Material Surface Reproduction and Perceptual Deformation with Projection Mapping for Car Interior Design

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Abstract

Car interior design, such as dashboard, broadly consists of two parts. One is shape design, where the processes of 2D drawing, 3D modeling and evaluation with full-scale mockups are iterated, which takes a massive amount of time and cost. The other is material design such as surface property tuning, where designers compare material samples. This way, however, has a limitation on the number of material samples to compare and does not allow applying of the samples of interest to the whole mockups in early phases. In this paper, we apply projection mapping technique to boost the design process by altering the appearance of the surface of projected objects and enabling various shape and material evaluations in early phases. Our proposed system uses multiple projectors, one of which is 4K projector to reproduce fine leather surface. Utilizing physiological and psychological depth cues, the system allows the user to perceive the projected mockup as deformed. Psychological experiments confirm that users perceive deformation and have controlled impression on leather reproduced with certain parameters. In addition, we discuss the usability of the proposed system as a support system of car interior design.

Index Terms: Human-centered computing—Interaction design—Interaction design process and methods—Scenario-based design; Computing methodologies—Computer graphics—graphics systems and interfaces—Perception

1 Introduction

Car interior design broadly consists of two parts. One is shape design, which is the process of 2D drawing, 3D modeling with Computer-aided design (CAD), building full-scale physical mockups and evaluating them iterates many times until the final shape design is decided, which takes a massive amount of time and cost. This process of sensibility evaluation with full-scale mockups is necessary because designers and engineers can hardly tell the precise effects of interior shape to user experience until they actually embody the designs. For instance, it is said that physical parameters of dashboard such as height or curvature somehow affect users' sense of safety and spaciousness. The other is material design, where designers compare leather material samples with each other to decide which leather material to be used. This method, however, does not allow them to apply materials of interest to the whole mockups in early phases of product design due to the physical limitations of the material samples. Material design is often ill-defined because the relationship between users' subjective impressions toward materials of interest and the materials' physical properties such as color and fine depth of leather texture is unclear. In both parts, decision making in early phases is important [2], but it is hard because of the situations explained above.

In order to tackle the problems in industrial design mentioned above, a number of CAD systems have been investigated, and different methods and used facilities have different constrains that can be crucial to industrial design. Head-mounted Display (HMD) can visualize product's concept in early phases by showing the user real objects and virtual objects in one scene [14] or giving the user immersive experience in virtual space. However, systems with HMD require the user to wear devices that are often too heavy for long time use. As the displays are located near to the user's eyes, AR systems with HMD cause great differences in focal length between real objects and virtual objects. VR applications with HMD as well often cause VR sickness that comes from sense of cramped or vergence-accommodation conflict (VA conflict). Due to the constraint of display size, systems with HMD suffer from a narrow field of view (FOV). These physiological incorrespondences or differences from actual use scenarios cannot be ignored in sensitivity evaluation. Another method is Immersive Projection Display (IPD) [3][6], which is valid for simulating virtual environment with a wide FOV. Since screens surface are flat, IPD often induces VA conflict when making the user to perceive virtual objects with very different surface from that of the screens.

We employed projection mapping technique which alters the appearance of real objects by superimposing virtual images [21]. By projecting depth cues such as shadow or occlusion, the users perceive physical deformation of projected objects without any physical changes. Perceptual deformation can be improved by stereoscopic projection [1]. Unlike HMD techniques, projection mapping does not require the user to wear any devices for monoscopic projection and has a wide FOV. Moreover, projection mapping causes little VA conflict for subtle surface deformation because the differences between virtual object surface and display surface is smaller than that of systems with HMD or IPD. Therefore, it is possible to evaluate various shapes and materials by tuning the parameters such as curvature for shape design and glossiness for material design in environment in which customers actually use products.

We propose a novel projection mapping system to improve the process of car interior design which allows on-the-fly perceptual deformation and surface material manipulation with multiple projectors. The preliminary experiment shows the usability of projection mapping technique and confirms that superimposing shadow and occlusion can enhance perceived deformation. However, it is insufficient to reproduce fine leather texture, which plays an important role in car interior design. In this paper, we have added functionalities of high-resolution textures projection, head tracking and stereoscopic projection by introducing IR-camera based tracking system and multiple projectors (Figure 1). We conducted psychological experiments to validate the effectiveness of the proposed system. In addition, we discuss tradeoff of material surface reproduction and

