MR Visualization of Wheel Trajectories of Driving Vehicle by Seeing-Through Dashboard

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Abstract

A lot of efforts aim to realize a society where autonomous vehicles become general transportation in industrial, political and academic fields. In order to make autonomous vehicles more familiar with the public, it is necessary to develop not only advanced auto driving control but also comfortable environments for the passengers. This paper proposes our trial to improve comfort of passengers on autonomous vehicles. We developed an experimental vehicle equipping Mixed Reality (MR) display system which aims to reduce anxiety using visual factors. Our proposed system visualizes a road surface that is out of the passenger’s field of view by projecting the see-through image on the dashboard. Moreover, it overlays the computer graphics of the wheel trajectories on the displayed image using MR so that the passengers can easily confirm the auto driving control is working correctly. The displayed images enable passengers to comprehend the road condition and the expected vehicle route out of the passenger’s field of view. We investigated change of the mental stress by introducing methods for measuring physiological indices, heart rate variability and sweat information.

Keywords: Autonomous Vehicles. Comfort of passengers. Mixed Reality. Physiological indices.

Index Terms: H5.2 [Information interfaces and presentation]: Multimedia Information Systems — User Interfaces

1 Introduction

Governments in every country are discussing about the realization of a society in which autonomous vehicles are popularized [15,18,20]. For the accomplishment of this society, auto manufacturing industries are actively developing autonomous driving systems [7]. Also, in academic fields such as the grand challenge sponsored by DARPA [4], researches and developments about autonomous driving systems based on advanced sensor technologies are progressing. As the result, several systems are becoming capable of traveling in real road environment [7].

Each government defines levels of ability of autonomous driving systems [15,18]. For example, National Highway Traffic Safety Administration (NHTSA) classifies the ability into five levels, from Level 0 to Level 4 [15]. At Level 3 which the auto manufacturing industry aim to sell around 2020, the vehicle

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Figure 1: Our system visualizes a road surface that is out of the passenger’s field of view by see-through the dashboard. MR visualization of wheel trajectories is realized by overlaying the CG data onto the displayed road surface.
controls acceleration, braking and steering automatically, but the passenger needs to deal with eventual emergencies. At Level 4 which is the goal of automated driving, the passenger never needs to be concerned with driving in any circumstance.

The main purpose of using vehicles is not only transportation of luggage, but also human being. Taking this into account, in order to popularize autonomous vehicles, it is necessary to realize a system which makes the passengers more comfortable in addition to the advanced auto driving controls [5]. In the case of Level 3, the passenger must be prepared for an eventual manual control to avoid accidents always, thus feeling mental stress as a result. We are researching to aim reducing the stress using visual media technology. As example of the stress of passengers, we can bring “surprise”, “irritation” and “anxiety” to mind. Surprise occurs in case that a vehicle ahead activated the brakes suddenly or a pedestrian rushed unexpectedly into the road. However, since such stress comes after the accident happens, it is difficult to reduce by MR display in advance. Seeing-Through screen object for the passengers of vehicle such as walls and buildings is expected way to control the stress [29]. In order to carry the approach out, we need to develop not only a MR display system on a vehicle, but also large-scale infrastructure of visual media that captures and translates multiple video sequences in real time. So, we leave the stress to the future works.

Unsatisfactory or unexpected action by the autonomous control system for the passenger irritates him or her as a consequence. In order to reduce the stress, we have to carefully observe the passenger’s feeling and behavior using several types of sensors, and give appropriate stimuli to reduce the irritating stress. However, since the degree of the stress depends on sensibility and taste of driving (acceleration, braking and steering control) of each passenger, it is difficult to understand the correct reason occurring the stress.

Due to the reason mentioned above, in this paper, we mainly consider about to reduce the stress given by anxiety. Figure 2 shows a typical situation that gives an anxiety stress to the passenger. Because it is difficult for passengers on an autonomous vehicle to understand the road condition out of the field of view and the controlling information of the automated system, he or she feels anxiety regarding the possibility of running off in case of driving through a narrow road. In such case, it is possible to reduce the stress by showing the visual information to solve the anxiety in advance.

