Automobile Interior Design Support Using Projection Mapping onto Full-Scale Physical Mockup and Driving Simulator

Ryotaro Yoshida[1], **Toshihiro Hara**[2], **Yusaku Takeda**[2], **Kenji Murase**[2],
Daisuke Iwai[1], **Kosuke Sato**[1]

r.yoshida@sens.sys.es.osaka-u.ac.jp
[1]Osaka University, 1-3 Machikaneyama-cho, Toyonaka-shi, Osaka, 560-8531, Japan
[2]Mazda Motor Corporation, 3-1 Shinchi, Fuchu-cho, Aki-gun, Hiroshima, 730-8670, Japan
Keywords: mixed reality, projection mapping, driving simulator, vehicle design tool

ABSTRACT

We developed a system that projects 3-dimensional (3D) models of car interior using projectors to promote more efficient and flexible designing. It allows designers to evaluate the interior while feeling as if they are driving a car. This design environment is achieved by reproducing the lighting environment with projection mapping.

1 Introduction

When designing automobile interiors, 3D interior models designed with computer-aided design (CAD) software are molded into full-scale models using clay, and the designs are usually evaluated using the clay models. Evaluation and modification of the clay model are repeated, and changes to the clay model are reflected in the 3D interior model using a 3D scanner. This design method allows us to evaluate the interior by looking at a real scale model, but the creation and modification of the clay model are time-consuming and expensive. Another problem is that it is difficult to examine the texture samples on the surface of interiors by applying them to the entire clay model.

Conventional design support systems solved these problems by visualizing the 3D models on head-mounted displays (HMDs) instead of producing the clay models [1][2]. However, the problem of the HMD-based mixed reality is that it cannot provide perceptual cues that are important for interior design [3]. HMD makes the user's depth perception incorrect [4] and has the limitation of narrowing the field of view. So, we decided to use projection mapping [5], which has less of these effects and does not require the user to wear displays, to visualize 3D models.

Fig. 1 shows the overview of this system. In this system, the dashboard and A-pillars are design targets as the main interiors. The interior with the desired shape and surface texture can be projected by the projector.

Furthermore, since the surface texture of the interior surface can be freely changed by changing the lighting calculation of the 3D model, it can represent the lighting environment while driving. This means that the evaluation of interiors can be based on the impressions that the driver feels as if driving. The goal of this research is to develop a system that can reproduce the lighting environment on the interior surface by projection mapping synchronized with the driving simulator and evaluate the interior as if driving.

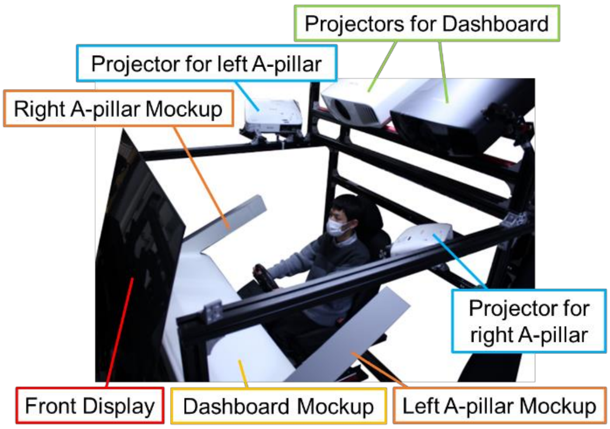

Fig. 1 Projection mapping system overview

We introduce a motion platform in the driving simulator to present motion cues, which is important for reproducing the driving sensation of a real car [6]. In addition, the motion platform can reduce VR sickness by presenting vibrations and tilts synchronized with the driving simulator's motion [7].

Using a motion platform makes the user's eye position change significantly. Therefore, it is necessary to re-render the interior model surface to project it stereoscopically from the user at all times. However, the effects on the perception of the projected interior and the user's VR sickness are not yet clarified when the projected contents change according to the user's eye position. The purpose of this research is to investigate the appropriate projection conditions for presenting car interiors by projection mapping in combination with a driving simulator using a motion platform.