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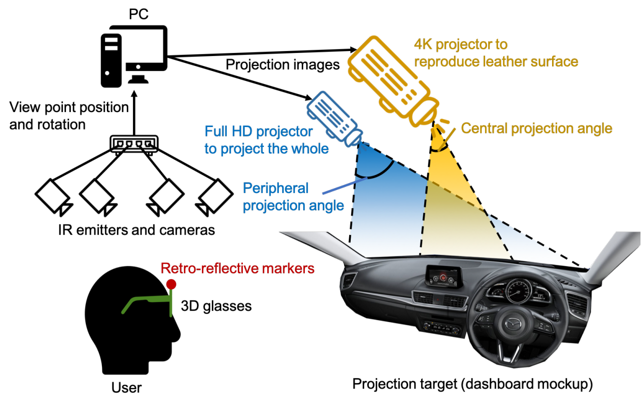


Figure 1: Outline of the proposed system.

perceptual deformation and guideline to reproduce material surface with desired impression in projection mapping.

The contribution of this paper is to determine a guideline of application of projection mapping for car interior design as follows.

- Stereoscopic projection affects material perception and hence monoscopic projection is more suitable to reproduce material surface with intended impression.
- A single parameter designed based on roughness can manipulate glossiness, roughness, specularity and saliency with our proposed system.
- In case of leather texture applied to virtual object, stereoscopic projection is not always necessary for perceptual deformation.

2 Related Work

Industrial design applications of projection mapping have been developed. Porter et al. [18][17] developed projection mapping methods for rapid prototyping to demonstrate their usability through subjective experiments. Their methods enables the user to rearrange the layout of common components of a car dashboard and to interact with virtual objects projected onto it with their finger tracked. Marner et al. [11] gave examples of SAR application for arrangement of buttons on machineries so designers can evaluate optimum arrangement for usability. Menk et al. [12][13] developed a technique for truthful color reproduction and the main applications include color evaluation in product design. These studies, however, assume that the shape of the object is defined in advanced and manipulates only the surface appearance. HYPERREAL by Hisada et al. [8] simultaneously utilizes stereoscopic projection for shape manipulation and adds specular reflection to simulate metallic glossiness of car exterior, but it does not deal with fine leather texture, which is difficult to reproduce only with specular reflection. Besides, it remains in usability of deformation and does not investigate how projected result affects human perception and impression, which is important in product design. In this paper, we not only apply projection mapping to product design, but also conduct psychological experiments to investigate how the technique affect on human perception and impression.

The relationship between visual stimulus and material perception itself has been also investigated to boost material design process. Many studies [7][4] have investigated the mechanism of how human perceive and judge material from visual stimulus and found distinct and systematical relationship related to material class membership, but they do not mention the effect material perceptions give to subjective impression. Because they conducted the experiments, where materials of interest are applied to designated shaped model displayed on 2D screen, it is hardly possible to take into account an interaction of material and shape on impression. Our proposed system with projection mapping technique, which alters the surface appearance while holding the sense of existence, can take it into account.

With the demand of material design support, AR techniques have been also researched to apply to the field of visual perception. SoftAR by Punpongsanon et al. [19] visually manipulates the sense of softness utilizing pseudo-haptics caused by projection corresponding user's finger movement. Although this method works to manipulate perceived softness of deformable objects, leather materials used for car interior in general are not soft enough for this method to be used. Okutani et al. [15] investigated appropriate surface properties for observers to have stereoscopic capture (perceptual deformation) and showed that projection target materials with high specular reflection and salient surface degrade stereoscopic capture. As the study demonstrates, projection of only shade and shadow is not suitable for some materials, which is crucial in applying projection mapping to designing of product with such materials. In addition, in a scenario of product design, this method does not allow parametric material evaluation as the evaluation is limited by the number of available material samples. Our proposed system reproduces parameterized fine leather materials of high quality for computer graphics based on fine geometric structure of actual leather material. Since the parameterized material can be applied to the whole model in virtual model, our system does not cause separation of projection target surface and perceptual shape.

There is a need to investigate material perception and impression reproduced by AR because the mechanism of visual perception is unclear and visual stimulus might lead to a different impression and recognition when applied to AR. It is confirmed that stereoscopic AR displays by dot patterns increases transparency by Otsuki et al. [16] or Ghasemi et al. [5]. Kawabe et al. [9] show that the brain can perceptually infer the presence of invisible transparent liquids by analyzing the spatiotemporal structure of dynamic image deformation. As these research show, there are a lot to be investigated about visual perception induced by AR and our research focuses on that in car interior design.