As the visual displaying method, we pay attention to Mixed Reality (MR) to visualize the road condition and the control information of vehicle. MR displays the computer-generated (i.e., CG) information by superimposing it on the real world. There has been a great discussion about visual support systems for drivers using MR technique [8,11,12,13,16,19,21,22,24].

The aim of our research is to reduce mental stress of the passenger and to improve comfort by using MR who boards the autonomous vehicle. This paper proposes a system that sees-through the dashboard, overlaying wheel trajectories on the road’s surface in the see-through image [19]. Thanks to the see-through image and wheel trajectories, the passenger easily understands the road condition and the prospected vehicle route out of the passenger’s field of view. Moreover, we measure physiological indices for estimating the stress level and analyze the changes of it.

2 RELATED WORKS

Morales et al. surveyed by questionnaire about comfort of a passenger on an autonomous wheelchair after conducting on the test-drive experiments [28]. In another research by Morales et al., the experimenters instructed participants to press a push button when they felt mental stress subjectively [27]. Moreover, Dong et al observed physical change of a driver on an automotive vehicle, for example, such as eye movements and head ones, distinguishing distraction and fatigue [26]. However, the survey by questionnaire has difficulty in estimating the stress level in real time. This way, pressing the push button subjectively and observing any physical change, is possible to watch reactions of stress in real time, however it is difficult to measure detailed change in the stress. Therefore, we apply a method measuring physiological indices to estimate the stress level [3,14,25]. The passenger equips sensors which allows to measure detailed stress change in real time. There are researches introducing such method for measuring driver’s stress [1,6,9,23]. These researches observe LF/HF as heart rate variability and skin conductance response (SCR) as sweat information. LF/HF indicates the ratio between low and high frequency (LF and HF) of heart rate variability spectra. We also use these indices to estimate the stress level.

MR systems are actively researched and developed which assist visual information for the drivers on an automotive vehicle [8,11,12,13,16,19,21,22,24]. Bark et al. described that a route which was overlaid on forward view by using head-up-display helped the driver to notice a turning point Earlier [12]. Tonnis et al. indicated that displaying a forward hazard on the head-up-display enabled to notice it earlier as well [13]. Moreover, Yoshida et al. developed a system which displays out of the passenger’s field of view as if the interior of a vehicle were transparent by using MR [21]. Geometric consistency between the see-through image and the real world through the vehicle windows is corrected, which enables to see them continuously. However, there is little information on understanding vehicle routes or spatial relationship between the wheels and end of the road. Therefore, we developed an MR system which overlays computer graphic of wheel trajectories corresponding to a steering on the image see-through the dashboard [19]. Victor et al. presumed that visualizing hazard or a travelling route beforehand has a possibility to reduce anxiety of a passenger on an autonomous vehicle [24]. However, the presumption has not confirmed whether MR system reduce the anxiety or not.

3 SEE-THROUGH DASHBOARD WITH WHEEL TRAJECTORIES BY PROJECTION BASED MR

We develop an MR system which displays the road surface that is out of the passenger’s field of view by seeing-through the dashboard with superimposing the wheel trajectories [19]. This system enables the passenger to comprehend the road condition and expect vehicle route. The main contribution of our system is to reduce anxiety regarding the possibility of running off in case of driving a narrow road.
Figure 1 shows our developed system. The process of the see-through dashboard is described as follows. A camera attached to the front of the vehicle captures images of the road out of the passenger’s field of view. Next, a projector positioned near the viewpoint of the passenger projects the image transformed by a homography matrix on the dashboard.

The suitable homography transformation calculates by geometric consistency among “the image plane capturing the road surface”, “a projected plane (dashboard)” and “the real road surface” around the vehicle. Although there are various shapes of dashboards depending on the model of the vehicle, we approximate the shape using several flat screens covering the dashboard. Reflective sheets are attached on the screens to show the projected image clearly in spite of daytime.

