulator

In the simulator, we conducted an experiment using the head-up display giving direction to the driver which way they should go at a cross-road. Figure 8 describes the nine positions we set on field of the head-up display to see how the driver would look at the object for each point while driving the simulator. For each points, we presented four kinds of objects. Three arrowhead objects indicating to "turn left", "go straight", and to "turn right". The last object indicats to "temporary stop". Figure 9 shows the four objects we actually used to conduct the experiment. Figure 10 shows the experiment scenery of the motorcycle simulator where the driver is riding the driving simulator in the immersive CAVE environment, and Figure 11 describes an example of the displayed object and the viewpoint measured by the eye-mark recorder. We performed this experiment with two subjects, randomly shown the four kinds of objects for twelve times in each display position. In total, we obtained 108 data from each subject.

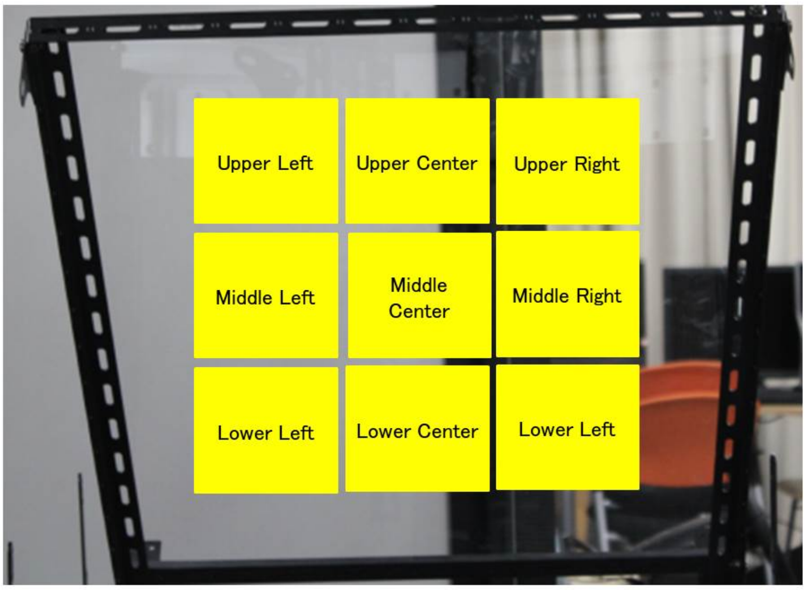


Figure 8. Nine positions on head-up display

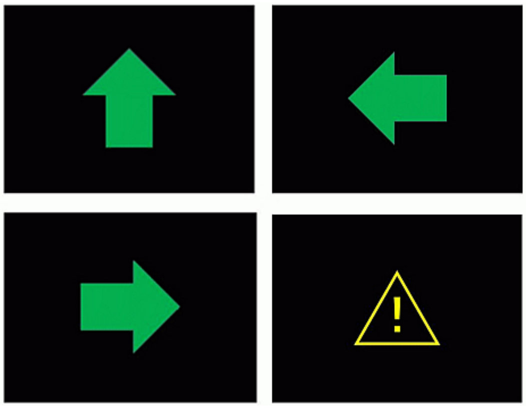


Figure 9. Objects presented to the subject

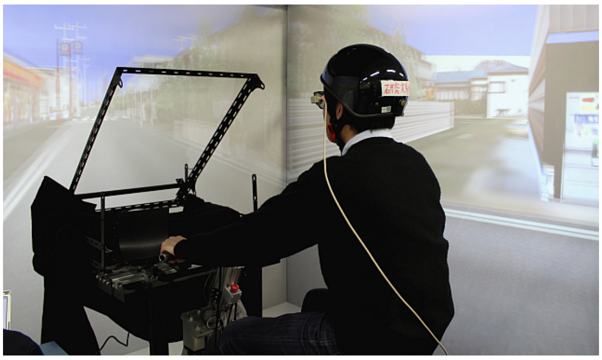


Figure 10. Experiment in the immersive CAVE environment

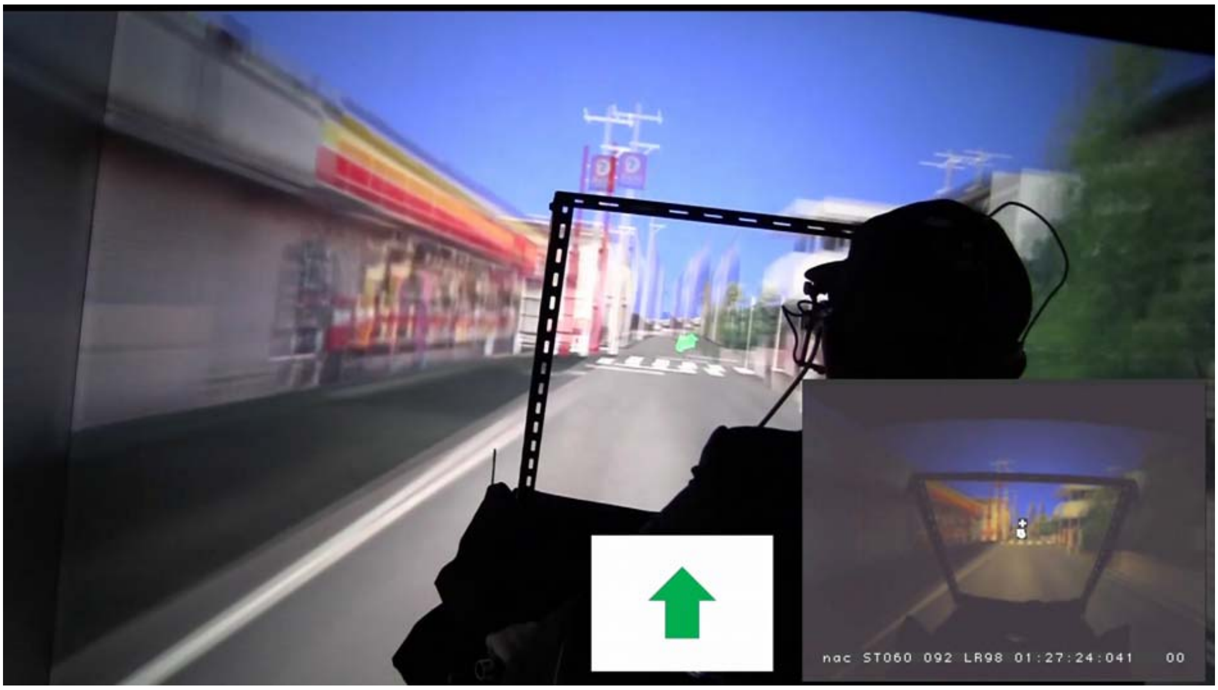


Figure 11. Example of displayed object and viewpoint measurement of eye-mark recorder

RESULTS