3 Proposed System

3.1 Overview

We propose a novel projection mapping system with two projectors and head tracking system. The system uses two projectors to realize both reproduction of fine leather surface and deformation of the whole dashboard simultaneously. One of the projector is a 4K projector to project the central part of the car dashboard mainly to reproduce leather surface and the other is a full HD projector for the peripheral area of the dashboard which the 4K projector does not cover. We used a full HD projector for the peripheral area because the peripheral area is often observed in peripheral vision and low resolution projection is sufficient. Because the two-pass rendering method explained in Subsection 3.2 requires the viewer's head's position and rotation, we mounted 3D tracking system with infrared sensors and cameras (Figure 2).

3.2 Image Generation

The system employs two-pass rendering method [20] for the user to perceive undistorted projected images projected on non-planer surface (Figure 3). First, we assume that the geometric surface of projection target and the relative position and rotation of the user are obtained. Second, we construct a virtual scene consisting of two virtual surface; one is the surface of 3D model of virtual objects (VS), and the other is the surface of 3D model of the projection target (RS). Third, as the first pass, we implement perspective off-screen rendering of VS from the user's view point and project the

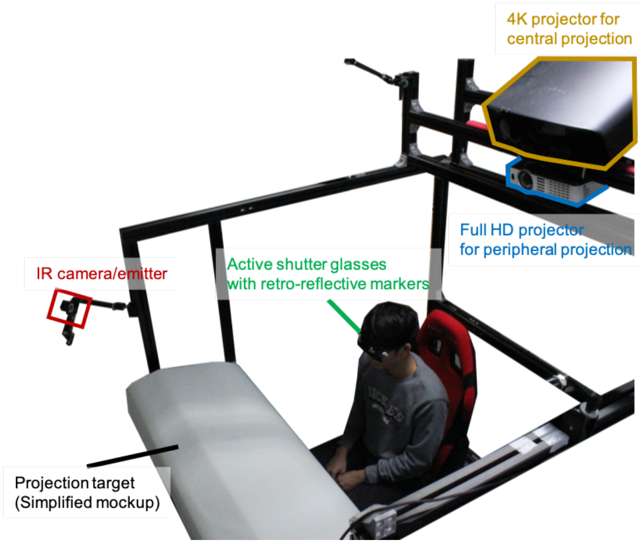


Figure 2: The created proposed system.

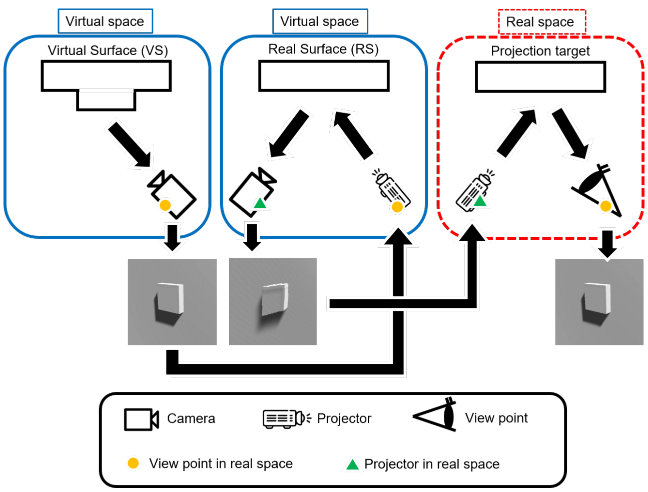


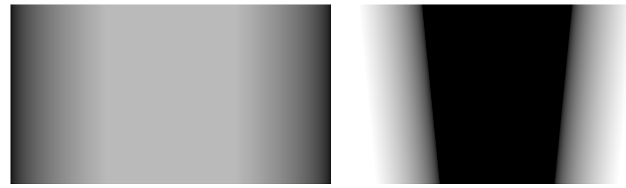
Figure 3: Two-pass rendering pipeline.

obtained image onto RS, which is a two dimensional representation of VS on RS. Finally, as the second pass, we implement perspective rendering of RS from the projector's position and the rendered images are projected from projectors in a real space. For stereoscopic projection, we perform this process twice for each of the user's eyes. This whole process is performed for each type of the projectors.