3.1 Correcting Geometric Distortion in See-Through Image

If the captured image is displayed on the dashboard, a positional difference among the capturing camera, the projector, and the viewpoint of the passenger causes geometric distortion as shown in the left of Figure 3. In our system, this distortion is corrected by suitable homography transformation for the captured image. Although in our system, the screen on the dashboard are configured by several flat screens, the description as follows about the see-through process is simplified by describing it in the case of a single screen. The process can be replicated for each flat screen realizing the see-through dashboard with multi screens.

As shown in Figure 4, Si (i=1,2,3,4) on the screen (dashboard) pass through in straight lines connecting the viewpoint of a passenger O and Ri (i=1,2,3,4) on the road surface. By transforming the captured camera image using homography transformation makes possible to Ri to be projected on the Si area, the passenger is able to see the road surface as if the dashboard were transparent. When the camera captures the road surface, Ri is observed as Ci on the camera image. And when the projector projects Pi in a projector image plane onto the screen (dashboard), Pi should be observed as Si. Thus, it is possible to realize see-through dashboard display by estimating a homography matrix H transforming Ci to Pi as shown in the right of Figure 4.

3.2 Calculating Wheel Trajectories and Superimposing

An accelerometer sensor attached on the steering wheel estimates an angle of the outer turning front wheel. As shown in Figure 5, the turning radius for drawing CG of each wheel’s trajectories are calculated geometrically from equations as follows:

\[ r_1 = l_b \sin(\theta) \]  \hspace{1cm} (1)
\[ r_2 = \sqrt{r_1^2 + l_t^2} \]  \hspace{1cm} (2)
\[ r_3 = r_2 \cos(\theta) \]  \hspace{1cm} (3)
\[ r_4 = r_3 - l_t \]  \hspace{1cm} (4)

where \( \theta \) is front the wheel angle, \( l_b \) is the distance between the center of the front and rear wheels, and \( l_t \) is the track width.

CG library such as OpenGL draws the CG of the wheel trajectories on the road surface which is captured by the camera. The intrinsic or extrinsic parameters of the camera enable to overlay the CG in position are calibrated by Zhang’s method [30] in advance.

Figure 1 shows an example of our implementation. Showing a green line representing the front wheel trajectory and a red one as the rear wheel trajectory, helps the passenger to distinguish the front one or rear one thanks to the complementary color relationship. Note that the CG of the wheel trajectories is superimposed in position on the see-through image that achieves geometric consistency.

4 Experiment

We investigated how the stress of a passenger in an autonomous vehicle is changed by the presence or absence of the MR system which shows the road surface out of the passenger’s field of view with wheel trajectories. In this experiment, a participant who sits on the passenger’s seat of a vehicle driven by an experimenter are assumed as a passenger getting on an autonomous vehicle.
4.1 Decision of Stress Level by physiological index

Two physiological indices, the ratio between the power of Low Frequency and High Frequency bands of heart rate variability (LF/HF) [3,17] and skin conductance response (SCR) [14,25] as sweat rate, measures the stress level of the passenger.

LF/HF shows activity of the autonomic nervous system. Low Frequency (LF) is a band of heart rate variability in power spectrum range between 0.04 and 0.15 Hz and High Frequency (HF) is a band between 0.15 and 0.40 Hz. LF/HF has been one of the most widely used physiological index [1,6,23]. Functions of both sympathetic nerve and parasympathetic nerve affect LF. A function of parasympathetic nerve mainly affects HF. When humankind feel mental stress, sympathetic nerve is activated [2,10], therefore LF increases and HF decrease [17]. As shown in Figure 6, a mean of LF/HF is calculated in each section divided into sub-sections which inflict stress or not. When a mean of the section which inflicted a stress is higher than the other sections where a stress is not inflicted, the stress level is high. LF/HF increases especially for continual stress, that’s why we inflict mental stress to participants for 10 seconds.

