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Image-based Perceptual Editing: Leather "Authenticity" as a Case Study

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Abstract. *Traditionally, the appearance of an object in an image is edited to elicit a preferred perception. However, the editing method might be arbitrary and might not consider the human perception mechanism. In this study, the authors explored image-based leather "authenticity" editing using an estimation model that considers a perception mechanism derived in their previous work. They created leather rendered images by emphasizing or suppressing image properties corresponding to the "authenticity." Subsequently, they performed two subjective experiments, one using fully edited images and another using partially edited images whose specular reflection intensity was constant. Participants observed the leather rendered images and evaluated the differences in the perception of "authenticity." The authors found that the "authenticity" perception could be changed by manipulating the intensity of specular reflection and the texture (grain and surface irregularity) in the images. The results of this study could be used to tune the properties of images to make them more appealing.*
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1. INTRODUCTION

From the appearance of objects, we usually perceive various impressions and *shitsukan*, which is a Japanese word that means sense of quality. This Japanese word is widely related to material perception and object recognition [1–3], and basic studies on *shitsukan* have advanced under the national project in Japan [4, 5]. Furthermore, many studies have focused on the visual perception of materials [6, 7]. When consumers buy products, they make decisions based on whether they have compelling *shitsukan* [8, 9]. They also edit the appearance of objects in photos to give them a more attractive look when posting them to social networks or storing them in memory devices.

In previous studies, we focused on genuine and artificial leathers used in a variety of products such as car interiors, clothing, and bags [10, 11]. Product designers want to use genuine leather for products owing to its attractive appearance, but they often use artificial leather due to the high price and animal rights issues related to genuine leather [12, 13]. However, the appearance of products made of artificial leather makes a different impression on consumers when compared to products made of genuine leather. Therefore, we estimated the leather "authenticity" using the hierarchical perception model shown in Figure 1. The model in Refs. [8] and [9] was constructed according to our hypothesis based on reports from previous psychophysics [14, 15] and brain science [16, 17] studies, and it represented the human perception process. The model consists of three steps. The first step involves the attainment of stimulus properties, which include physical (e.g., surface texture) and psychophysical properties (e.g., $L^*a^*b^*$), through measurements. The second step involves the attainment of sensory attributes, which include representative impressions, that is, the main impressions people perceived from the leather, through subjective experiments. The third step involves the determination of "authenticity" through subjective experiments.

Nevertheless, we did not explore whether a change in the value estimated by the model actually alters our perception. In this study, we aim at altering the "authenticity" perception by emphasis/suppression based on the estimated model. However, it is difficult to obtain real leather samples with an altered "authenticity" perception. Therefore, we use leather images and explore image-based perceptual editing.

In related studies, various image editing methods have been proposed, but few have focused on editing for material appearance and perception [18–25]. Sawayama and Nishida (2018), Motoyoshi et al. (2007), and Sharan et al. (2008) proposed an image filter based on the statistical properties of images such as kurtosis and skewness for translucency and glossiness, respectively [19–21]. However, they focused on the material appearance owing to the physical properties of the object. In this study, we focused on high-order *shitsukan*, that is, "authenticity." In addition, Boyadzhiev et al. (2015) investigated the effects of changing some appearances through the band-sifting operator method using the spatial frequency of the image [22]. However, they followed the reverse procedure compared to ours. That is, they first propose an image-sifting method and then explore the type of perceptual changes due to the sifting results according to the participants. Furthermore, they did not mention

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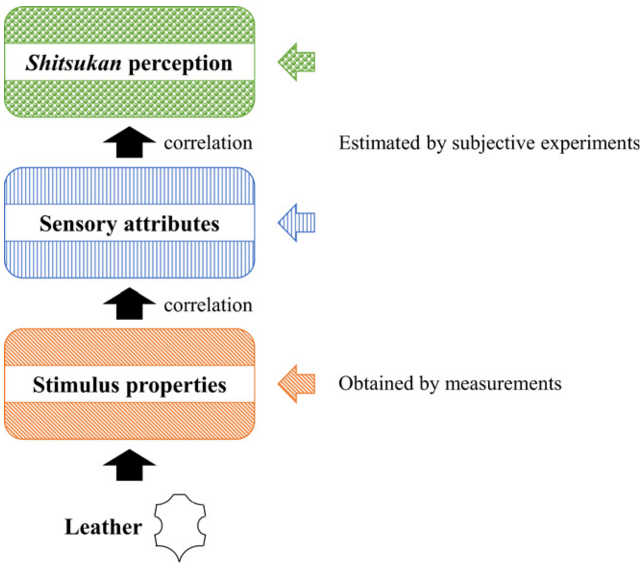


Figure 1. Hierarchical perception model.

high-order perceptions, such as "luxury" and "authenticity." On the other hand, as shown in Fig. 1, we explored image editing for changing the perceptual "authenticity" applied to the estimated model, which quantified human perception derived from our previous study [10].

The rest of this article is organized as follows. In Sections 2 and 3, we describe our previously proposed model for perceptual "authenticity" and the creation process of an "authenticity" edited image based on the estimated model. In Section 4, we present the materials and methods used for the subjective evaluation experiments. In Sections 5 and 6, we provide the experimental results and a discussion. Then, we draw conclusions and highlight some limitations of this study.