After rendering images, we add gradation mask to rendered images for overlapped area of 4K projector and full HD projector for the following two reasons. One reasons is to reproduce fine leather texture in 4K projector's projection area, where full HD projector's image pixels must be black to prevent each pixels from being visible and to keep high pixel density in the area. The other reason is because the boundaries between the two projectors are too salient due to the differences in color space and brightness of the projectors and the error of projector calibration. We manually adjusted color space and brightness and generated the masks (Figure 4).

3.3 Apparatus

The proposed system uses a 4K projector (VPL-VW245, SONY) and a full HD projector (TH671ST, BenQ) for the whole projec-



(a) For 4K projector images. (b) For full HD projector images.

Figure 4: The mask images used in the proposed system.

tion, both of which are 30fps. To realize stereoscopic projection the user wears active shutter glasses (TDG-BT500A, SONY) to which we attached retro-reflective markers for tracking. We rendered on a PC (OS: Windows 10 Pro, CPU: Intel Core i7-6800K, RAM: 64GB, GPU: NVIDIA Quadro M2000) with 3DCG software Unity (2018.2.15f). For the head tracking, we used 4 motion capture camera with infrared emitters (Flex 3, OptiTrack) along with a competitive software (Motive, OptiTrack). The projection target is a dashboard mockup whose cross section is simplified with nonlinear line to the original dashboard's cross section (Axela, Mazda). The dashboard mockup (140 × 50 × 18 × [mm]) is created by extruding the cross section and the surface is covered with white matte paper, which is suitable for being projected.

Projectors have to be calibrated to superpose images onto the corresponding positions in the real space. For projector calibration, in the proposed system we implemented a function of calibrateCamera in OpenCV 3 with correspondence points of 3D coordinates in virtual space and 2D coordinates in the projector images.

4 Usability Evaluation for Shape Design

We conducted an experiment to evaluate the basic usability of the proposed system for shape design by measuring maximum visual deformation amount that the user perceives as real deformation, which is denoted as maximum DPD (degree of perceived deformation) in this paper. This experiment is approved by the ethics committee of Graduate School of Engineering Science, Osaka University and the subjects gave informed consent.

4.1 Method

We experimented the proposed system in a dark room. Subjects sit on the driver seat and observe the dashboard projected (Figure 5). In the preliminary experiment, the system used only a full HD projector and take shadow and perspective into account as depth cues. This experiment used only a full HD projector as well as the preliminary experiment to evaluate the influence of the other depth cues that the proposed system uses but were not used in the preliminary experiment, such as motion parallax, binocular disparity and texture.

4.2 Evaluation

We used the method of adjustment to find maximum DPDs with the keyboard. Subjects are asked "to find the maximum deformation amount at which you perceive the projected image as real deformation." Subjects adjust deformation amounts using the arrow keys of the keyboard on their laps. Subjects are also made to look at a certain point according to the condition. The trial is done in each conditions described below.

4.3 Conditions

The conditions of this experiment broadly consists of three parts, deformation way, projection way and gazing point.

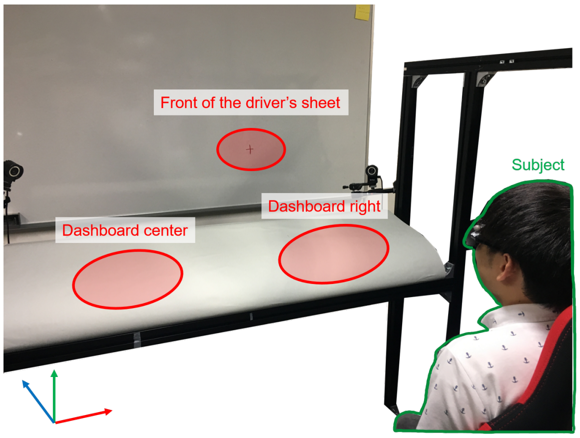
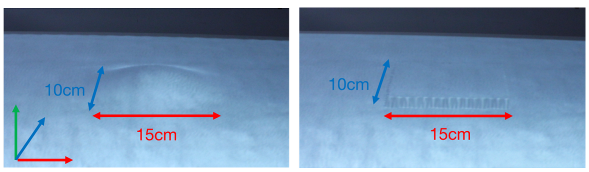


Figure 5: Physical configuration of the experiment of usability evaluation for shape design (right-hand drive).



(a) Gaussian deformation. (b) Cubic deformation.

Figure 6: Local deformation.

