Rendering Method of 2-Dimensional Vibration Presentation for Improving Fidelity of Haptic Texture

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***Abstract*—In recent years, touchscreens have been used all over the world, however, most of them are without realistic haptic feedback. Some of them have feedback, but most of them have vibration direction limited to one direction. Here we propose a novel rendering method for direction-controlled 2-dimensional vibration display to present texture information. In this paper, we proposed a dimension-controlled rendering method of texture information that enables vibration control in the X and Y-axis precisely by using lateral force. Further, to improve the fidelity for large-scaled texture, we proposed to combine image features information of the textures. We held an experiment to evaluate the fidelity of the proposed method. The result shows that the proposed method can present randomized textures and large periodic textures more precisely than the conventional method.**

Keywords–Haptic Rendering; Vibrotactile display.

I. INTRODUCTION

In recent years, touchscreens have been used all over the world due to the spread of smartphones and the like, however many of them do not have realistic vibrotactile feedback. At the research level, several haptic devices using a liquid crystal panel have been developed. For example, Chubb et al. developed a haptic device employing friction change induced by squeeze film effect[1], and Konyo et al. proposed vibration frequency control and virtual pointer [2]. Wang et al. developed a sliding system using shear force [3]. These vibration stimuli realize high reproducibility, though, the direction of the vibration is limited to one-dimension. This is because it has been found that receptors transmitting vibrational stimulus in the skin cannot discriminate the direction of vibration[4]. For this reason, the direction of vibration has not been regarded as much importance in the tactile research so far, and most of them have employed one-dimensional vibration.

However, there is some distribution of the receptors in the skin. Thus, the input signals from multiple receptors may induce discrimination of multi-dimensional vibration. In this paper, we propose a rendering method to reproduce biaxial acceleration information through our lateral-force-displaying device using X–axis and Y-axis vibration information. We report the results of experiments on the reproducibility of tactile sensation by comparing the conventional method and proposed one. We propose a novel rendering method to display multi-dimensional vibration. Further, to improve the fidelity for large-scaled texture, we proposed to combine image features information of the textures. We held an experiment to evaluate the fidelity of the proposed method. The result suggests that the proposed method can present randomized textures and periodic textures more precisely than the conventional method.

II. PRESENTATION OF TACTILE TEXTURE INFORMATION USING VIBRATION

Many researchers are considering methods of presenting tactile texture information using vibration information from various viewpoints [5], [6]. Romano et al. proposed a method for recording texture on a tablet by recording acceleration, position, and contact force overtime when touching a texture with a dedicated tool [7]. Saga et al. proposed a simpler recording/playing method by omitting the measurement of pressure and using a compensation method when reproducing vibration [8]. They reproduce the sense of direct touch by recording vibration information with fingers and reproducing the recorded information by using the shearing force presentation device.

III. METHODS

We extend the method of Saga et al. and propose a method to accurately record the vibration information on the X and Y axes and reproduce it on our device.

A. Recording phase

The triaxial acceleration sensor (ADXL - 335) is fixed to the finger with tape and the acceleration information is recorded from several textures. Since Saga et al. recorded acceleration information by the audio input, it was recorded as one-dimensional data. In this research, to accurately acquire three-dimensional data, acceleration information was processed by a microcontroller, Arduino, which packs three-axis information as one packet and transmitted to a PC using serial communication. On the PC, packed vibration information was unpacked and recorded by the Processing application.

The acceleration is sampled at 1 kHz. To accurately present the recorded vibration direction and reproduce faithful vibrations, using correct vibrations which are suitable for the user ' s movement direction is essential. Therefore, when recording vibration information, we stored vibration separately not in one direction but two directions, X and Y-axis. This makes it possible to more accurately reproduce vibrations not only for textures that give similar vibrations regardless of the direction in which the fingers are moved but also for textures with significantly different vibrations depending on the direction in which the fingers are moved.

B. *Display phase*

Reproduction of vibration is carried out by using pre-recorded vibrations in two directions and a shearing force presenting device. In the presentation phase, vibration patterns are generated by using the vibration information of these two directions.

The compensation method used by Saga et al. resampled the acceleration by using the ratio of the moving speed of the finger during recording and playing. In our proposed method, we use a new compensation method extended the method of Saga et al. in this experiment. The compensation method is described below.