2. ESTIMATION MODEL FOR "AUTHENTICITY"

In this section, we describe our previously proposed model for estimating the perceived "authenticity" of leather. Based on the hierarchical model shown in Fig. 1, we first performed measurement experiments using the constructed goniophotometer system to acquire image properties under multi-angle conditions [10, 11]. The color measurement was made under five angle conditions (the measurement and illumination angles were 45° and {−15°, 0°, 20°, 30°, or 45° }, respectively, in the normal direction, i.e., geometry of −15°/45°, 0°/45°, 20°/45°, 30°/45°, and 45°/45°). Moreover, the measurement of surface characteristics was made under four angle conditions (the measurement and illumination angles were 0° and {15°, 25°, 45°, or 60° }, respectively, in the normal direction, i.e., geometry of 15°/0°, 25°/0°, 45°/0°, and 60°/0°). Next, several subjective experiments were conducted using ten leather samples (Figure 2) to extract the representative impressions perceived by the participants from the leather. The samples were black and had approximate dimensions of 300 mm × 210 mm. RGB images were captured under D65 diffuse lighting conditions. Because the appearance of the leather depends on the angle of observation, the participants observed the sample attached to a bending jig from a fixed position. Figure 3 shows the observation conditions. In these experiments, the responses collected from the participants were narrowed down by stepwise experiments. Finally, the representative impressions were estimated using factor analysis. From the results, we could estimate that the participants mainly perceived "surface shape" relating to the surface roughness and surface large grain and "impression of stateliness," which means an impressive and dignified appearance. These impressions can be expressed by Eqs. (1) and (2), respectively, by multiple regression analysis using the image properties. The property values had dissimilar ranges. Therefore, they were converted to Z scores and were used as the variables. By a conversion to Z scores, we could compare the magnitudes of the influence of explanatory variables.

$$\text{“Surface shape”} = 0.76 \cdot x_1 - 0.31 \cdot x_2 \tag{1}$$

$$\text{“Impression of stateliness”} = 0.71 \cdot y_1 + 0.24 \cdot y_2 - 0.44 \cdot y_3. \tag{2}$$

Here, x_1 and x_2 are the "large grain under shade condition" (geometry of 60°/0°) and "L^* value under the specular angle" (geometry of 45°/45°), respectively; y_1, y_2, and y_3 are the "surface irregularity under the shade condition" (geometry of 60°/0°), "surface irregularity under the highlight condition" (geometry of 15°/0°), and "kurtosis value under the shade condition" (geometry of −15°/45°), respectively. In this study, x_1, y_1, and y_2 were calculated from the integral values of 0–0.1 (surface irregularity) and 0.1–1.0 (large grain) cycle/mm sub-bands of the spatial frequency characteristics of each recorded image. Furthermore, x_2 was obtained from the average L^* value of the recorded specular reflection image (geometry of 45°/45°); y_3 was obtained from the kurtosis value of the recorded image (geometry of −15°/45°). From the above equations, "surface shape" was perceived by mainly surface with large grain and "impression of stateliness" was perceived by mainly surface irregularity. The R^2 values between the subjective scores of "surface shape" and "impression of stateliness", and the estimated scores calculated from Eqs. (1) and (2) were 0.91 and 0.96, respectively.

Finally, the "authenticity" was estimated by multiple regression analyses using representative impressions converted to Z scores as follows:

$$\text{“Authenticity”} = 0.59 \cdot \left|\text{“surface shape”}\right| + 0.56 \cdot \text{“impression of stateliness”}. \tag{3}$$

In Eq. (3), the representative impression values were converted to Z scores and used as the explanatory variables. Figure 4 shows the correlation between the value estimated using Eq. (3) and the subjective score for "authenticity." In this study, participants strongly perceived "authenticity" for the samples with large scores. On the other hand,

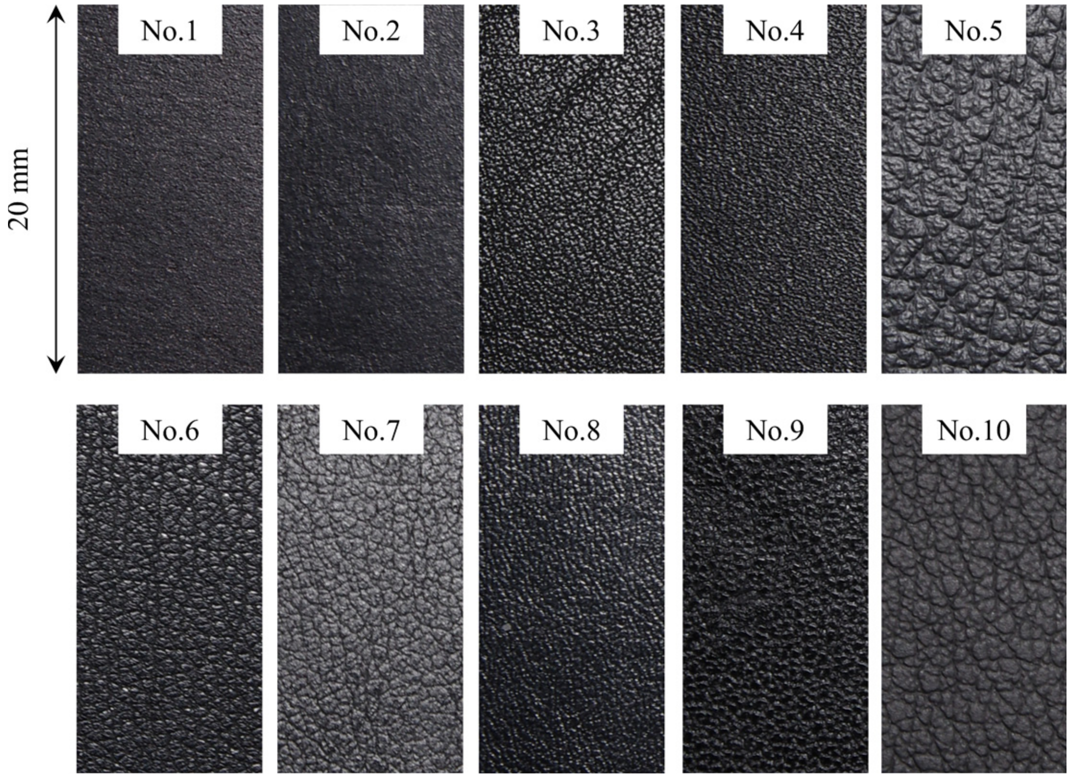


Figure 2. Test leather samples. Samples 1–4 were genuine cow leather, while samples 5–10 were artificial leather.