4.3.1 Deformation

We tested local deformation and global deformation. In local deformation, we deform only a part of the dashboard. Local deformation has two types; one is cubic deformation and the other is Gaussian deformation (Figure 6). Local deformation appears either in dashboard center or dashboard right as seen in Figure 5. These two types of local deformation come from the result of the preliminary experiment that shaper edge induces better deformation perception. The horizontal size is both approximately 15 $\times$ 10 [cm]. Subjects adjust the height of deformations to find the maximum DPD.

In global deformation, on the other hand, we deform the whole dashboard by approximating the sectional surface with Bezier curve (Figure 7). Subjects adjust the height of the control point (Figure 7) to find the maximum DPD.

4.3.2 Projection Way

We used two types of projection; monoscopic projection and stereoscopic projection. Monoscopic projection is a normal way of projection. Stereoscopic projection uses binocular disparity as a cue for human's spatial perception. Synchronized with active shutter 3D glasses that user wears, it gives disparity to the left and right eyes.

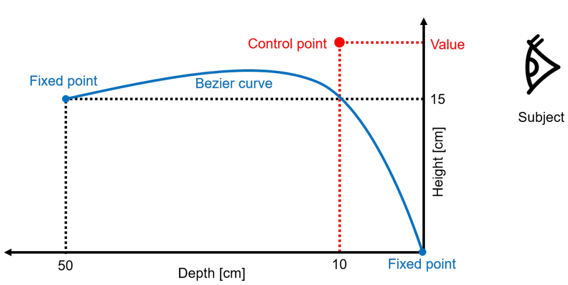
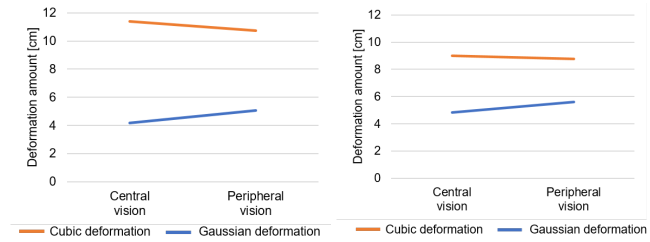


Figure 7: Global deformation.



(a) Monoscopic projection. (b) Stereoscopic projection.

Figure 8: Interaction between "deformation pattern" and "vision."

4.3.3 Gazing Point

To investigate the effect of central and peripheral vision, we fixed subjects' gazing point to three positions (dashboard center, dashboard right and front). Subjects are told to look at the designated position in each conditions.

For analysis, we set up a parameter vision (central vision and peripheral vision) combining deformation position and gazing point, i.e. central vision is when deformation position and gazing point are the same and peripheral vision is when deformation position and gazing point are not the same.

4.4 Subject

10 subjects participated in the experiment and their ages are between 22 and 25 (Mean = 23.1, SD = 1.04 [years]). 8 subjects were male and 2 subjects were female.

4.5 Result

The overall mean of maximum DPD in upward and downward local deformation are 7.44cm and -8.40cm respectively. For local deformation, three-way ANOVA with projection way, deformation pattern and vision confirmed an interaction in upward deformation between deformation pattern and vision ($F(1,9) = 6.94$, $p < 0.05$) as shown in Figure 8. There was no statistical difference for global deformation.

4.6 Discussion

ANOVA of local deformation confirms an interaction between "deformation pattern" and "vision." In cubic deformation, central vision results in higher value than peripheral vision, while in Gaussian deformation peripheral vision results higher value than central vision. However, as seen in Figure 8, there is no explicit interaction and we do not confirm clear relationship between them.

The overall mean of maximum DPD in upward and downward local deformation are 7.44cm and -8.40cm respectively, which is a huge improvement from the preliminary experiment, where maximum DPD was around 1cm. The main factor of the improvement is considered to be use of texture because all the changes from the preliminary experiment except texture were tested through ANOVA, which didn't confirm any main effects. Therefore, it is likely for texture to play an important role for perceptual deformation. Maximum DPD can be increased with well-designed texture based on the research by Kim et al. [10], where they investigated the visual cues to infer 3D structure and found that inference is better when the surface textured follows principal direction or is isotropic than when it follows a uniform direction or sinusoidally varies. In our experiment, the tested texture's direction is rather uniform and well-designed texture can improve maximum DPD.

5 Usability Evaluation for Material Design

The preliminary experiment showed that perceptual deformation actually occurs with the proposed system. Assuming that, we conducted another physiological experiment to investigate the system's basic capability of reproducing leather surface and its impression to clarify the relationship between the parameters we set up and subjective impression toward projected images. This experiment is approved by the ethics committee of Graduate School of Engineering Science, Osaka University and the subjects gave informed consent.