First, information to be recorded and reproduced is defined (The superscript **D** =X,Yrepresents the direction of movement, r and p represent the phase of record or play).

$$\mathbf{a}_r^{\mathscr{D}}(t_r) = \begin{pmatrix} a_{rx}^{\mathscr{D}} \\ a_{ry}^{\mathscr{D}} \end{pmatrix} \qquad (1)$$

The t_r shows the elapsed time in the recording phase. The finger position $\mathbf{X}_p$ during playing phase is obtained, and the finger movement speed is derived from the following value.

$$\mathbf{X}_p(t_p) = \begin{pmatrix} x_p \\ y_p \end{pmatrix} \qquad (2)$$

At this time, the moving speed of the finger during playing phase ($\dot{\mathbf{x}}_\mathbf{p}$) is calculated using the moving distance in unit time ΔT.

$$\dot{\mathbf{x}}_\mathbf{p} = \frac{\Delta \mathbf{X}_p(t_p)}{\Delta T} = \begin{pmatrix} \frac{\Delta x_p}{\Delta T} \\ \frac{\Delta y_p}{\Delta T} \end{pmatrix} \qquad (3)$$

Because the elapsed time between frames during recording and playing phase should be the same, the presented vibration is calculated using the ratio of recording speed $\dot{\mathbf{x}}_\mathbf{r}$ and playing speed $\dot{\mathbf{x}}_\mathbf{p}$.

$$\mathbf{a}_p^{\mathscr{D}}(t_{p_{n+1}}) \quad = \quad \mathbf{a_r}^{\mathscr{D}}(t_{p_n} + \frac{|\dot{\mathbf{x}}_\mathbf{p}(t_{p_n})|}{|\dot{\mathbf{x}}_\mathbf{r}(t_{p_n})|}\Delta T) \qquad (4)$$

In this experiment, the moving speed in the recording phase, $\dot{\mathbf{x}}_\mathbf{r}$ = 5 cm/s. In the playing phase, the vibration is presented using the $\mathbf{a}_p^{\mathscr{D}}(t_{p_{n+1}})$ (Eq. 5), which is a linear joint of a^X anda^Y . As shown in Figure 1, depending on the movement direction, switch the acceleration information. If the movement vector of the user's finger is (α, β), the presented acceleration $\mathbf{a}_p(t_{p_{n+1}})$ is obtained using the following formula

$$\mathbf{a}_p(t_{p_{n+1}}) = \left|\frac{\alpha}{\sqrt{\alpha^2+\beta^2}}\right| \mathbf{a}_r^X(t_{p_{n+1}}) + \left|\frac{\beta}{\sqrt{\alpha^2+\beta^2}}\right| \mathbf{a}_r^Y(t_{p_{n+1}}) \qquad (5)$$

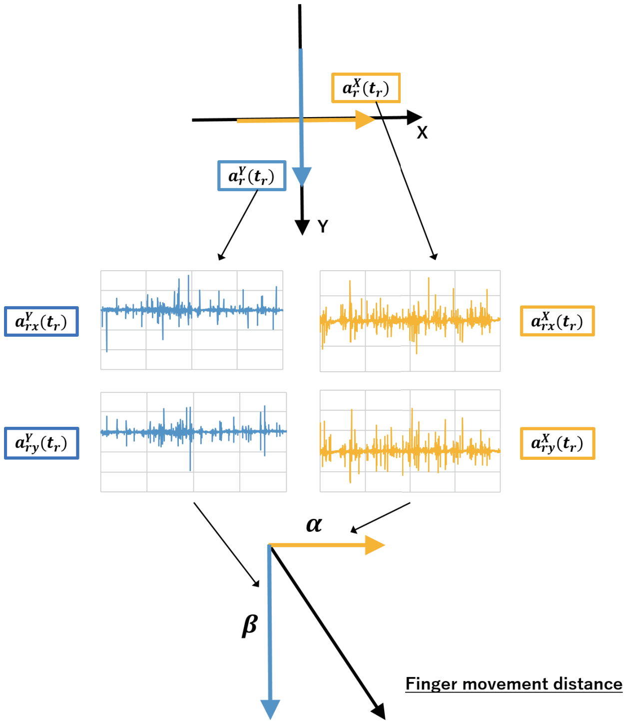

Figure 1. Presentation method of vibration according to the movement direction of the finger

IV. SUPERPOSITION INFORMATION OF IMAGE FEATURES

The proposed method has a problem that tactile reproducibility decreases for a texture having a certain spatial frequency (e.g., tiled-floor). Hence the fidelity of the texture decreases. We considered that the problem is caused by the periodicity and continuity of the presented vibration. Therefore, we propose to combine another rendering method to resolve this problem by employing image information.