2 Proposed System

2.1 System Configuration

Our system uses a total of four projectors to project the interiors as shown in Fig. 1. The projectors for the dashboard are VPL-VW245 made by SONY, and those for the A-pillars are EB-FH52 made by EPSON. We use mock-up shaped like a planar dashboard and planar A-pillars as projection targets. In addition, a flat panel display is placed forward to show the car window image. It is a 65-inch OLED monitor made by LG.

The interior models are placed in a virtual space and projected using 2-pass rendering [8] for perspectively correct projection mapping. The user's eye position is tracked in real-time by Optitrack Motive. The car window image is also presented as seen by the user by 2-pass rendering. We use Unity as a 3D computer graphics(CG) engine for 2-pass rendering.

2.2 Rendering Implementation

In our system, the surface texture of the interiors can be modulated by changing the calculation of the lighting model. The luminance value L of a vertex on the model surface is calculated by the following equation.

$$L = (1-s)D + sS + \big((1-s)f + s\big)I(r) \tag{1}$$

$$D = \left(\frac{\vec{N}\cdot\vec{L}+1}{2}\right)^{a} \tag{2}$$

$$S = 2\big(\max(0, \vec{R}\cdot\vec{V})\big)^{29(1-r)} \tag{3}$$

$$f = F_0 + (1-F_0)\big(1-\vec{V}\cdot\vec{N}\big)^{5} \tag{4}$$

where $\vec{N}$ is the normal vector at the vertex, $\vec{L}$ is the direction vector of the virtual light, $\vec{R}$ is the reflection vector of the virtual light, and $\vec{V}$ is the direction vector of the line of sight; D, S and $I(r)$ represent diffuse, specular, and indirect reflection. We prepared physical parameters that represent the surface specular reflectance s, the surface roughness rate r, and the Fresnel reflection coefficient F_0. These parameters can be used to modulate the surface texture, and they take 0 to 1. The parameter a represents the intensity of the ambient light.

In D, the Lambert diffuse reflection model is generally used, but we formulated the above equation instead for more natural lighting. The fact that the lighting by this equation looks natural was confirmed by preliminary user studies. S is based on Phong's specular reflection model. In $I(r)$, the color of indirectly reflected light from the surrounding virtual city is calculated by the cube mapping method, and the surface roughness parameter r is used to blur the indirectly reflected image. f represents Fresnel reflectance by Schlick's approximate equation.

2.3 Lighting Reproduction while Driving

To reproduce the lighting environment while driving, the interior model is driven in a virtual city as shown in Fig. 2. By driving in the virtual city, the virtual light direction changes, and the lighting on the interior model surface changes by the equation shown in section 2.2. In addition, shadows of city objects (buildings, trees, etc.) are mapped on the interior model, which can reproduce the changes in shadows while driving (Fig. 3).

Fig. 2 The interior model for driving in virtual city

Fig.3 City object's shadow on the interior model

2.4 Driving Simulator with Motion Platform

The interior model is driven in a virtual city according to the inputs from the steering controller and pedal controller as shown in Fig. 4. These controllers are G29 made by Logcool, which we can adjust its reaction force and apply vibration to it. The motion of the vehicle is calculated using the dynamic bicycle model. It means that the vehicle motion is calculated by successively solving the equations of motion based on the longitudinal and lateral forces generated by the tires. The longitudinal force is calculated by a linear approximation of the torque curve based on the engine rpm, and the lateral force is calculated by a Magic Formula model [9] based on the calculated slip angle.