5.1 Method

The proposed system works in a dark room. Subject sit on the driver seat assuming right-hand drive and observe the dashboard projected (Figure 2). Subjects wear the active shutter glasses with retroreflective markers to track their view point and to realize stereoscopic projection.

5.2 Evaluation

While looking at the projected images, subjects answer the questionnaires about the overall impression of the dashboard and material surface. They answer with seven point Likert scale where -3 is "Disagree," and 3 is "Agree." The overall dashboard evaluation mostly consists of the intuitive and subjective impression including the material surface and the shape about the following items.

- Authenticity
- Harmony
- Simplicity

Material surface evaluation is about how subject find the projected surface ignoring the whole shape. Subject evaluate material surface of the center of the projected object, which only the 4K projector for reproduction of material surface projects images onto. The evaluation items are as follows;

- Glossiness
- Non-uniformness
- Specularity
- Saliency
- Color uniformness
- Translucency

These items are often used for material perception and car interior design [22]. Subjects also answer with either "Yes" or "No" whether they have stereopsis or not. They can see the questionnaire displayed on tablet by them whenever they want during the experiment.

5.3 Condition

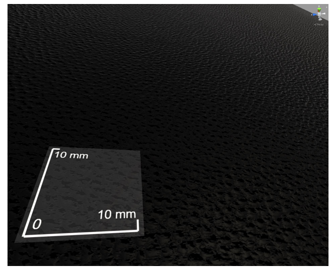
The conditions of this experiment broadly consists of three parts; projection way, material and shape of virtual object.

5.3.1 Projection Way

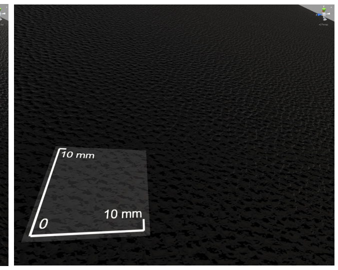
In order to investigate whether stereoscopic projection gives influence on impression of material surface and perceptual deformation, we tested the both monoscopic projection and stereoscopic projection. With monoscopic projection the input is 4K images and the 4K projector projects 4K images holding the resolution, while with stereoscopic projection, the input images are side-by-side full HD images, which is projected after converted to 4K resolution by the 4K projector.

5.3.2 Material

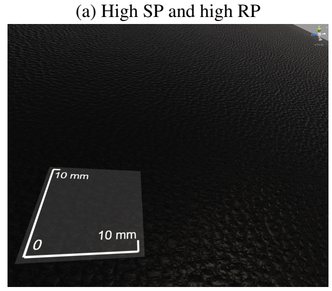
Reproduction of leather material with computer graphics is necessary for the user to perceive projected image as fine geometric structure of leather surface. To realize it, we used computer graphics model created from the fine geometric structures of leather.



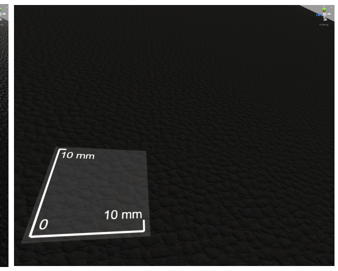
(a) High SP and high RP



(b) High SP and low RP



(c) Low SP and high RP



(d) Low SP and low RP

Figure 9: Leather surface reproduction with various parameters. For the scale comparison, a transparent plane of 10 ×10[mm] is put on the plane the material is applied to.

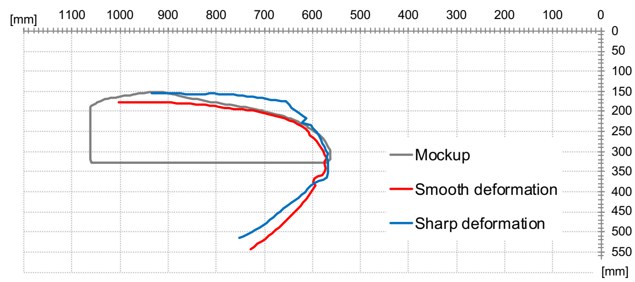


Figure 10: Sectional view of the tested dashboards.

