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A Touch Panel for Presenting Softness with Visuo-Haptic Interaction

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Abstract

This paper proposes a system capable of presenting softness using a touch panel. Many studies of touch panel-based haptic displays have developed methods for manipulating macro-roughness (shape), fine-roughness (texture), and friction. On the contrary, few studies have examined the sensation of softness. One reason for this is that to represent the spring constant of the object material, it becomes necessary to present a reaction force in the vertical direction, and this requires a large-scale device to move the surface up and down, or a device attached to the finger, both of which degrade the touch panel experience. To tackle this issue, we propose and have developed a system that can express softness not only visually but also haptically using a motor-driven film covering the touch panel to present a tangential force to the finger and with a simple visual shadow effect. In addition, we used the system to evaluate the subjective softness and confirmed the visual and haptic modulation with a realistic 3D image and a 2D image.

CCS Concepts

• ***Computing methodologies*** → *Visual effect;* • ***Hardware*** → *Micro-controller and actuators; Presenting a reaction force;*

1. Introduction

Many research projects are currently being conducted on presenting haptic senses to the surface of a touch panel. Haptic presentation on the touch panel surface is anticipated not only for feedback on an operation but also for application to presentation materials in electronic commerce, remote communications, and virtual reality. Haptics research has shown that there are five haptic sense dimensions for presenting a haptic feeling of the texture of objects; fine-roughness, macro-roughness, friction, hardness/softness and warmness/coldness [ONY12]. For the most part, three of these fine-roughness, macro-roughness, and friction, have been presented for the touch panel.

For example, Fukumoto's Active click [FS01] and Poupyrev's Ambient touch [PMR02] can present fine-roughness on a touch panel. Immersion Corporation's Touch Sense Tactile Feedback System [Imm] and Apple's iPhone & iPad series [App], which incorporate a transducer on the touch panel itself, present a click feeling and a press feeling.

There is also the touch screen [PM03] developed by Poupyrev et al. and the 2.5-Dimensional Tactile Display [SD12] using wire tension that was developed by Saga et al. to present macro-roughness.

Although it needs a pen tablet, Takasaki et al. developed SAW tactile display to present friction using acoustic wave [TTKM08]. Bau developed Tesla Touch [BPIH10] using electrostatic force to present friction, and FUJITSU's Haptic Sensory Tablet [FUJ14] uses ultrasonic vibration. These can present not only friction but also roughness. Levesque also demonstrated that variable friction on a touch panel have a positive impact on many sides to the users [LOM*11].

On the other hand, presentation of hardness/softness and warmness/coldness on a touch panel is rare. The hardness/softness is important in many aspects such as to facilitate electric commerce for online shopping for cosmetics, remote communications where users can softly touch each other, and virtual reality. In these cases, it is important to reproduce a variety of softness, such as human skin.

This paper focuses on presenting hardness/softness using a touch panel. This has so far required presentation of a reaction force in the vertical direction, requiring a large-scale device or devices attached to the fingers [MSTK12] [NY16]; this degrades the experience and value of the touch panel, which should be easy to use anytime and anywhere.

With this as the background, our research goal is to develop a touch panel capable of presenting softness with a simpler mechanism. We propose presentation of a reaction force in the tangential direction, which greatly reduces the size of the mechanical components. We also provide visual effects such as a shadow to accompany a deformation. We hypothesize that although the finger

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movement and force presentation is limited to the tangential direction, combination with a visual effect will enable users to perceive hardness-softness equivalent to that perceived with vertical motion.

In this paper, we evaluate our reaction force presentation device and compare methods of presenting 2D and 3D images.

2. Related Work

2.1. Presenting softness to a touch panel

Research using a touch panel to create a sense of softness is relatively rare. In the few studies that exist, Matoba presented a real softness [MSTK12] by making the surface itself physically deformable. Nakamura also proposed a design that can present a reaction force on a touch panel by controlling the skin contact area with electrostatic actuators [NY16], which requires a sophisticated mechanism attached to the finger. There are some other studies that present softness by generating a reaction force in the vertical direction [SYI13]. Overall, hardness-softness devices with a touch panel are either large or require a device to be attached to the finger, both of which, we think, are unsuitable in practical situations involving the dairy use of touch panel.