In order to provide a driving experience closer to that

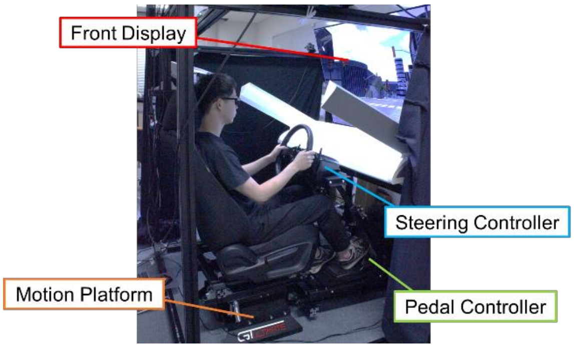

Fig. 4 Driving simulator system overview

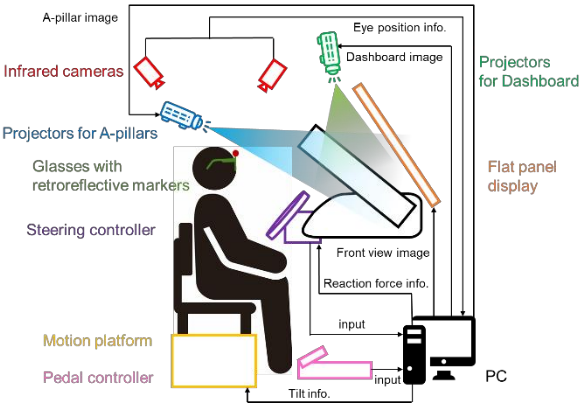

Fig. 5 System flow diagram

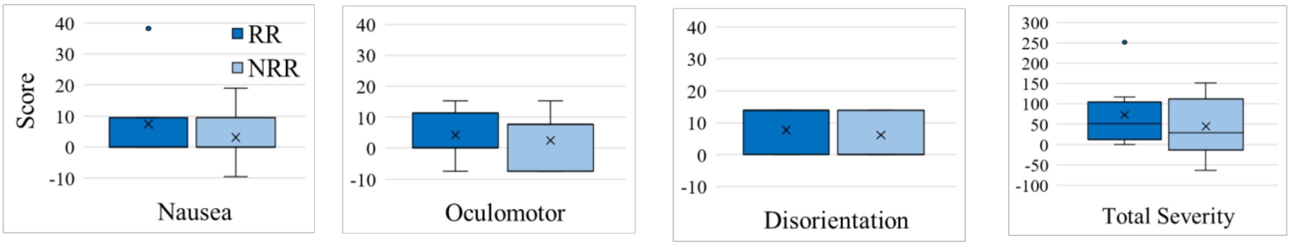

Fig. 6 The result of SSQ

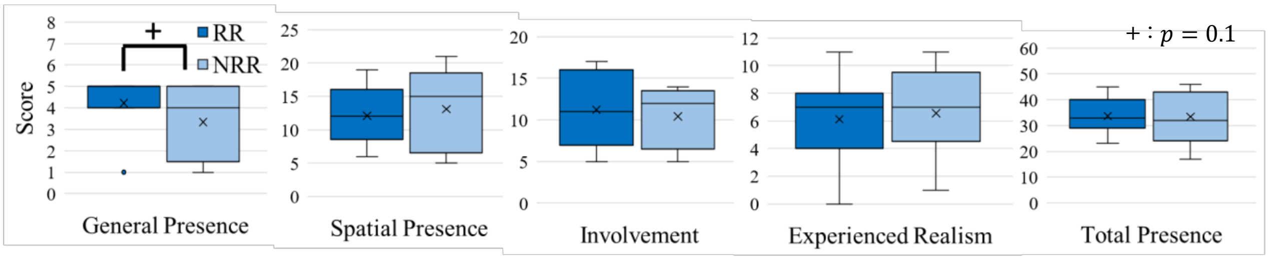

Fig. 7 The result of IPQ

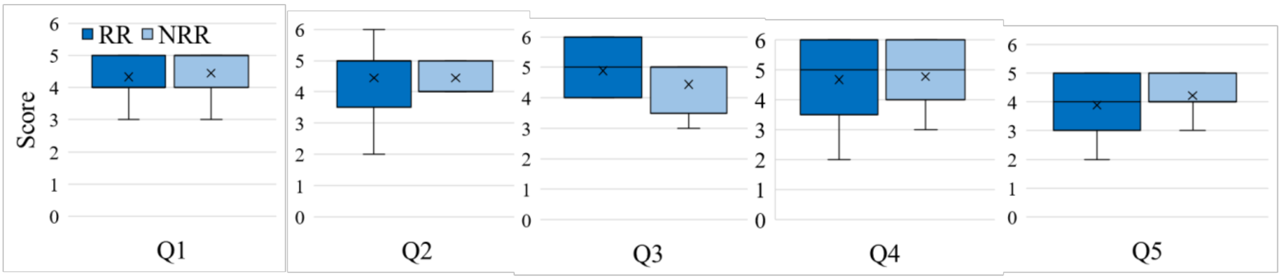

Fig. 8 The result of questionnaires

of a real car, the vehicle motion is fed back to the user. The self-aligning torque is calculated from the Magic Formula model, and the reaction force is presented from the steering controller. The longitudinal and lateral G caused by the vehicle motion are also presented by the motion platform. The motion platform's tilt is proportional to the acceleration calculated from the vehicle motion equations. We use Motion Platform V3 made by Next Level Racing, which allows roll pitch tilt. Fig. 5 shows the overall system flow diagram.

3 Experiment

3.1 Purpose

The purpose of this subject experiment is to investigate whether the re-rendering of the interior model according to the user's eye position affects the presence of the interior.

3.2 Method

Subjects drove freely in a virtual city for 10 minutes in a driving simulator and performed a task to find some color boxes placed in the virtual city. They were instructed in advance to observe the interiors at times. After the driving task, they answered questionnaires regarding the presence of the system, VR sickness, and the interior model rendering. We used the SSQ test [10] for VR sickness and the IPQ test [11] for the presence. We use the following questionnaire with a 7-point Likert scale for investigating the impression of the interior model.

Q1 The interiors looked stereoscopically as if they were real.
Q2 The surface texture of the interiors was natural.
Q3 Lighting on the interiors was natural while driving.
Q4 Shadows on the interiors were natural while driving.
Q5 I felt uncomfortable with the interiors while driving.