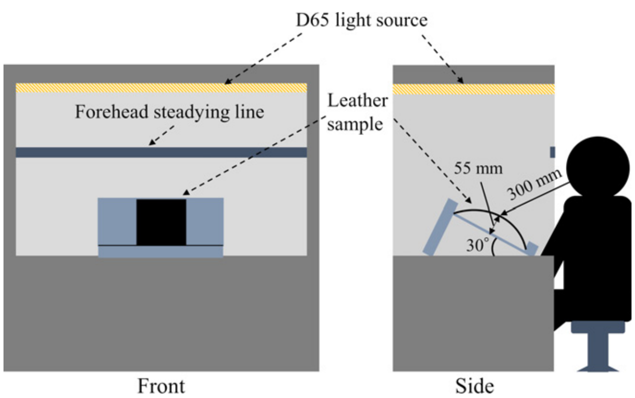
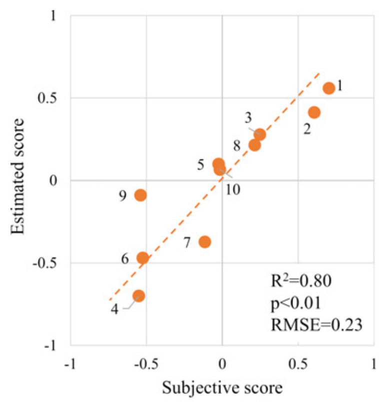


Figure 3. Experimental observation conditions.



(a)

Sample No.	Subjective score
1 (genuine)	0.70
2 (genuine)	0.61
3 (genuine)	0.25
8 (artificial)	0.21
10(artificial)	-0.02
5 (artificial)	-0.02
7 (artificial)	-0.12
6 (artificial)	-0.52
9 (artificial)	-0.54
4 (genuine)	-0.55

(b)

Figure 4. Result of estimated "authenticity." (a) Relationship between subjective and estimated scores. (b) Table of subjective scores.

participants strongly perceived "no authenticity (artificial)" for the samples with small scores. In this model, the R^2 value was 0.80, the p-value was less than 0.01, and the root mean square error was 0.23. The estimated value of sample 9 was particularly different from the subjective score. It might be improved by adding properties other than the representative impressions used in Eq. (3) in explanatory variables. Furthermore, the results of the validation experiments with 12 additional samples confirmed that all additional samples were within the 95% prediction interval of the model.

In this study, we explored the changes in the perception of "authenticity" by emphasizing/suppressing the image properties, which are used to estimate the representative impressions through image editing.

3. GENERATING EDITED IMAGE

We generated a rendered image where "authenticity" was edited following the steps shown in Figure 5. The original leather image acquired by a digital single-lens reflex (DSLR) camera was converted to an $L^*a^*b^*$ image. Next, the L^* image was split into spatial frequency sub-bands corresponding to the surface irregularity and large grain, and each amplitude was adjusted. Following this, the resynthesized leather image

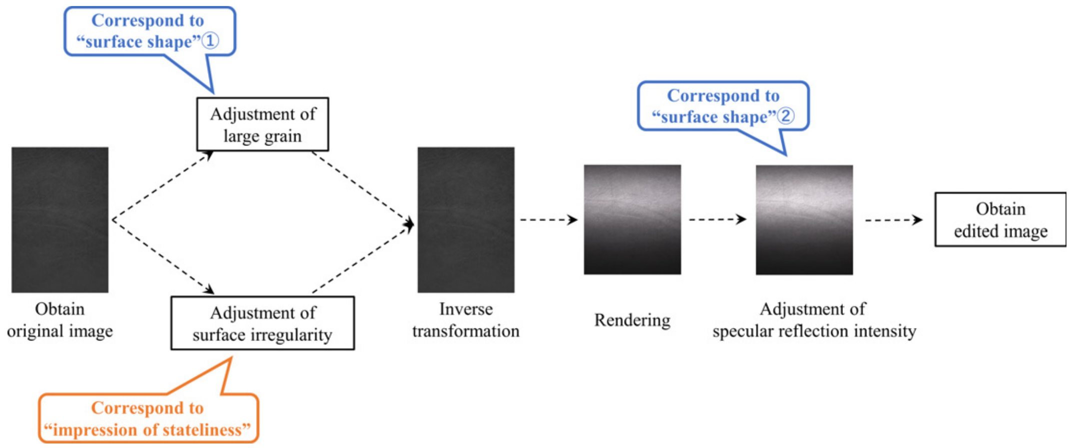


Figure 5. Rendered image generation procedure.

was converted into a rendered image under multi-angle reflection conditions by physically based rendering (PBR). Finally, we obtained the edited image by adjusting the specular reflection of the rendered image. In Sections 3.1–3.4, we describe each procedure in detail.