When we actually operate a touch panel, the basic finger movement is in the tangential direction. Many studies have been carried out on presenting a force in the tangential direction when using a touch panel that do not aim to present a feeling of softness. Gesture output uses a thread-driven transparent film which covered on a touchscreen to actuate the user ' s finger to present symbolic information [RRP*13]. There have also been several other attempts to actuate the user ' s finger by driving the four corners of a touch panel [SD12], using belts [HKPG15], and synchronized presentation of a lateral shear force with electrostatic adhesion [MPC16]. In this study, we present the reaction force using the belt winding mechanism driven by DC motors proposed by Nakamura et al. [NYK17], which can easily coexist with a touch panel.

2.2. Visual Modulation

There are many studies to present a haptic sensation by visual modulation. Lecuyer proposed a pseudo-haptic feedback system that can express a force sensation using a computer mouse, which cursor movement is dynamically modulated [LCK*00]. Another study expressed elastic hardness by pseudo-haptic [AJML17]. Kokubun [KBN*14] developed a system that present object deformations with visual and haptic modulation. SoftAR [PIS15] showed that softness perception can be modulated by visual presentation of shadows representing the transformation and deformation of objects. Based on these previous attempts, we also provide a visual effect to give an increased sense of softness.

3. Proposed method

When we touch an object, a reaction force is presented in a direction perpendicular to the tangential plane between the touching finger and the object (Figure 1 (a)). However, driving a touch panel vertically generally requires a large setup. Our proposed method therefore, presents a reaction force in a direction tangential to the touch panel (Figure 1 (b)), and includes a visual shadow effect to convince the user that the deformation is vertical.

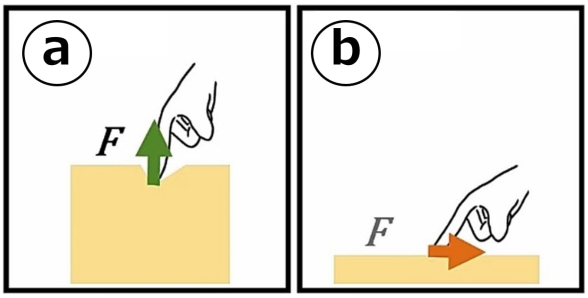

Figure 1: *(a) Previous devices presented a reaction force in the vertical direction. (b) Our proposed device presents a reaction force in the tangential direction.*

3.1. Device to present a reaction force

We employed a device to present a reaction force that employs an embedded belt winding mechanism driven by DC motors [NYK17]. This time we use a transparent film as a belt, then it covers the touch panel, and when the user ' s finger is moved across the touch panel, the film on the touch panel moves in the same direction as the finger. At the same time, a force can be presented in the direction opposite to the movement of the finger by driving the film with two DC motors installed at the front and back of the touch panel. Because the motors are driven by pulse-width modulation, we can assume that the exerted force is proportional to the duty ratio. The displacement x of the film on the touch panel moved by the force of the finger is read by an encoder attached to the motor, and the velocity v is calculated by dividing this displacement x by the fixed time t. We set the spring constant k and the damper constant c, and the reaction force F is determined from Equation 1. This makes it possible to present the user with the sense of a force with one degree of freedom in the tangential depth direction, which conveys the feel of a material with a certain spring and damper coefficient.

$$F = -k * x - c * v \tag{1}$$

3.2. Visual effect

When a finger touches a deformable object, a semicircular shadow is formed around the finger as it touches and dents the object. In our system, this shadow is presented as a visual effect. The shadow is displayed when the finger touches the display through the film of the haptic presentation device (Figure 2 (b)). The size of the visual effect can also be adjusted in proportion to the displacement of the finger, giving the impression that the object is being deformed vertically.