A. *Recording of image features*

To solve the problem in displaying larger periodic textures, we propose a vibration presentation method using image features. The parameters of feature points, such as size and angle, are considered to represent some texture information. Therefore, our method extracts the information contained in the texture image, processes it into a one-dimensional form that can be used for augmenting vibration. The procedure of presenting the actual vibration information and image information by augmentation is shown below. OpenCV is used for image processing. The procedure is described below;

1) Acquire features from texture images using AKAZE
2) Extract the size information representing the diameter of the important region around the feature
3) Obtains one-dimensional information by averaging information in each of the x-axis and y-axis directions and then normalizing
4) Augment the size information corresponding to the display position on the vibration information and presented

As large periodic textures, we used a self-made texture of a tile pattern made of polylactic acid (PLA). Figure 2 shows

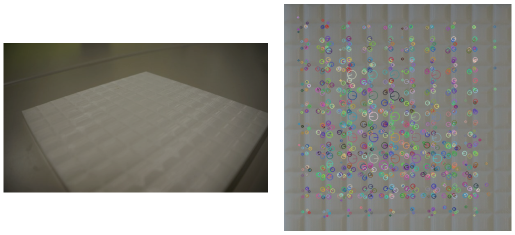

Figure 2. (left)self-made texture : (right)image future

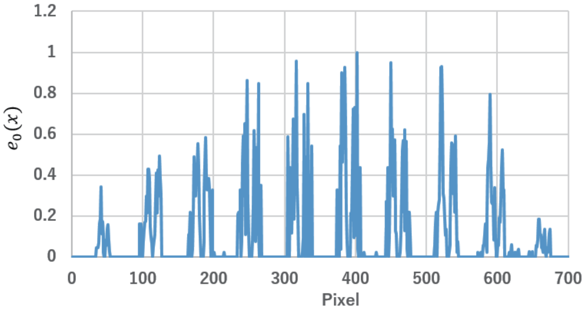

Figure 3. Image features extracted from self-made tile texture

the result of the extraction of image features from the image of the self-made texture.

Image features can also be acquired for textures with other certain spatial frequencies in the same way, and by superimposing image features corresponding to finger positions on texture vibration information, it is effective for textures with low tactile reproducibility vibration is presented. Figure 3 shows one-dimensional image features extracted from a self-made tile texture $(e_0(x))$. Further, to avoid the diminishing of vibration at no feature area, we also prepared normalized features after applying a logarithmic function to the image features $(e_1(x))$. Figure 4 shows a normalized image features$(e_1(x))$.

B. *Presentation of vibration information using image feature*

The presented vibration is calculated by the following equation. ax, ay is the presentation vibration on the x-axis and y-axis, and e is the size information of the image feature to be superimposed.

$$a(x,y) = a_x e(x) + a_y e(y) \tag{6}$$

By using this presentation method, it is possible to emphasize and present only the characteristic parts of the texture. Figure 5 shows the vibration information before the image feature is augmented, and Figure 6 shows the vibration information after the image feature is augmented. Figure 7 shows the vibration information after the augmentation of $e_1(x)$.

V. EXPERIMENT

A. *Experiment preparation*

We used 10 textures for an experiment. The textures are the following; soft artificial grass1 which is close to natural grass, artificial grass2 which is harder than natural grass, stiff carpet1, soft carpet2, self-made tiled texture, 40 coarse sandpaper, three types of placemats with different feels, and punched plastic plates. Figure 8 shows the image of the texture used in the experiment.

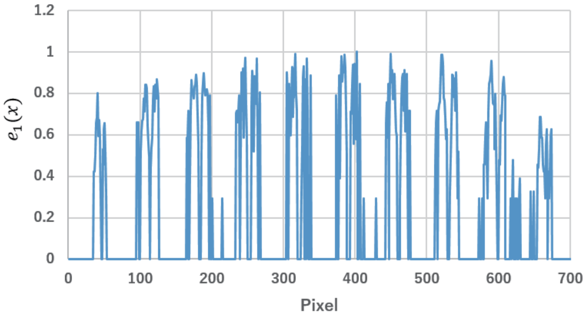

Figure 4. Image features with logarithmic function

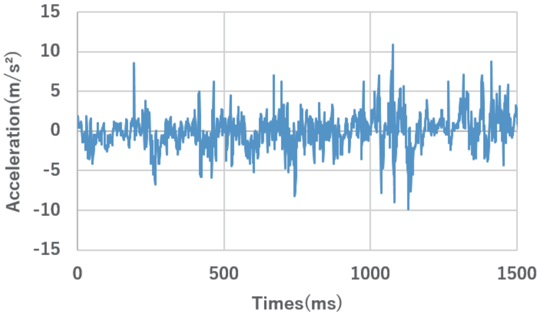

Figure 5. The vibration information before the image feature is superimposed

Participants were 6 healthy men aged 22 to 24. During this experiment, they wear eye masks to block visual information and headphones to block external sounds. They were all right-handed, and they used their right index fingers for rubbing movement.