The subject wears the glasses with markers, and his eye position is tracked. The experiment was conducted under two conditions: the RR (Real-time Re-render) condition, in which stereoscopic projections were rendered continuously according to the tracked position, and the NRR (Not Real-time Re-render) condition, in which stereoscopic projections were rendered with the virtual viewpoint position fixed at the eye position in the basic posture. To avoid the order effect, the condition to be performed first differs depending on the subject. The subjects conducted the two conditions on separate days. The physical parameters of the lighting described in section 2.2 were set to $m = 0.1$, $r = 0.3$ and $F_0 = 0.05$.

3.3 Results & Discussion

The results of the SSQ are shown in Fig. 6. In the SSQ, the higher the score, the greater the VR sickness. t-test showed no significant difference between the RR and NRR conditions in any index of the SSQ. However, as a result of the t-test between the first and second conditions performed by each subject, significantly higher scores were observed in the first condition for oculomotor and total severity (significance level $p = 0.05$). This means that the order effect is significant regardless of the condition. Most of the subjects in this experiment had a poor driving experience and drive less than a few times a year. Then, they were often nervous about driving during the first experiment. Therefore, we think that they spent more effort on the driving task the first time, and their scores were higher than the second time when they were a little more used to it. In fact, the subjects who drive less frequently tended to have higher SSQ scores the first time.

Fig. 7 shows the results of the IPQ. In the IPQ, the higher the score, the greater the sense of the presence of the system. In the general presence, the t-test showed that there was a tendency for there to be a significant difference between the conditions (significance level $p = 0.1$), but overall, the results showed that it was not possible to say that there was a difference in the presence.