3.1 *Original Image*

To obtain the original image, the DSLR camera (Pentax K-1 Mark II; RICOH Imaging, Tokyo, Japan) was used to measure the leather sample set under a standard light source (SpectraLight QC; X-Rite, Michigan, USA). The standard illuminant D65 was used, and the illuminance of the observation area was set as 1270 lx. The camera captured RAW images with an image size of 7360 × 4912 pixels at a depth of 14 bits. For the measurement, we used the pixel shift resolution system, which is a function of the camera [26]. Using this system, when developing a RAW image into an RGB image, it is possible to reduce false colors and noise, improving the image quality on that of an image taken with a conventional Bayer system. The RAW image with a resolution of approximately 489 dpi acquired in this step was mapped into an Adobe RGB image and trimmed to 3184 × 4771 pixels.

3.2 *Adjustment of Surface Properties*

To adjust the surface irregularity and large grain, we first converted the RGB image into a device-independent color space. The $L^*a^*b^*$ image was calculated using an XYZ image derived from an RGB image by linear transformation. We carried out the correction to reproduce the actual leather appearance as accurately as possible. CIE XYZ tristimulus values were converted by multiplying the RGB data of the three-dimensional vector by a 3 × 3 matrix ($\boldsymbol{M}_1$), which approximated the camera sensitivity function to the CIE 1964 (10 deg) color matching function (Eq. (4)). This equation is also known as the Luther condition:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \boldsymbol{M}_1 \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \tag{4}$$

We next performed a Fourier transform to obtain the two-dimensional spatial frequency characteristics of the L^* image. In our previous studies [10, 11], we defined the surface irregularity and large grain as an integral value of 0–0.1 and 0.1–1.0 cycles/mm sub-bands, respectively. Therefore, in this study, we focused on the sub-bands of each spatial frequency band. The surface properties associated with each representative impression ("surface shape" and "impression of stateliness") were adjusted by enhancing/suppressing the amplitude of each sub-band. That is, by enhancement, the contrast of the surface irregularity and large grain components in the image became higher than that of the original image. On the other hand, by suppression, the contrast of these components became lower. In the estimation model of the representative impressions, each surface property was characterized by an angle condition. However, the properties of the actual leather surface were distributed continuously. Therefore, in this step, we adjusted the entire sample surface. Additionally, by adjusting the surface properties, the kurtosis could be adjusted simultaneously. For example, by emphasizing the surface irregularity, the surface L^* distribution became more variable, and the kurtosis value was suppressed. The adjusted two-dimensional spatial frequency was inversely transformed into the L^*_{inv} image and then into the RGB_{inv} image through the inverse of the process described above.

3.3 *Rendering*

Image editing steps were performed on the measured leather planar image. However, in previous experiments, the participants observed curved samples. Therefore, we transformed a planar image into a curved shape using PBR software (Blender 2.8) and acquired a rendered image that reproduced the appearance under the observation conditions of the previous subjective experiment. Figure 6 shows the rendered scene and an example of the rendered image. The rendered image was output at 1065 × 1200 pixels and was converted from 489 dpi to 163 dpi by downsampling to match the resolution of the color management display

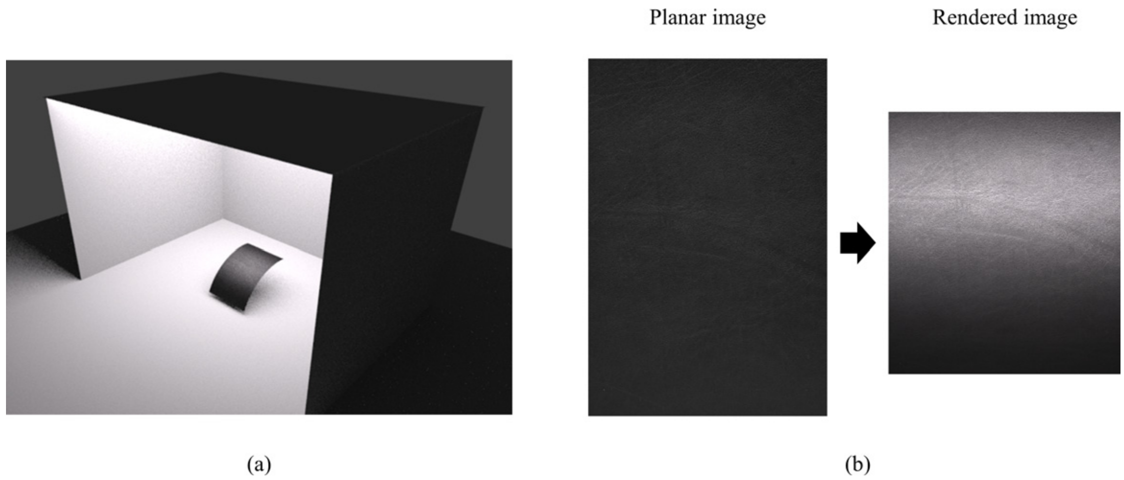


Figure 6. Acquisition of rendered image. (a) Rendered scene. The rendering environment reproduced the observation conditions of the previous study as accurately as possible. (b) Example of the rendered image.

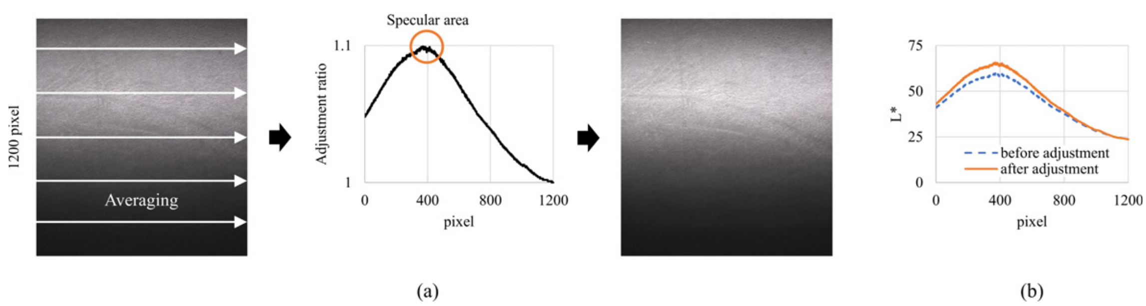


Figure 7. Procedure for adjusting the specular reflection intensity (Example: 1.1 times emphasis). (a) Adjustment procedure. (b) Average L^* value in the width direction before and after adjustment.

used in the subjective experiment described in detail in Section 4.