Simulator Experiment Data Analysis

To analyze the data, we defined three types of duration. We defined the first duration as "Detection time", representing the amount of time it took the subject to start looking at the object after presented by the head-up display.

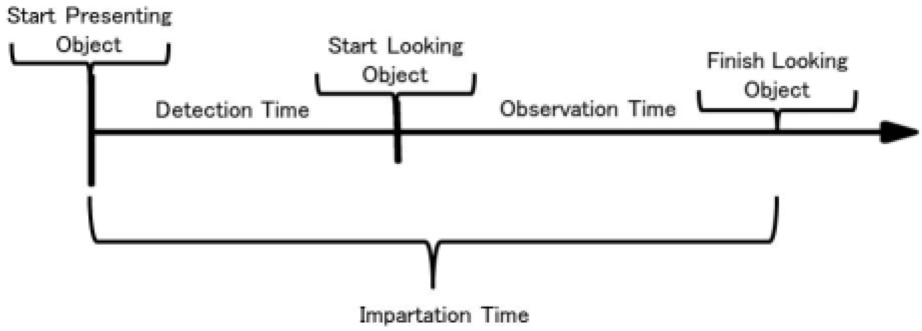


Figure 12. Visualized timeline of the defined duration

The second duration is defined as “Observation time”, representing the amount of time the subject looked at the displayed object. The third duration defined as “Impartation time” which is the total amount of time, meaning the sum of “Detection time” and “Observation time”. This third duration is the time that the driver takes their viewpoint off the road surface. We consider all the durations defined to be smaller the better, since it implies taking the driver viewpoint off the road surface may leads to the latency of awareness against risky situations. Figure 12 is the visualized timeline of the three durations we defined.

For analysis, we first looked through splitting the nine positions into three areas in two ways; the “Left” “Center” “Right”, and “Upper” “Middle” “Lower”. We performed analysis of variance to check for a significant position, and then performed a multiple comparison between the three positions. After observing the trend, lastly we performed a multiple comparison for all nine positions. Figure 13 shows how we divided the nine positions.