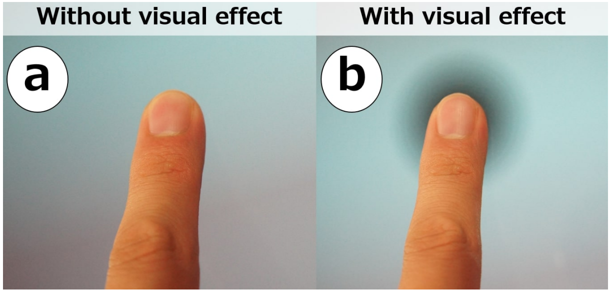

Figure 2: *(a) Without visual effect. (b) With visual effect. The area of shadow can be adjusted.*

4. Experiments

4.1. Experiment1: Evaluation of softness using our reaction force presentation device

Generally, when we touch a real object, we press down with our fingers perpendicularly. In our reaction force presentation device, the direction of operation is limited to front-back movement in the tangential direction. This experiment examines the range of hardness our device can present and whether users will interpret it as a feeling of softness.

4.1.1. Experimental condition

In this experiment, five types of reaction force presentation were performed using our device. For comparison, we used human skin gel (Excel, human skin gel). Gels with a variety of hardness were prepared by changing the ratio of the main agent to the curing agent. The same film (Toray, Lumirror S10, film thickness 50 μ m) that was used for the reaction force presentation device was paved on the gels to achieve a fair comparison between the gels and the device. The hardness of each gel was measured using a durometer (TECLOCK, TYPE E2, GS-743G). Subsequently, seven gel specimens were prepared with Asker hardnesses of 12, 21, 29, 38, 47, 55, and 63. This range of hardness corresponds to the range from the human skin to the eraser. In this experiment, the experimenter subjectively adjusted the spring constant k and damper constant c of the haptic presentation device so that the haptic sensation resembled that of the hardness 38 gel, which was the middle hardness of our prepared gels. Then we prepared five sets of parameters, by fixing the ratio of c to k and multiplying these parameters by factors of; $\frac{1}{2}$, $\frac{1}{\sqrt{2}}$, $1(F_b)$, $\sqrt{2}$, and 2. The reason for choosing these parameters is that there are clear differences for the experimenter among these parameters.

4.1.2. Experimental procedure

An overview of the experiment is shown in Figure 3. Participants were asked to sit in front of a desk with the haptic device and gels placed on top. The height of the chair was adjusted so that the participant's fingers could be easily moved on the device. White noise from headphones (BOSE, QuietComfort 15) blocked environmental noise including the motor sounds. Participants practiced touching both the haptic device and the gels with their eyes closed. They were asked to touch and move the film tangentially from back to front and to touch and push the gels perpendicularly. After these preparations, one of the five types of reaction force was presented with the haptic device, and the participants were asked to touch it with their eyes closed. Next, they were asked to touch the seven gels in any order as many times as necessary to choose one gel that best matched the feeling of softness presented by the haptic display. They were allowed to go back to the haptic device at any time. Five types of reaction force, four times for each (20 times in total), were presented in random order. We recruited 12 participants (five females, seven males, 21 to 25 years of age) from inside and outside our laboratory. None of them had any experience with the devices in this experiment.

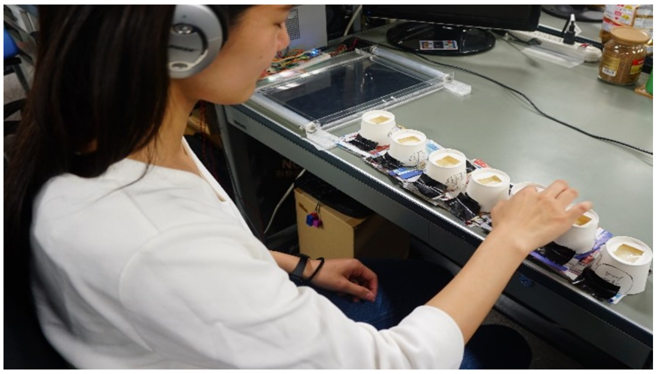

Figure 3: *Overview of Experiment 1.*

4.1.3. Results & discussions

The experimental results are shown in Figure 4. The horizontal axis represents the hardness of the human skin gel and the vertical axis represents the number of answers. The answers have a wide distribution, indicating that the device could present hardnesses from human skin to the eraser. When the presentation of the reaction force was $\frac{1}{2}$ or 2 times the original value, the answers were biased toward hardnesses 21 and 47, respectively. In contrast, the answers for $\frac{1}{\sqrt{2}}$, 1, and $\sqrt{2}$ times the original value tended to be dispersed compared with the other two reaction forces. Nevertheless, a tendency to experience a soft feeling for a weak reaction force and a hard feeling for a strong reaction force was clearly confirmed.