3.4 *Adjustment of Specular Reflection Intensity*

We edited the specular reflection intensity of the rendered image to adjust the "surface shape." However, because the surface brightness changes continuously, the local adjustment was not reasonable. Therefore, the specular reflection intensity was adjusted as shown in Figure 7. First, we transformed the rendered image into an $L^*a^*b^*$ space image and calculated the average value in the width direction of the L^* image. Next, the L^* value was adjusted so that the maximum average value was an arbitrary intensity (1.1 times in the figure) and the minimum average value was 1.0 times, which changed greatly around specular reflection. In contrast, the change was smaller for diffuse reflection. Using this method, we adjusted the specular reflection while maintaining continuous brightness. Then, we acquired the final edited image by retransformation from the $L^*a^*b^*$ space.

4. SUBJECTIVE EXPERIMENTS

Subjective experiments were conducted using the edited images generated by the procedure described in Section 3. In these evaluations, we explored whether the perception of "authenticity" was transmuted by image editing based on its estimation equation.

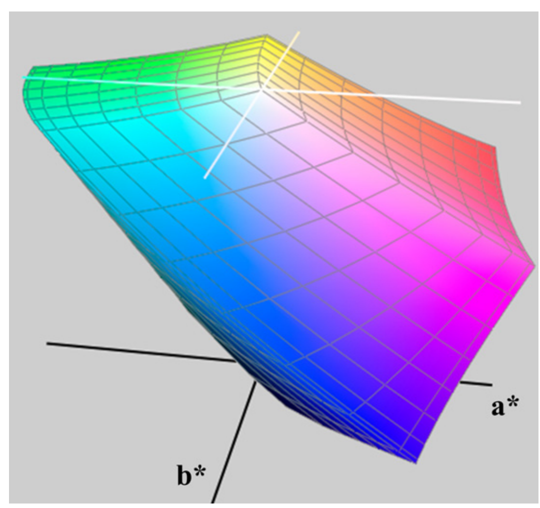


Figure 8. Display color gamut.

Two experiments were conducted. In one experiment, fully edited images were used. In the other experiment, partially edited images were used, where only the surface properties were edited, that is, the specular reflection

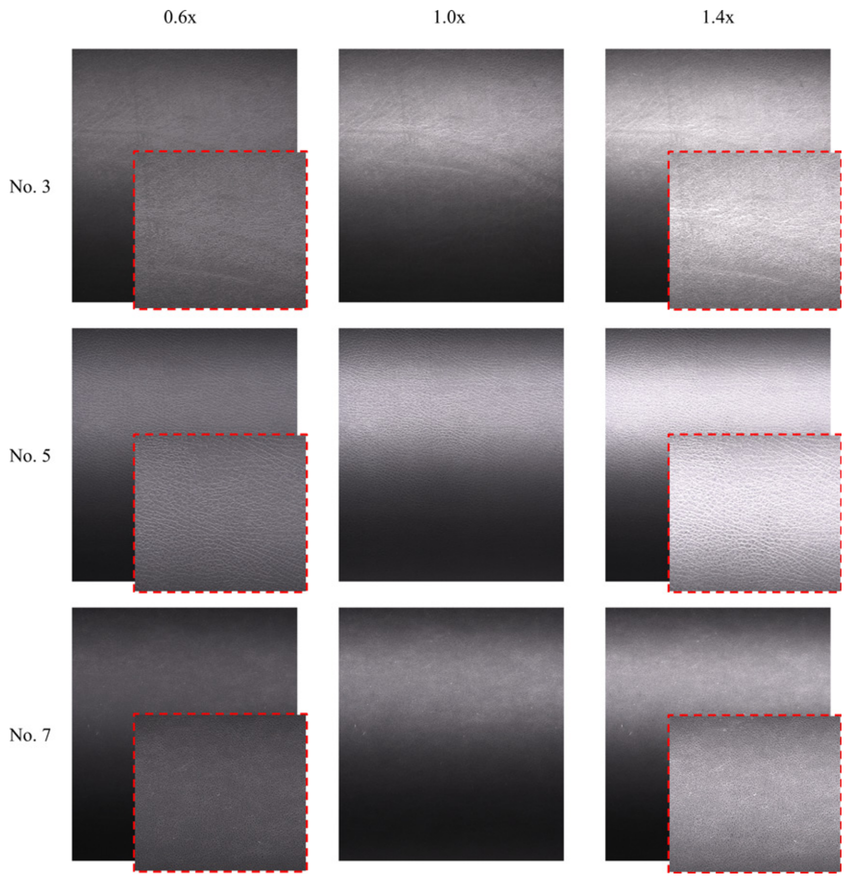


Figure 9. Example of the edited images used in Experiment 1. The red frame is an enlarged image.

intensity was constant. In the fully edited images, the change in specular reflection intensity was particularly noticeable. Therefore, we explored the change in perception when editing only the surface properties. Twelve people participated in both experiments, including eight people who had already participated in our previous studies [10, 11] to calculate the subjective "authenticity" score. The participants were our colleagues (20–40-year-old men) who were common leather consumers with an average eyesight including a correction of approximately 1.0. In addition, they had standard color recognition abilities.