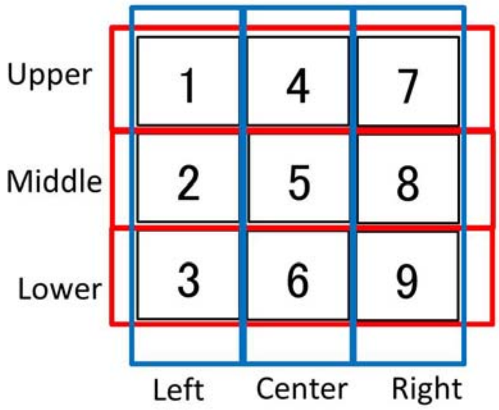


Figure 13. 2 ways of dividing into three areas

Detection Time

Looking through the results, we observed that the “Left” and “Right” were faster than “Center”. On the other hand, there was no significance between “Upper” “Middle” “Lower”, only showing the fastest average was the “Lower” positions. From these results, we weakly assumed that “Lower Left” and “Lower Right” could potentially be effective positions. Looking through the multiple comparisons of all nine positions, the “Lower Left” and “Lower Right” scored faster than the “Lower Center”, which was the position slowest position at 5% significance difference. Figure 14 shows the analyzed results for “Left” “Center” “Right”, “Upper” “Middle” “Lower”, and the multiple comparisons. The position numbering in multiple comparisons corresponds to the position in Figure 13.

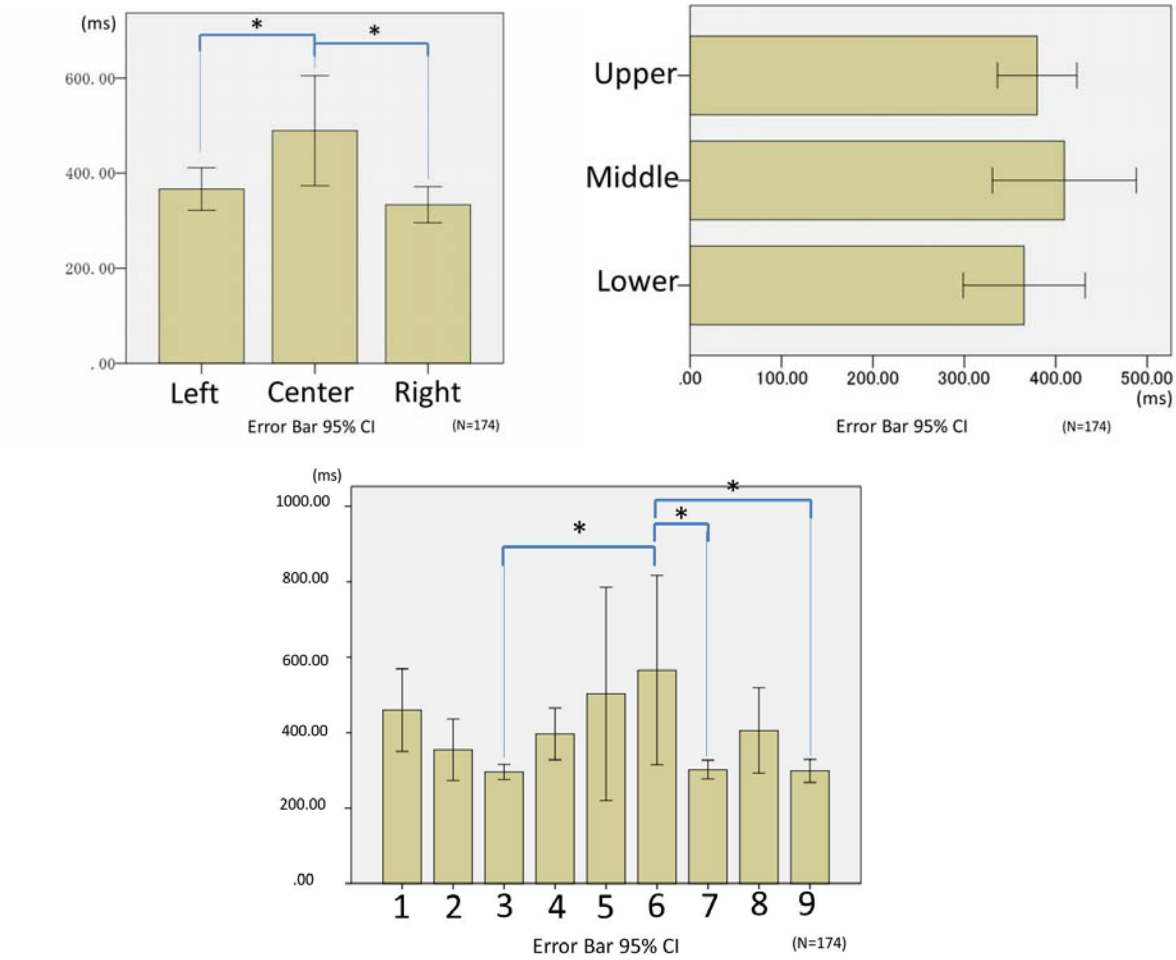
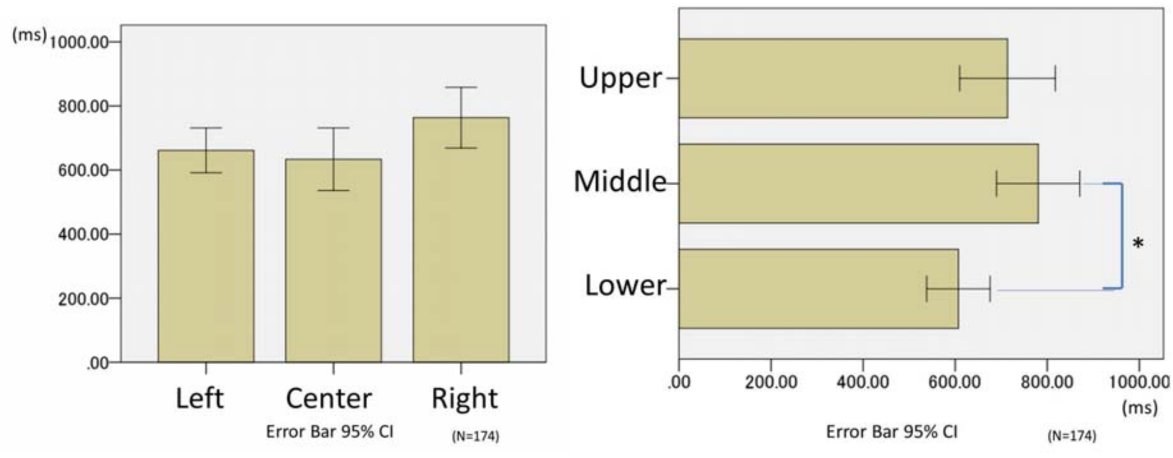