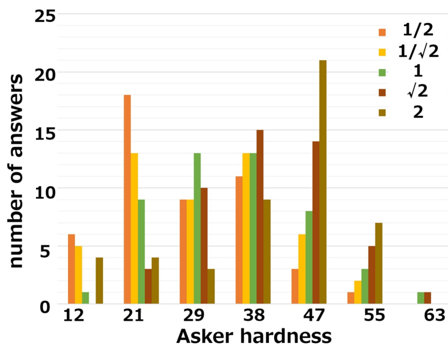

Figure 4: *Distribution diagram for Experiment 1. (Horizontal axis: Asker hardness (unitless). Vertical axis: number of answers.)*

Figure 5 shows the results for the average value of the selected Asker hardness when a reaction force with each coefficient was presented. The horizontal axis is the parameter of the reaction force presentation, and the vertical axis is the averaged Asker hardness. Although the Asker hardness is not a physical quantity with a guaranteed linearity, we simply calculated the average as a simple process this time. From the results of the Bonferroni correction for the analysis of variance, significant differences were found between a plurality of conditions. From this, we can conclude that when a different tangential reaction force was presented using our reaction force presentation device, it was perceived, or at least interpreted, as a different hardness.

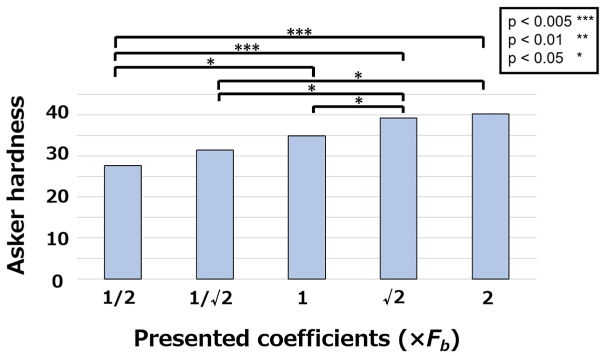

Figure 5: *Average value of Asker hardness when each reaction force was presented. (Horizontal axis: presented coefficients (normalized). Vertical axis: Asker hardness (unitless).)*

4.2. Experiment 2: Evaluation of visual and haptic modulation with a realistic 3D image

The reaction force presentation device we propose here uses a touch panel and a system that provides a visual impression of the vertical deformation. In this experiment, a half-silvered mirror and a real object were used to present a realistic 3D image on a display, and participants evaluated the visual and haptic modulation.

4.2.1. Experimental condition

This experiment evaluated the effect of visual and haptic modulation on a realistic 3D image.

Conditions

The following three conditions for the visual effect were prepared.

(V1) No shadow was presented, as in Figure 2 (a).

(V2) A shadow of constant size was presented, as in Figure 2 (b) (Effect 1).

(V3) A shadow was presented with a diameter that was propotional to the finger displacement, as in Figure 2 (b) (Effect 2).

The following two conditions for haptic presentation were prepared.

(H1) No reaction force was presented.

(H2) Reaction force was presentated.

A total of six conditions were prepared by combining the above conditions. For the reaction force, we used the parameters for the standard conditions in Experiment 1, which were confirmed to represent a hardness of around 38. We prepared a gel with the same hardness as a standard stimulus. The gel was also used for the visual presentation, and the participants saw a mirror image of the gel while using the device (Figure 6). The object was presented on the display using a half-silvered mirror. This method was selected to present a realistic 3D image because it is the simplest method of presenting high-resolution 3D vision without any latency associated with head movement. A black curtain was used to exclude the ambient light. The tablet at the bottom presents visual shadow effect around the user's fingers. The luminance of the display viewed from the observation position through the half-silvered mirror was about 12 cd/m^2, and the luminance of the darkest portion drawn as a shadow was about 3.5 cd/m^2. The mirror image of the gel illuminated from the sides was 66.5-75.7 cd/m^2.