SCR shows the rate of sweat that occurs because of the sympathetic nerve activity. As shown in Figure 6, when the value remains unchanged or declines, the stress level is low. On the other hand, a large rise in SCR means high stress level. SCR tends to react in the case of feeling strong anxiety.

4.2 Experiment Environment

As shown in Figure 7, a narrow straight course employed as the experiment environment inflicts stress to the passenger, build by using low blocks. The course is 15.0 meters in length and 2.0 meters in width, wider than the vehicle width by 0.3 meters. It is impossible for the passenger to visually recognize the low blocks close to the wheels because the blocks are located out of the passenger’s field of view. Moreover, a difficulty to comprehend the travelling direction of the vehicle causes that the passenger fears running onto the low blocks. Our proposed MR system visualizes the out of the passenger’s field of view with wheel trajectories, enabling the passenger to visually recognize the positional relationship between obstacles in form of blocks and the car wheels. Therefore, it is expected to reduce the anxiety of the passenger. Figure 8 shows the environment of a passenger.

4.3 Components of System

Our proposed MR system in the vehicle and the physiological index measurement system are composed by the following equipment. A laptop PC (Lenovo: ThinkPad E420) with Intel Core i7 2.80 GHz CPU and 8.00 GB RAM generated the seeing-through image. The webcam (Logitech: c270) with 1280 pixels x720 pixels resolution and 60 degree of horizontal angle of view is attached to the front of the vehicle and captures the road surface out of the passenger’s field of view. A projector (CASIO: XJ-A256) with 1280 pixels x 800 pixels resolution and 3000 lumens brightness is suspended from the ceiling, which shows the see-through image on the dashboard. Moreover, retro-reflective material is put on the screen that reflects light back to its source. This screen enables the passenger to clearly observe the projected image even under sunshine in the outdoor environment when the viewpoint of the passenger is close to the projector lens as shown in Figure 8. An android phone which has an accelerometer measured steering wheel angles. The measured values are transmitted via Bluetooth to the laptop PC to generate CG model of the trajectories.
The participant was equipped with an electrode (POLAR: Electrode Soft Strap) for electrocardiograph and sweat sensor (eSense: Skin Response) that measured LF/HF and SCR in 10 Hz.

### 4.4 Experimental Procedure

A participant sat on the passenger seat of the vehicle driven by the experimenter, putting on sensors for measuring LF/HF and SCR. Before the experiments, all participants are given an explanation that the experimental vehicle driven by the experimenter is assumed as an autonomous vehicle. As shown in Figure 7, the experimental vehicle turned right towards a starting point of the narrow straight course at 5 kilometers per hour and passed the course as it was. The participants are instructed to look down until the vehicle arrives at the starting point and they are also instructed to keep their eye to the front through the narrow straight course. This instruct adjusts the timing that the participants start to feel anxiety by recognizing the narrow straight course. This trial was carried out four times. Two trials employed the MR system and the others are carried out without it. Considering the order effect, the participants are divided into two groups. The participants of one group do the experiment alternately in the order of the trial with MR, without MR. The order of another groups is without MR, with MR alternately.

### 4.5 Results

This section shows results of 8 participants, comparing the physiological index in both the case of applying MR system and without it in the narrow straight course. Figure 9 shows means and variances of LF/HF measured in the two trials with MR system and the two trials without it. Note that, the means and variances of LF/HF are calculated from standardized value. Moreover, Figure 10 shows results of SCR about 2 participants. The left figure in Figure 10 is a result of one participant whose SCR seems to have a relationship with the narrow straight course. Whereas, the right figure in Figure 10 is a result of another participant whose SCR seems to have no relationship with it.

As shown in Figure 9, the results of 5 participants showed that the mean of LF/HF in the trials with MR system was smaller than the value of them without the MR system. In contrast, the results of two other participants showed that the value in the trials with MR system was larger than without it. These results of the seven participants had a significant difference below 0.05 significance level by paired t-test whose factor was presence or absence of MR system. Whereas, the result of the other participant had no significant difference by same paired t-test. LF/HF reacts when the participant feel continual mental stress. Taking this into account, MR system reduced such stress in five participants among eight in total.