Figure 14. Detection time analysis

Observation Time

For the observation time, there was no significance between “Left” “Center” “Right”, only showing “Center” ’s average was slightly faster than the other two. For the second way, “Lower” marked the fastest time compared to the “Upper” and “Middle”, and 5% faster compared to “Middle”. Looking through the multiple comparisons, we observed other significant differences between the different positions. Especially the “Lower Left” and “Lower Right” scored faster average at 5% significance compared to the slowest position “Upper Right”. Figure 15 shows the analyzed results for “Left” “Center” “Right”, “Upper” “Middle” “Lower”, and the multiple comparisons. The position numbering in multiple comparisons corresponds to the position in Figure 13.



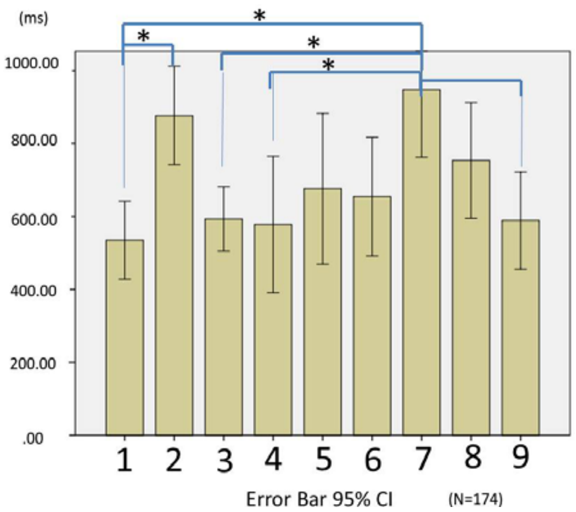


Figure 15. Observation time analysis

Impartation Time

From the results of “Detection time” and “Observation time”, we assumed that “Lower Left” and “Lower Right” have the potential of being faster at 5% significance compared to the slowest position. For the “Left” “Center” “Right”, there was no significant difference. Same to the “Observation time”, “Lower” scored faster at 5% significance compared to “Middle”. For the multiple comparisons, “Lower Left” and “Lower Right” scored faster at 5% significance compared to the slowest position “Upper Right”, as expected. Figure 16 shows the analyzed results for “Left” “Center” “Right”, “Upper” “Middle” “Lower”, and the multiple comparisons. The position numbering in multiple comparisons corresponds to the position in Figure 13.