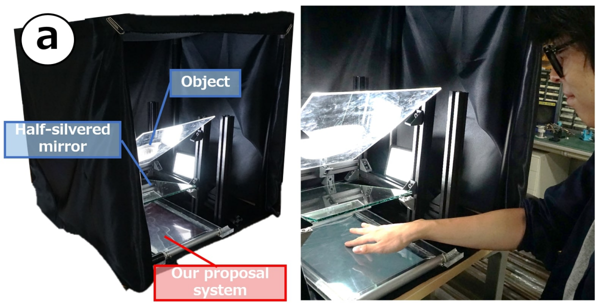

Figure 6: *Overview of Experiment 2: (a) Overall view; (b) Inside view*

4.2.2. Experimental procedure

Participants were asked to sit in front of the system. They adjusted the height of the chair so that they could see the 3D image presented by the half-silvered mirror and could move their fingers freely on the display. Next, they were asked to wear noise cancelling headphones (BOSE, Quiet Comfort 35), which present white noise to block environmental noise, including motor sounds. Next, they were asked to touch the real gel of Asker hardness 38 vertically and remember the feeling as a standard. We then randomly presented one of six combinations of conditions. Participants were asked to touch the image of the gel using the device. At the same time, they were asked to move their fingers about 2.5 *cm* in the forward direction. After each trial, they were asked to evaluate the following five properties using a seven-point Likert scale: 1) hardness of touch (1: hard, 7: soft), 2) visual naturalness (1: unnatural, 7: natural), 3) haptic naturalness (1: unnatural, 7: natural), 4) comfort of the whole experience (1: unpleasant, 7: pleasant), 5) strangeness or incongruity of the whole experience (1: feels strange, 7: does not feel strange). For these properties, the real gel was set to a score of 4. Six combinations of conditions were presented three times, resulting in 18 trials in random order. We recruited ten participants, (three females, seven males, 21 to 25 years of age) from inside and outside our laboratory.

4.2.3. Results & discussions

The results for properties 1 through 5 are shown as boxplots in Figure 7 to Figure 11. The vertical axis represents the score on the Likert scale and the horizontal axis represents the six conditions. The Friedman test revealed significant differences in the main effect between the six conditions in all results. Multiple comparisons using Bonferroni corrections were performed and the results are shown in the graphs.

Figure 7 shows the results for hardness of touch. Significant differences were found in seven of nine combinations of with and without haptic presentation. With haptic presentation, there was a tendency to feel the same or more hardness than the real specimen. On the contrary, when there was no haptic presentation, the feeling tended to be softer. This is probably because the finger was able to move smoothly on the screen without resistance.

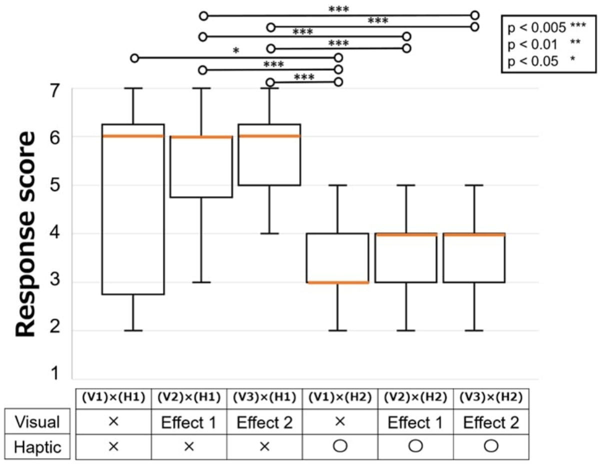

Figure 7: *Results for hardness (1: hard, 7: soft)*

The results for visual naturalness are shown in Figure 8. There were significant differences between the condition with haptic and visual presentation and the condition without haptic and visual presentation. This shows that both visual and haptic presentations contributed to the visual naturalness. In addition, in the four conditions with visual presentation, many people marked scores higher than 4, meaning that it felt visually more natural than touching a real object. This is possibly because the visual effect caused the scene to be closer to the participants' ideal representation of the object in their brain.