We designed a shader to parameterize the appearance of the material and applied it to surface specular physical based model from Unity, which is the 3DCG engine we used in the system. We defined the two parameters; one is *Roughness Parameter* (RP) and the other is *Specular Parameter* (SP), which are customized parameters based on roughness and specularity respectively. Roughness and specularity here are properties from Unity's surface specular model. We also designed two values, high and low that are the combination of other properties such as albedo and normal of surface specular model. By setting SP and RP either high or low, we prepared 4 leather materials for the experiment (Figure 9).

5.3.3 Shape

We tested three types of shape model of dashboard as a virtual object; mockup (the projected target), smooth deformation and sharp deformation (Figure 10). Based on actual car dashboards, we prepared smooth deformation and sharp deformation because the preliminary experiment result implies the effect of sharpness of deformation on perceptual deformation.

All the 12 combinations of the conditions (3 shapes, 2 levels of RP and 2 levels of SP) are tested in a random order (Figure 11). This procedure is operated in both monoscopic and stereoscopic projection in a random order.

Figure 11: Appearance of projected images with monoscopic projection.

5.4 Subject

12 subjects participated in the experiment and their ages are between 19 and 25 (Mean = 22.6, SD = 1.44 [years]). 9 subjects were male and 3 subjects were female.

5.5 Result

We tested three-way ANOVA with projection way, SP and RP for each shape and there are several items where we confirmed common statistical differences or tendencies in all the shapes.

The following four items have the main effect of RP; glossiness (mockup: $F(1,11) = 20.77$, $p < 0.01$. smooth deformation: $F(1,11) = 36.62$, $p < 0.01$. sharp deformation: $F(1,11) = 15.58$, $p < 0.01$), roughness (mockup: $F(1,11) = 15.82$, $p < 0.01$. smooth deformation: $F(1,11) = 8.86$, $p < 0.05$. sharp deformation: $F(1,11) = 16.64$, $p < 0.01$), specularity (mockup: $F(1,11) = 17.60$, $p < 0.01$. smooth deformation: $F(1,11) = 29.12$, $p < 0.01$. sharp deformation: $F(1,11) = 29.98$, $p < 0.01$), saliency (mockup: $F(1,11) = 6.57$, $p < 0.05$. smooth deformation: $F(1,11) = 9.48$, $p < 0.05$. sharp deformation: $F(1,11) = 15.91$, $p < 0.01$). In those items, higher RP leads to higher score of each item (Figure 12).

In the item of translucency, the tendency of the main effect of projection way is seen, where stereoscopic projection leads higher translucency than monoscopic projection. For mockup, there was a significant tendency ($F(1,11) = 4.02$, $p < 0.10$). For smooth deformation, there was a significant difference ($F(1,11) = 5.04$, $p < 0.05$). For sharp deformation, there was no significant differences nor tendencies, but the score of stereoscopic projection (-0.812) is higher than that of monoscopic projection (-0.979).

We didn't confirm any of such common tendencies or differences in all the three shapes in the terms of overall dashboard evaluation (Authenticity, Harmony and Simplicity).

Table 1 shows the times when the subjects answered "Yes" to the question whether they had a stereopsis. Each combination of model shape and projection way has 48 trials. From Table 1 we can tell that the total number of mockup, smooth deformation and sharp deformation are 75, 83 and 87 respectively. For every shape model, three-way ANOVA with projection way, SP and RP confirms that

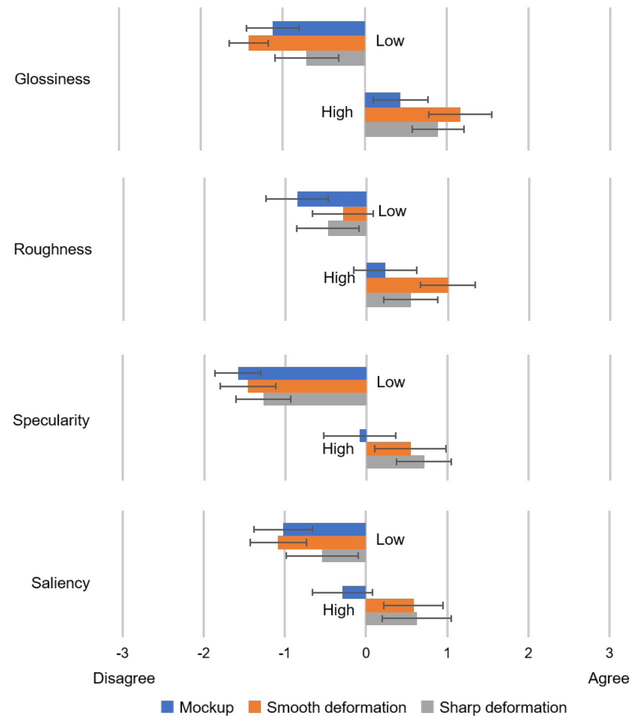


Figure 12: The mean and the standard error in the items of glossiness, roughness, specularity and saliency by high and low RP. "High" is high RP and "Low" is low RP.