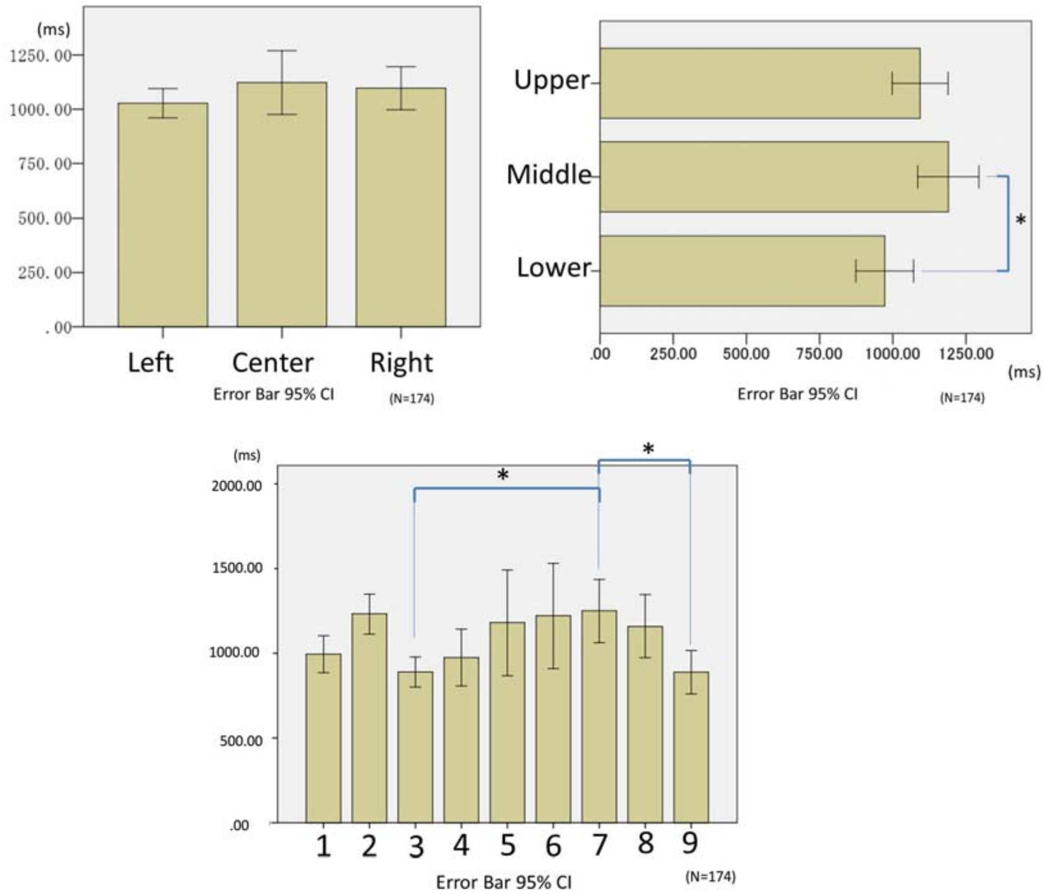


Figure 16. Impartation time analysis

Head-up Display Usage From the Experiment Results

From the experiment results, we conclude that the "Lower Left" and "Lower Right" are the most suitable positions to display the object and effectively inform the driver. However, since these two positions were not significantly faster compared to the other seven locations, it is premature to determine that the other locations are not suitable. For example, the multiple comparison in Figure 16, although it is not significant, other positions like "Upper Left" and "Upper Center" scored a fast average in "Impartation time", which means it have a possibility to consider as effective. To obtain conclusive evidence, we think that an additional experiments with more subjects are necessary.

CONCLUSION

In this study, we proposed and developed a head-up display as a navigation system for motorcycle riders. To evaluate the usage of the head-up display, we conducted an experiment using the motorcycle simulator in the immersive CAVE environment. In the experiment, we investigated where the motorcycle driver is looking at while driving the simulator and where the effective position is to present the navigation information to the driver. From the result of the experiment, we conclude that the displaying information on the lower left or lower right positions is effective since the driver was capable of obtaining information in a short time.

For further research, it shall be necessary to conduct additional experiments using other types of objects indicating different type of navigation information to confirm for any dependency with the presented information. It shall also be necessary to verify for audio augmentation usage to this system rather than just comparing the audio navigation as a substitute system.

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Kenichiro Ito graduated the Faculty of Business and Commerce at Keio University in 2010. Then, obtained the master's degree in 2013 at System Engineering from the Graduate School of System Design and Management, Keio University. He enterend the doctoral course in 2013 to the Graduate School of System Design and Management, Keio University.

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