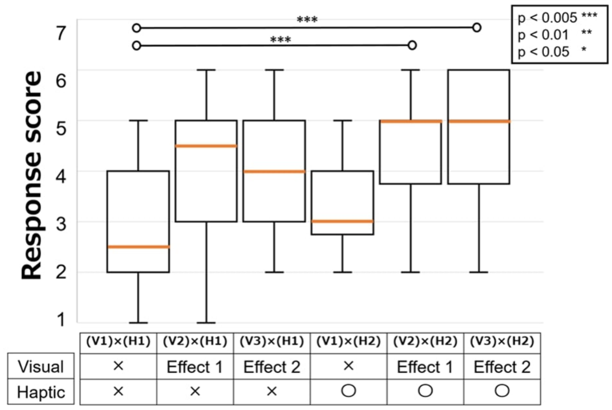

Figure 8: *Results for visual naturalness (1: unnatural, 7: natural)*

Figure 9 shows the results for haptic naturalness. Significant differences were found between seven of the nine combinations with and without haptic presentations. It is predictable that haptic sensation becomes more natural when haptic presentations are presented. However, there was no significant difference between the condition with visual presentation and without haptic presentation and the condition with haptic presentation but without visual presentation. This indicates that haptic naturalness is improved by adding a visual presentation. In addition, with both visual and haptic presentations, the median value exceeded 4, which means that many people considered it to be more natural than touching a real object. As with visual naturalness, this is possibly because the combination of haptic and visual effects made the haptic feeling closer to the participants' ideal representation of the object in their brain.

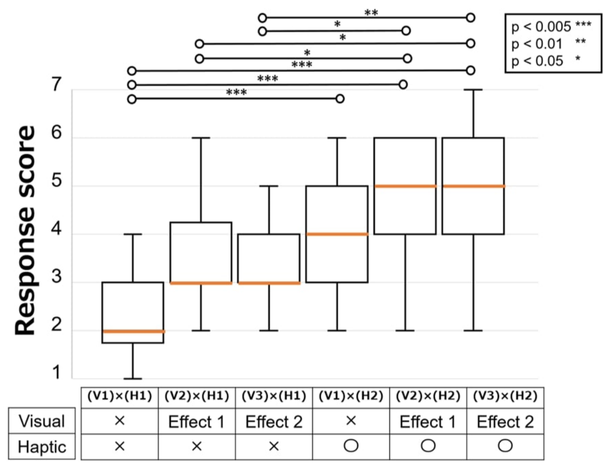

Figure 9: *Results for haptic naturalness (1: unnatural, 7: natural)*

The results for the comfort of the whole experience are shown in Figure 10. Significant differences were found between the four combinations, all including conditions without visual and haptic presentation. Specifically, conditions with haptic presentation always showed significant differences with those without visual and haptic presentation, meaning that haptic presentation is important for the comfort of the experience.

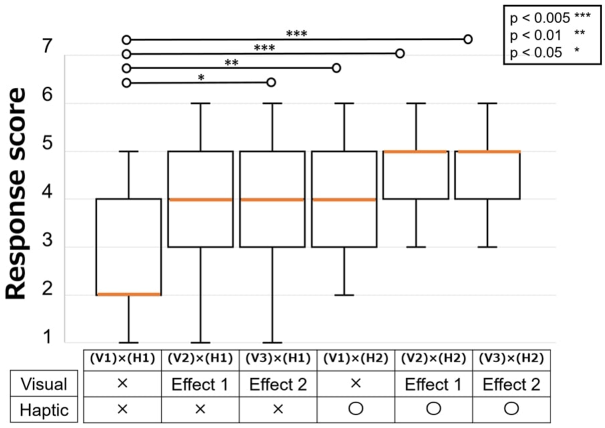

Figure 10: *Results for the comfort of the experience (1: discomfort, 7: comfort)*

Figure 11 shows the results for the strangeness of the whole experience. Significant differences were found between the condition with neither visual nor haptic presentations and all other five conditions. From this, it was found that the sense of incongruity for the whole experience was reduced by visual presentation as well as haptic presentation.