We used the color management display SW271 (BenQ Corp., Taipei, Taiwan) with a resolution of 3840 × 2160 (163 dpi) and a wide color gamut, which reproduced 99% of the colors displayed using the Adobe RGB model. In addition, we calibrated the display under the following conditions (color gamut: Adobe RGB; color temperature: 6504 K; gamma: 2.2; white point coordinates: (0.314, 0.331); brightness: 245 cd; the environment is similar to the actual leather observation environment). Figure 8 shows the color gamut of the display in the CIELAB color space under the above conditions.

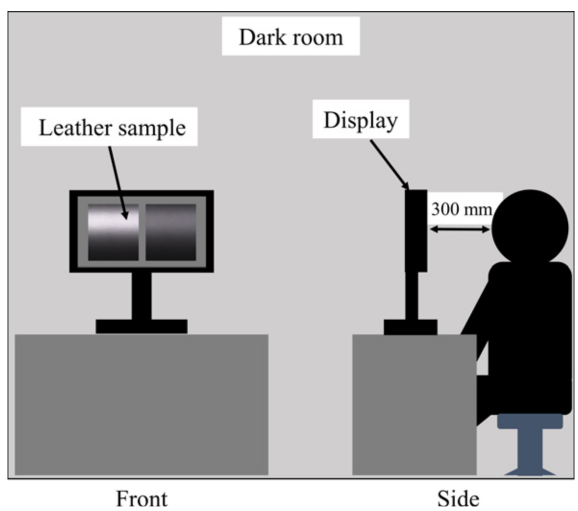


Figure 10. Experimental conditions.

4.1 *Description of Experiment 1*

In this experiment, we used images, Nos. 2–7 and 10, of the leather samples shown in Fig. 2. The "authenticity" of each sample was edited to $1.2_\times$ and $1.4_\times$ for emphasis and $0.6_\times$ and $0.8_\times$ for suppression. In other words, we prepared five images for each sample, including the original edited image. However, the subjective "authenticity" scores of the samples had both positive and negative signs (see Fig. 4). Therefore, the samples with negative subjective "authenticity" scores

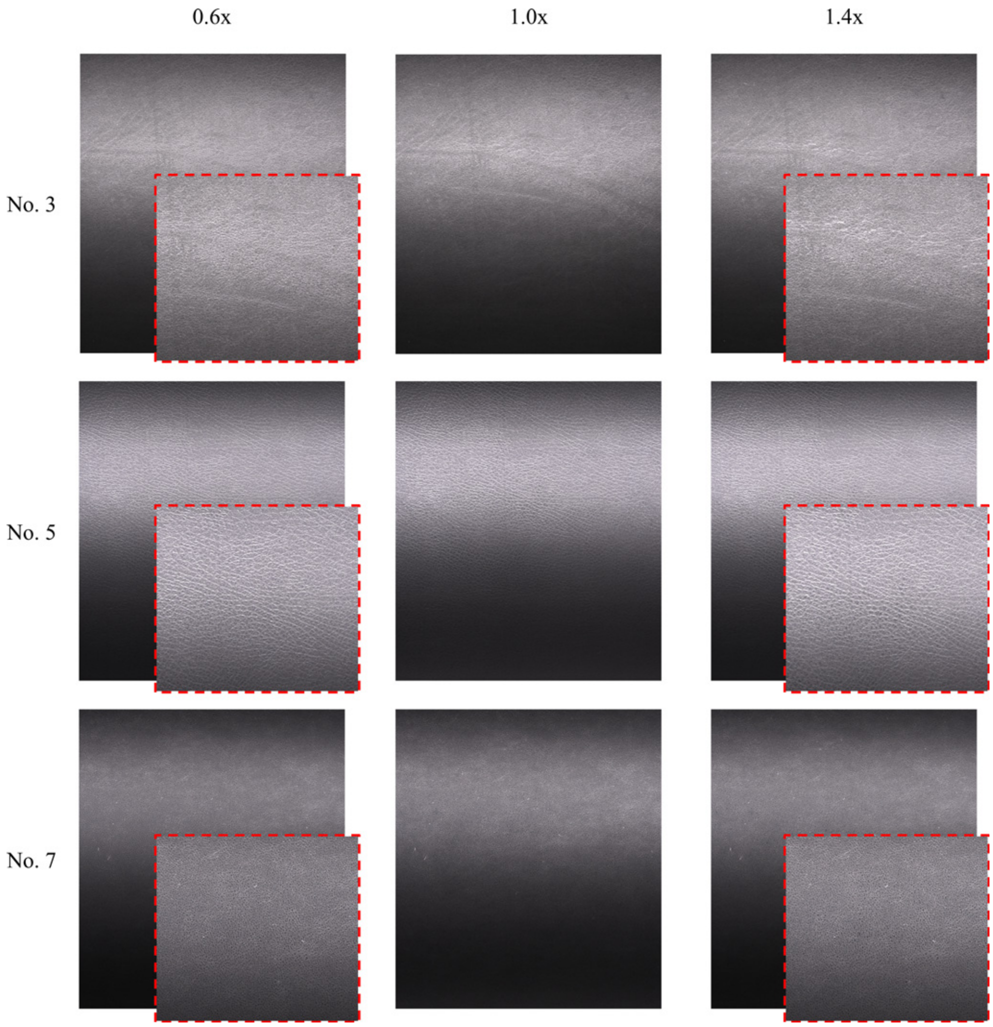


Figure 11. Example of the edited images used in Experiment 2. The red frame is an enlarged image. Because only the surface properties are edited, the difference between the images is small.

had the opposite emphasis/suppression intensity scores ($0.6_\times$ and $0.8_\times$ for emphasis and $1.2_\times$ and $1.4_\times$ for suppression). Here, with respect to the above intensity of emphasis/suppression, the image was actually edited with the intensity transformed nonlinearly by the Stevens power law. That is, the emphasis/suppression intensity was raised to the power of 0.33. Figure 9 shows a part of the sample prepared.