B. *Experiment procedure*

We compared several rendering methods of vibration for each texture. 5 stages Likert scale were used for evaluation.

1) Ask the subject to touch the sample texture placed on the weighing scale and train them so that the pressing force to be kept about 50 gf for 5 minutes
2) Have they touch the real texture for 10 seconds to learn the tactile sensation
3) Ask them to touch the texture presented on the display for 10 seconds and evaluate it in five steps how much the texture have fidelity
4) Change the presentation method and have it evaluated in the same way as steps 2 and 3.
5) Only when the texture to be displayed was a large periodic texture, a method of augmenting image features is also used, and the user is asked to select whis is the better method for fidelity, $e_0(x)$ or$e_1(x)$
6) After completing steps 2 to 5 for all ten types of textures, we finished the experiment.

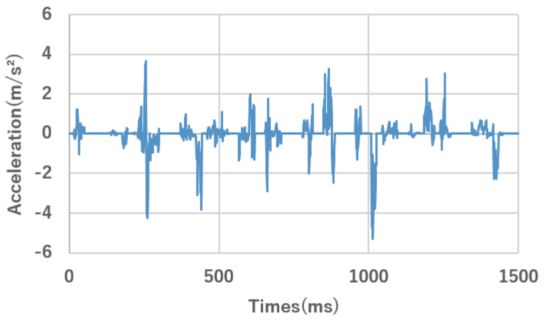

Figure 6. The vibration information after the image feature is superimposed

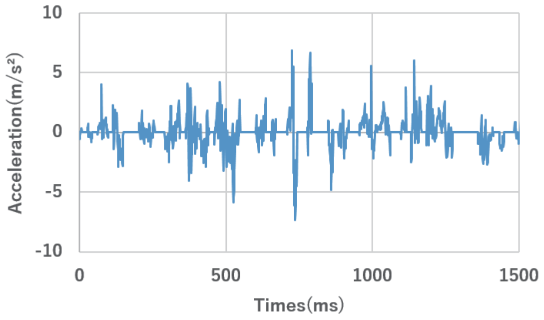

Figure 7. the vibration information after the image feature to which the logarithmic function is applied is superimposed

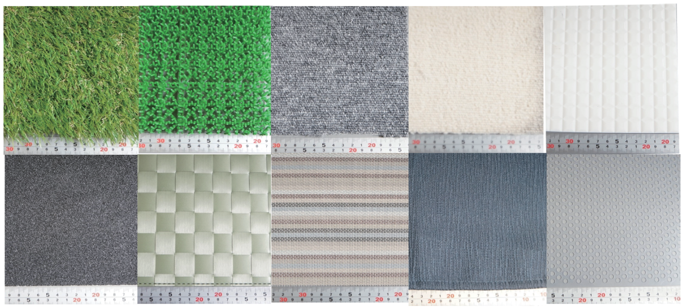

Figure 8. Texture used in experiment

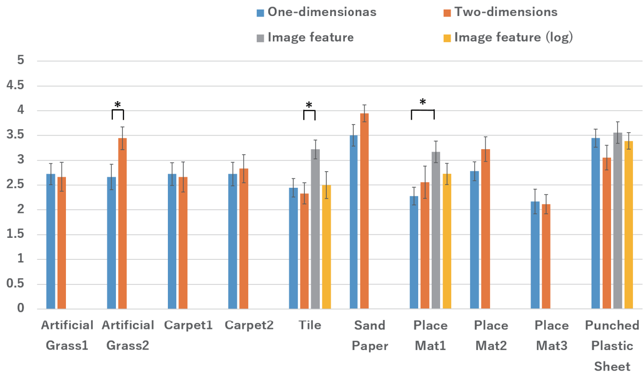

Figure 9. Result of reality evaluation

To eliminate the influence of the order effect, experiments are conducted by changing the order of presenting patterns for each subject.

VI. RESULTS AND DISCUSSION

A. *Reality of virtual texture*

The results of reality evaluation of the virtual texture are shown in Figure 9.