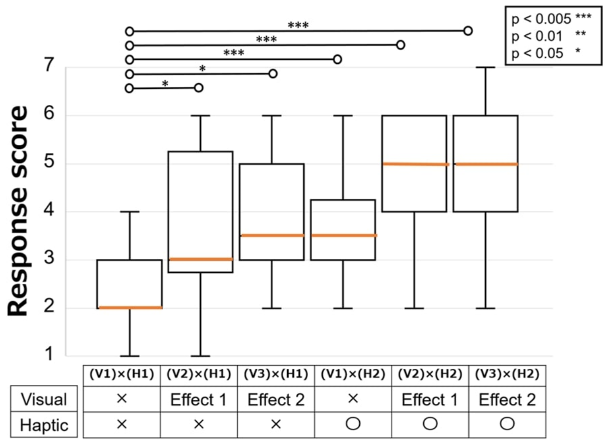

Figure 11: *Results for the strangeness of the whole experience (1: feels strange, 7: does not feel strange)*

4.3. Experiment 3: Modulation comparison between with a 3D image and with a 2D image

In the previous experiment, we showed that it was possible to present and operate a softness sensation not only visually but also haptically, even when the direction of finger movement (tangential) and visual deformation (vertical) were not consistent. One possible explanation is that because the 3D image was presented by a half-silvered mirror, users might have felt as if their hands were moving in 3D space, rather than on a 2D plane, making the direction of the finger movement ambiguous. In other words, when the visual image is 2D, which is mostly the case for ordinary touch panels, the inconsistency in the direction of deformation between the visual and haptic might degrade the experience.

To answer this question, we conducted a comparative evaluation with a 3D image and a 2D image.

4.3.1. Experimental conditions

In this experiment, two types of images and two types of visual effects were presented, comprising a total of four conditions. For haptic presentation, we presented a reaction force that was the same as (H2) in Experiment 2 in all conditions.

Conditions

The following two types of presentation images were used.

(I1) A 2D image of a photograph, as shown in Figure 12 (a).

(I2) A realistic 3D image or a real object, as shown in Figure 12 (b).

In both cases, the half-silvered mirror was used to present a virtual image on the touch panel, as in Experiment 2.

Two conditions from Experiment 2 were used to present the visual effect.

(V1) No shadow was presented, as in Figure 2 (a).

(V2) A shadow was presented with a diameter that was proportional to the finger displacement, as in Figure 2 (b) (Effect 1).

The (V3) in experiment 2 was not employed this time, since neither (V2) nor (V3) showed a significant difference in that experiment. A realistic human face (bio-skin doll) was used as the object of the presentation image, because we considered that the difference between the 2D and 3D conditions was larger than for the simple silicone block used in Experiment 2. We adjusted the luminance of the touch part in each presentation image to be about the same; (I1) was about 169 cd/m^2 and (I2) was about 166 cd/m^2.

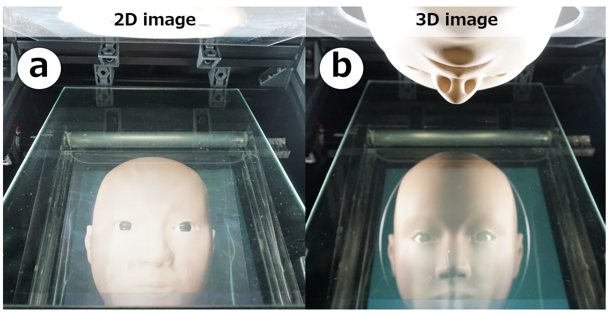

Figure 12: *Presented image (a) 2D image; (b) 3D image*

4.3.2. Experimental procedure

Participants were asked to sit in front of the system. They adjusted the height of the chair so that they could see the 3D image presented by the half-silvered mirror and could move their fingers freely on the display. Next, they were asked to wear noise cancelling headphones (BOSE, Quiet Comfort 35), which presented white noise to block environmental noise, including motor sounds. After becoming accustomed to how to touch the reaction force presentation device, participants were presented with one type of condition randomly from the four. They were instructed to touch the cheek part of the image. After each trial, they were asked to evaluate the following two properties using a five-point Likert scale: 1) softness of the object (1: hard, 5: soft), 2) strangeness or incongruity of the whole experience (1: feels strange, 5: does not feel strange). This time, we did no set a standard stimulation. Four conditions were presented three times, resulting in 12 trials in random order. We recruited nine participants, (two females, seven males, 21 to 23 years of age) from inside and outside our laboratory.