Figure 10 shows the experimental conditions. The participants observed the display placed in a dark room from a distance of 300 mm. At the beginning of the experiment, we informed the participants that the images to be displayed were the leather rendered images reproducing the curved state attached to the bending jig of the previous subjective experiment (see Fig. 3).

The experiment was conducted using Thurstone's paired comparison method, whereby two leather-edited images were compared on the display. The participants observed the pair of images displayed and selected the image that they perceived to have more "authenticity." The experiment was conducted for each sample; so the participants observed and evaluated 70 (${}_5C_2 \times 7$) edited image pairs. The order of the images displayed was random for each participant. Each sample pair was presented to the participants for up to 10 s.

4.2 *Description of Experiment 2*

The leather samples used in the experiment were the same as those in Experiment 1 (the rendered images, Nos. 2–7 and 10, of the leather samples shown in Fig. 2). Each sample image was edited for surface properties only, that is, the specular reflection intensity was not edited. Figure 11 shows a part of the sample prepared for the experiment. The experimental environment and the method were the same as those used in Experiment 1.

5. RESULTS AND DISCUSSION

5.1 *Experiment 1*

We obtained an evaluation score for each edited image by scaling the results of the paired comparison method. However, because the scaling was based on the normal distribution table, it could not be scaled when the evaluation of a certain image pair was extremely biased to one side (e.g., when all participants gave the same answer to a specific pair).

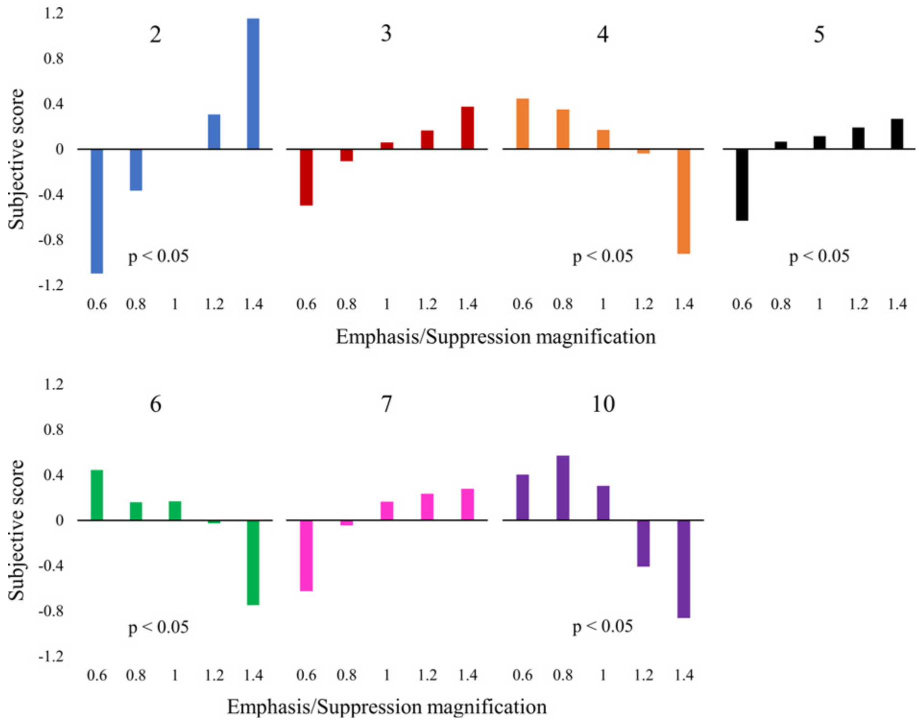


Figure 12. Result of Experiment 1. The *p*-value in the figure is obtained by ANOVA.

In that case, the data with missing values were scaled using the method proposed by Gulliksen [27].

Figure 12 shows the subjective score of "authenticity" obtained at different emphasis/suppression intensity scores (0.6_x–1.4_x) in Experiment 1. From the figure, it can be seen that the editing of the image and the intensity changed the perception of the participants. In some samples, although there was an inverse relationship between the scores of emphasis intensity (e.g., 0.6_x and 0.8_x of sample 10, which has a negative subjective score in Fig. 4), there was no inverse relationship between the scores of emphasis/suppression intensity (e.g., 0.8_x versus 1.2_x).

The results confirmed that most of the edited images changed the participants' perception along with the intensity. However, the results were different for the samples with subjective "authenticity" score approximately zero obtained in previous studies (samples 5, 7, and 10). Because these samples had small but negative values, according to our hypothesis, the participants should have perceived "authenticity" strongly under the intensity scores of 0.6_x and 0.8_x. However, as shown in Fig. 12, samples 5 and 7 elicited the opposite perception. In our previous study, the samples' subjective "authenticity" scores were calculated using Scheffe's paired comparison method. Therefore, we speculated that the calculated score of approximately zero indicated that participants' evaluations were divided between "authenticity" and "no authenticity." Hence, in this experiment, we considered that although in these samples, the perception of the participants could be changed, the direction of change was decided according to the majority among the divided evaluations because there was no common evaluation among the participants.