The proposed two-dimensional vibration rendering method was evaluated higher than the one-dimensional vibration presentation in artificial grass 2, carpet 2, placemat 1, and placemat 2 (Figure 9). However, as a result of Tukey ’ s test, no significant difference was obtained for textures other than artificial grass 2. We consider the reasons as follows. Among the textures that were highly evaluated for the two-dimensional vibration presentation, the following textures, artificial turf 2, sandpaper, and mat 2, have random spatial frequencies. Also, although no significant difference was obtained between sandpaper and mat 2, both scores exceeded 3.0. This suggests that our two-dimensional vibration presentation method is good at presenting textures with random spatial frequencies. With soft textures,such as artificial grass 1, carpet, and mat 3, there was no significant difference between the one-dimensional and two-dimensional vibration presentations. Our proposed method records vibrations in the X-axis and Y-axis directions and selects and presents vibrations by the direction of finger movement, making it easier to generate random-period vibrations than one-dimensional vibrations it is conceivable that. In particular, since the display surface is a hard material, it can be said that the evaluation of a texture having a hard random spatial frequency tends to be high. This may be related to the perception of softness due to the change in the contact area between the finger and the texture.

B. *Evaluation of image feature superposition method*

From Figure 9, as you can see that for some textures, the presentation method that augments image features on vibration information is highly evaluated.

From the two results, the proposed two-dimensional rendering method is suitable for presenting materials with random spatial frequencies (artificial grass 2 and sandpaper 2). In other words, it is not suitable for presenting materials with certain spatial frequencies (e.g., tile). We will discuss the reasons for this result. In the proposed method, independent vibrations are presented on the X-axis and the Y-axis, and it is speculated that vibrations with random periods are likely to occur, depending on the direction in which the finger is moved since the subject can freely move the finger during the experiment. However, it is difficult to present a periodic vibration. Also, the larger the period of the real texture, the easier it is for the users to recognize the periodicity. Therefore, the reality of the virtual texture tends to be lower when compared to the real texture. For these reasons, the users felt fidelity on materials with random spatial frequencies. On the other hand, they couldn ’ t feel fidelity on materials with large periodic patterns. Since the texture of tiles, place mat1 and punched plastic sheet has large periodic patterns, it is considered difficult to reproduce it with the two-dimensional rendering method.

However, from the results of the image feature-based rendering method, we found the method can display large periodic

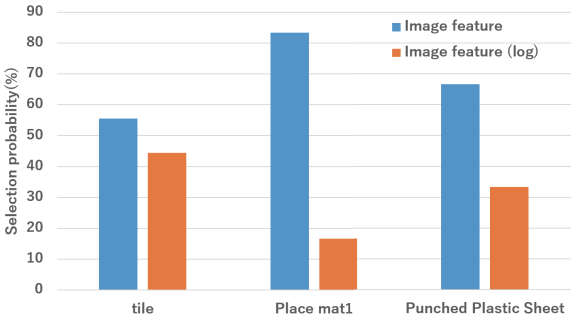

Figure 10. Result of reality evaluation

patterns. By using the image feature, we can emphasize the characteristic part of the texture. Figure 10 shows the result of selecting the higher evaluation one of the two image feature augmentation methods.

The method that did not apply the logarithmic function$(e_0(x))$ in all three textures received higher ratings. We consider the reason for this result. The method using a logarithmic function for image features $(e_1(x))$ reduced loss of vibration information but also reduced feature enhancement. In particular, since place mat1 has the longest distance between features among the three textures, that the periodicity of the features seemed to contribute more to the fidelity than the magnitude of the vibration. Also, the score of the punched plastic sheet texture exceeds 3.0 even in the case of a two-dimensional vibration presentation, although the texture has a certain spatial frequency. This is probably because the distance between feature points of the texture is small and it is difficult to recognize a constant period. This indicates that the two-dimensional vibration presentation method is not good at presenting textures that have a constant and large period.

VII. CONCLUSION

We proposed a method to record the vibration of a texture tracing using a three-axis acceleration sensor and reproduce it as faithfully as possible in two dimensions. Experiments show that our proposed method is suitable for displaying textures with random spatial frequencies. In addition, we proposed a presentation method that combines image features, and succeeded in improving the reproducibility of textures that are difficult to present.

ACKNOWLEDGMENT

This work was partly supported by JSPS KAKENHI 18H04104G1 (Grant-in-Aid for Scientific Research (A)) and 19K2287900 (Grant-in-Aid for challenging Exploratory Research).

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