Table 1: The total times of the subjects had stereopsis by projection way and shape. 48 trials are done for each condition.

	Monoscopic projection	Stereoscopic projection
Mockup	38	37
Smooth deformation	43	40
Sharp deformation	44	43

there is not any significant difference in projection way.

5.6 Discussion

The result shows that RP is the main effect in the items of glossiness, roughness, specularity and saliency, which suggests that these items can be manipulated by RP. There are considered to be several reasons why RP is the main effect in several items. One of the possible reasons is that some of the items have a lot in common with each other. For instance, glossiness and specularity are both related to metallic material. Another possible reasons is the design of RP and SP. Although RP and SP are designed mostly based on roughness and specularity respectively, they include other factors, which might affect the material surface impression. Furthermore, roughness and specularity which RP and SP are based on are these in fine leather structure (40×15 [mm]), which is tiled so many times when being applied to the whole mockup. There is a possibility that material properties in microscopic scale vary when they are tiled and seen in macroscopic scale such as that a headshot of a dragonfly with macro photography looks rough, while with human eye it looks smooth. It suggests that more items can be manipulated with appropriately designed parameters that take scale difference and other possible factors into account. Such parameters enables evaluation of technically unlimited number of materials.

The necessity and influence of stereoscopic projection should be discussed. The experiment shows that stereoscopic projection tends to increase translucency of projected surface. This trend is supported by the related work bu Otsuki et al. [16], where they confirm that stereo vision display causes pseudo-transparency, which in this experiment corresponds to translucency. Assuming designers do not want any unexpected changes in impression between CAD and actual products, this result implies that monoscopic projection is more suitable than stereoscopic projection for material design. This is also supported by the fact that stereoscopic projection has to sacrifice fps as it time-sequentially project two different images for each eye. As some subject pointed out the latency of image changes when they moved their view points, a lower projection fps can lead to a lower quality of user experience. However, this discussion remains in the area of psychological impression and we cannot assert that this is the case with physiological areas such as the relationship between dashboard shape and sense of safety. In order to use the proposed system in these areas, further research are needed.

The result that for stereopsis, there was no significant differences between projection way implies that stereoscopic projection is not always necessary for perceptual deformation when leather texture is applied. One of the reasons why stereoscopic projection is not always necessary is considered because users can utilize other psychological and physiological depth cues including material surface texture, which is supported by Okutani et al. [15] who show that adding salient features to a projected virtual surface works to induce stereoscopic capture. Although stereoscopic capture is a phenomenon in stereoscopic projection, we could assume the same principle and that in this experiment leather texture worked as salient features.

6 Conclusion

This paper has described the proposal of projection mapping system for car interior design, especially dashboard design and evaluation of its usability in shape design and material design. The proposed system uses two projectors, one of which is 4K projector to reproduce fine leather surface by projecting images rendered based on fine geometric structure of leather surface. The other projector projects the whole dashboard including where 4K projector does not cover.

We conducted two psychological experiments to evaluate the system's usability. The first experiment showed that the user perceives enough amount of local and global deformation for shape design and that projection way does not give any significant differences. We recognize it's because texture plays an important role to induce perceptual deformation. Therefore, in case of texture applied to virtual object, stereoscopic projection is not always necessary for shape design. The second experiment on material reproduction showed that the parameter designed based on roughness has the main effect of several items such as roughness and glossiness, which implies that well-designed parameters can manipulate desired items' impressions of material surface. It also showed that stereoscopic projection tends to increase perceived translucency. Assuming designers want to avoid unexpected impression change by projection, monoscopic projection might be more suitable for trustful reproduction of material surface than stereoscopic projection. Following the results of the two experiments, we conclude that the proposed projection mapping system is usable for both shape design and material design.

Future work includes to investigate material design to manipulate desired material impression while resulting texture is capable of inducing perceptual deformation. Now that the psychological experiments show the basis of the usability of the proposed system for design process, we plan to conduct more experiments with more subjects or for more practical purposes.

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