5.2 *Experiment 2*

Figure 13 shows the subjective score of "authenticity" obtained for different emphasis/suppression intensity scores (0.6_x–1.4_x) in Experiment 2. Similar to the result in Experiment 1, we could confirm that the editing of the image and the intensity changed the perception of the participants. In some samples, although there was an inverse relationship between the scores of emphasis intensity (e.g., 0.6_x and 0.8_x of sample 4, which has a negative subjective score in Fig. 4), there was no inverse relationship between the scores of emphasis/suppression intensity (e.g., 0.8_x and 1.2_x of sample 2, which has a positive subjective score in Fig. 4).

The purpose of this experiment was to explore whether it is possible to elicit a change in perception by only editing surface properties when the visually dominant specular reflection intensity is constant. From the results, the participants seemed to be able to determine the emphasis/suppression of "authenticity" only from the surface properties. However, comparing the subjective score ranges of each sample of Experiments 1 and 2, that is, the width of the maximum and minimum values, the score range in Experiment 1 was significantly wider ($p < 0.05$). We found that editing all the properties could elicit perceptual changes more clearly. Figure 14 shows the range of subjective scores obtained in the two experiments and the result of analysis of variance (ANOVA). From Fig. 14(a), it can be seen that samples 3 and 5 have a slightly larger score range in Experiment 2 than that in Experiment 1. We speculate that

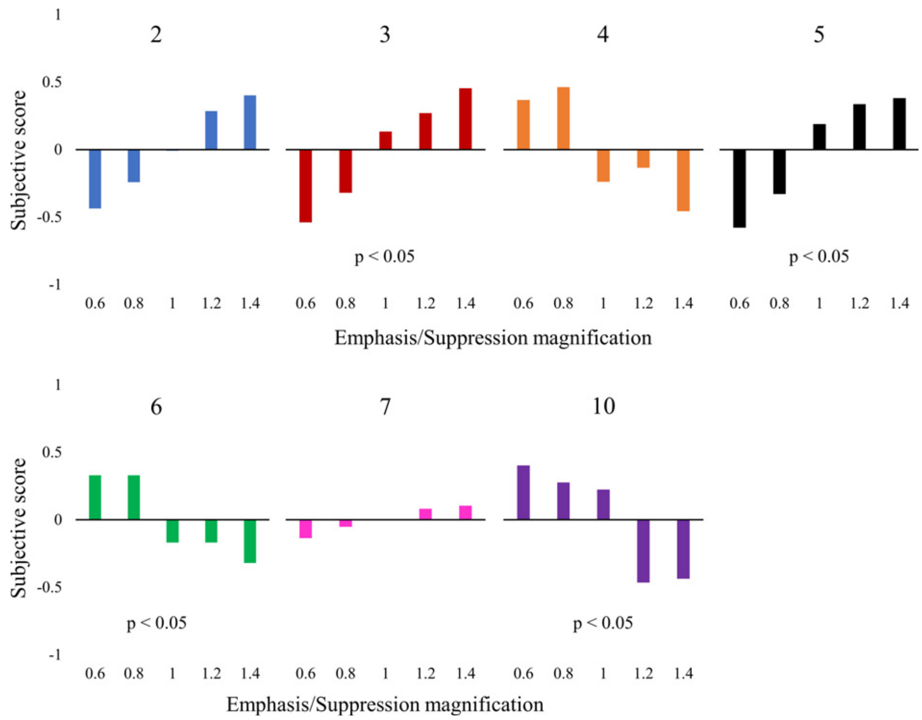
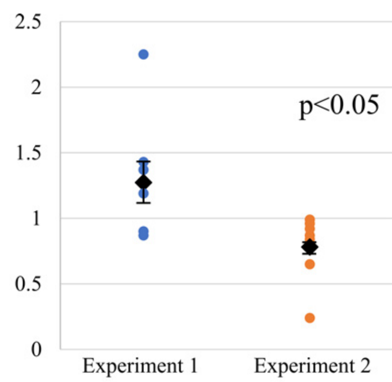


Figure 13. Result of Experiment 2. The *p*-value in the figure is obtained by ANOVA.

	Subjective Score Ranges						
	2	3	4	5	6	7	10
Experiment 1	2.25	0.87	1.37	0.90	1.19	0.90	1.43
Experiment 2	0.84	0.99	0.92	0.96	0.65	0.24	0.87

(a)



(b)

Figure 14. Differences in the subjective score ranges obtained in Experiments 1 and 2. (a) Score range table. (b) Result of ANOVA. The black square plot shows the average value and the black line shows the standard error.

because the samples had large wrinkles and grains on their surface, it was easier for participants to observe the surface properties when the specular intensity was constant.

6. CONCLUSIONS

We performed image-based "authenticity" editing according to an estimation model that we proposed in a previous study and explored the modulation of the "authenticity" perceived from leather images. To this end, we generated the rendered images with emphasis/suppression of the properties used in the estimation model. Next, subjective experiments were conducted using the images. The results showed that for the leather images edited in five levels, the participants' "authenticity" perception was changed approximately by an intensity we had predicted. In other words, as was the intent of this study, we were able to change the perception of "authenticity" by emphasis/suppression based on the estimated model derived in our previous study. We inferred that when manufacturing artificial leather, consumers' perception of "authenticity" can be changed by controlling the specific properties used in this study although further consideration is needed to confirm this hypothesis.

However, the image editing method proposed in this study has some limitations. In particular, the image editing emphasis/suppression ranges from $0.6_{\times}$ to $1.4_{\times}$. However, when we emphasized the image by, for example, $3.0_{\times}$, the edited image was perceived as an unnatural leather image by the participants. Therefore, it is necessary to conduct further subjective experiments to determine the emphasis/suppression range perceived as a natural leather image. In addition, the perception of other components of *shitsukan* due to image editing can be considered.

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