Fig. 8 shows the results of the questionnaire. In the questionnaire, the higher the score, the more natural the interiors looked. In the t-test, no significant difference was found between the conditions.

We expected that VR sickness would be reduced by rendering according to the head position, but we could not eliminate the influence of driving habituation. From the results of the questionnaire, it was found that the impression of the naturalness of the interiors did not change significantly regardless of re-rendering while driving because the subjects did not stare at the interior while driving.

In the comments from the subjects, the following points were raised for improvement: the lack of window frames in the image of the front monitor was unrealistic, the lack of images of outside on both sides of the A-pillar was unrealistic, the shadows on the interiors were too dark, and the silence while driving was unrealistic. We would like to improve the system based on these points and conduct the experiment again with an additional phase to get used to the driving simulator.

4 Conclusion

In this research, we developed an interior design support system using projection mapping and a driving simulator for efficient design and evaluation while feeling as if the evaluator is driving. We experimented to investigate whether the interior projection should consider the changes in eye position caused by the motion platform to improve the quality of the driving experience. As a result, we found that the general presence tended to improve when the projection was based on the real-time tracked eye position. However, the order effect caused by simulator habituation seemed to be significant. We would like to conduct the additional experiment by improving the experimental setup and conditions. We will also experiment to investigate whether it is better to present the interior projection by vibrating or tilting it in synchronization with the vibration and tilt of the motion platform.

References

[1] HaptX inc., “Nissan Design collaborates with HaptX to bring realistic touch to vehicle design”, https://haptx.com/nissan-collaboration/, 2021/7/21 access.

[2] Ford Media Center, “Ford Collaboration with Gravity Sketch Introduces Co-creation”, https://media.ford.com/content/fordmedia/fna/us/en/news/2019/05/06/ford-collaboration-gravity-ketch-co-creation.html, 2021/7/12 access.

[3] R. S. Renner, B. M. Velichkovsky and J. R. Helmert, “The Perception of Egocentric Distances In Virtual Environments – A Review”, ACM Computing Surveys, Vol.46, Issue 2, Article No.23, pp1-40 (2013)

[4] T. Sasaoka, M. Machizawa, Y. Okamoto, K. Iwase, T. Yoshida, N. ichida, A. Kishi, M. Chiba, K. Nishikawa, S. Yamawaki and T. Nouzawa, “The Shape of a Vehicle Windshield Affects Reaction Time and Brain Activity During a Target Detection Task”, Neuroscience, 14:183 (2020)

[5] T. Takezawa, D.Iwai, K. Sato, T. Hara, Y. Takeda, K. Murase, “Material Surface Reproduction and Perceptual Deformation with Projection Mapping for Car Interior Design”, IEEE VR (2019)

[6] T. Chapron and J. Colinot, “The new PSA Peugeot-Citoroën Advanced Driving Simulator Overall design and motion cue algorithm”, Driving Simulator Conference (2007)

[7] D. Yeo, G. Kim and S. Kim, “Toward Immersive Self-Driving Simulators: Reports from a User Study across Six Platforms”, CHI, pp.1-12 (2020)

[8] R. Raskar, G. Welch, M. Cutts, A. Lake, L. Stesin and H. Fuchs, “The Office of the Future: A Unified Approach to Image-Based Modeling and Spatially Immersive Displays”, SIGGRAPH, pp.179-188 (1998)

[9] H. B. Pacejka and E. Bakker, “The Magic Formula Tyre Model”, Vehicle System Dynamics, Vol.21, pp.1-18 (1992)

[10] R. S. Kennedy, N. E. Lane, K. S. Berbaum and M. G. Lilienthal, “Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness", The International Journal of Aviation Psychology, Vol. 3, pp.203-220 (1993)

[11] igroup presence questionnaire (IPQ), http://www.igroup.org/pq/ipq/index.php