SCR of one participant among eight reacted remarkably, increased before and after entrance of the narrow straight course. SCR shows remarkable reaction when the participant feels a strong anxiety. Therefore, this participant seemed to feel a strong anxiety entering the narrow course. However, MR system seemed to have no effect in reducing such mental stress for this case. By contrast, seven participants among eight in total seemed not to feel a strong anxiety to run through the narrow straight course. For example, the right figure of Figure 10 shows the result of one participant among the seven where the value transition is flat. Thus, the participants almost never fear significantly in this experimental situation.

![Figure 9: The difference in means of LF/HF depending on the presence or absence of the MR system.](image9.png)

![Participant H](image10_participant_H.png)

![Participant E](image10_participant_E.png)

![Figure 10: In the left figure, only participant “H” shows significant reaction in SCR. In the right figure, the others participants, for example participant “E”, shows no significant reaction.](image10.png)
4.6 Discussions

Tending to decrease means of LF/HF, the MR system seemed to suppress an increase in activation of sympathetic nerve. Two participants’ means of LF/HF in the case of the trial with MR are higher than without MR, which seems that they does not feel anxiety in such course but feel stress with the see-through image on the dashboard. Moreover, regardless of presence or absence of the MR system, there was no significant increase in SCR. therefore the participants seemed not to feel strong anxiety when the experimental vehicle entered the narrow course and was passing through it. Low speed of the experimental vehicle seemed to make it difficult to inflict strong anxiety on the participants. Five participants who tended to decrease means of LF/HF by employing the MR system had no significant reaction in SCR. Thus the reduced mental stress was continual and weak anxiety.

5 Conclusion

In order to improve comfort of passengers on autonomous vehicles, in this research, we tried to reduce mental stress of the passenger on the autonomous vehicle by applying our proposed MR system. This paper introduced our developed MR system which sees-through the dashboard using projection MR technique and overlays the wheel trajectories, corresponding to the steering angle, on the see-through image. This system enabled to remove visual factor of anxiety such as invisible road condition and auto driving control out of the passenger’s field of view.

We employed road environment to inflict anxiety on the passenger on the autonomous vehicle, investigated change in the stress level regarding presence or absence of MR system. Specifically, the narrow course is comprised by low blocks, inflicting anxiety on the passenger against running onto the low blocks out of the passenger’s field of view. Our proposed MR system makes it possible to visualize the road condition and vehicle route out of the passenger’s field of view. Therefore, it is expected to reduce passenger’s anxiety. In the experiment, we observed change of stress in real time by introducing methods to measure physiological indices such as LF/HF and SCR. LF/HF is extracted from heart rate variability and reacts to continuous stress. SCR indicates sweat rate which reacts strong stress.

The experimental results showed that the MR system decrease means of LF/HF in five participants among eight in total. On the other hand, SCR showed no significant reaction in both applying MR system and not. As a result, MR system tends to reduce weak and continuous anxiety which continued for ten seconds in narrow road.

In the future, we use real autonomous vehicle as the experimental vehicle. Moreover, to clarify the effectiveness of the MR system further studies by comparing a lot of results with experimental vehicle. Moreover, to clarify the effectiveness of the MR system and not. As a result, MR system tends to reduce weak anxiety on the autonomous vehicle, investigated change in the stress level regarding presence or absence of MR system. Specifically, the narrow course is comprised by low blocks, inflicting anxiety on the passenger against running onto the low blocks out of the passenger’s field of view. Therefore, it is expected to reduce passenger’s anxiety. In the experiment, we observed change of stress in real time by introducing methods to measure physiological indices such as LF/HF and SCR. LF/HF is extracted from heart rate variability and reacts to continuous stress. SCR indicates sweat rate which reacts strong stress.

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References