4.3.3. Results & discussions

The results for softness are shown in Figure 13. The four types of effects were presented on the horizontal axis and the response on the vertical axis. The orange line represents the median value. Friedman test revealed no significant difference in the main effect between the four conditions. We can therefore conclude that subjective softness was not affected by the difference in visual presentation, no matter whether it was 2D or 3D or whether or not a shadow was presented.

The results for Experiment 2 suggest that the visual effect was one of the factors affecting the perception of softness. However, there was no effect on softness perception at this time. This difference might be because we used a realistic human face this time, and subjects interpreted their finger movement as a stroking action, which is generally more gentle and appropriate human behavior, rather than a pushing action.

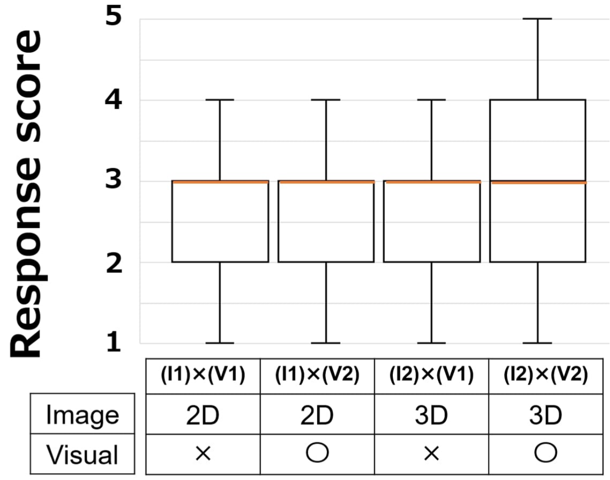

Figure 13: *Results for softness (1: hard, 5: soft)*

Figure 14 shows the results for strangeness of the whole experience. Significant differences were found between the pair with 2D/3D image representations. Even though softness sensation was not affected by 2D or 3D representations, strangeness, or some sort of mismatch did emerge when changing from 3D to 2D. There were several comments after the experiment that there was a feeling that the 2D image was impressed on the top of the photograph and that subjects felt like they were just tracing the image. It is possible that the 3D image presentation effectively made the direction of the finger movement ambiguous, making it feel less strange, whereas in the 2D image representation, the inconsistency in the direction of deformation between the visual and the haptic became apparent.

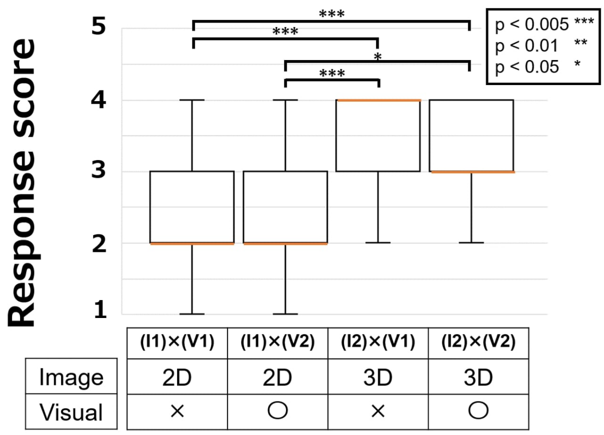

Figure 14: *Results for the strangeness of the whole experience (1: feels strange, 5: does not feel strange)*

5. Conclusion

This paper proposes a new visuo-haptic system with the aim of developing a touch panel capable of presenting hardness and softness with a practically simple setup. Softness was expressed by haptic and visual modulation with a tangential reaction force presentation device that used a belt winding mechanism driven by DC motors and by a visual effect on the touch panel, the softness was expressed by haptic and visual modoulation. The evaluation results confirmed that the device could present a sensation of softness, although the direction of finger motion and visual expression were not consistent. Regarding the presentation image, neither a 2D image nor a 3D image was found to affect softness perception, but a sense of incongruity was observed when using a 2D image. In future studies, we will explore more suitable environments and conditions that will avoid the feeling of incongruity when using 2D images. We also plan to develop interactive application content for our proposed system.

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