Toward the Modeling of Tactile Sensation on Electrostatic Tactile Display

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ABSTRACT

As one method of displaying tactile sensation on the touchscreen, electrostatic tactile displays have been developed. We evaluated the magnitude of tactile sensation on an electrostatic tactile display. Based on the result, we proposed a preliminary model to predict the magnitude of tactile sensation from the results of several input waveforms.

1 INTRODUCTION

Touchscreen interfaces have become increasingly popular worldwide. At the same time, numerous popular consumer electronics devices use a dedicated touchscreen as an interface. However, few touchscreens enable reactive tactile signals. Tactile display is needed to give tactile feedback to the user. Stimulus given to the user from the tactile display includes mechanical stimulation, temperature stimulation, electric stimulation. Several researchers have employed vibrations to display texture information. For example, Chubb, et al. [1] developed a tactile display that employs a squeeze film to represent the change in friction. Their devices provide simple but rich lateral force to the user's finger. Moreover, Saga et al. [2] proposed a method of feeling both large bumps and small textures simultaneously on a screen.

In recent years, other lateral-force-based tactile feedback devices that employ static electric fields have been developed (Senseg, Inc., Bau, et al. [3]). The sensation of electrostatic force is affected by various conditions. For example, different shapes of input waveform induce different sensations to the user. Related surveys, dealing with the effect of input frequencies, waveform or amplitude modulations etc., are conducted by many researchers [3, 4, 5, 6]. However, a model between input waveform and tactile stimulation has not been clarified.

In this research, we focused on evaluating how the user feels about the electrostatic-force-based tactile stimulation. Our goal is to create a model based on this evaluation result. Such a model could be an indicator of signal design in tactile presentation.

2 ELECTROSTATIC STIMULATION DEVICE and EVALUATION METHOD

2.1 Electrostatic Stimulation Device

Our electrostatic force displaying device is composed of a personal computer, a control circuit of high voltage, electrodes and an insulator. A personal computer is used to control the microcontroller on the high voltage circuit. The microcontroller generates any waveform output from the high-voltage generator. The high-voltage generator is developed by Kajimoto laboratory (The University of Electro-Communications, Tokyo). The device includes a microcontroller, called mbed, which controls maximum 600 V of output voltage by modifying its firmware. Thus, the waveforms are outputted to the electrode surface for displaying electrostatic tactile feedback.

The electrostatic force is generated when the user touches the display with his/her finger, and slides the finger on the display. When high voltage is applied to the electrode, the dielectric polarization is generated in the finger. In this state, the electrostatic force generates an attractive force to the finger, but the generated force is too weak for the user to sense. However, (s)he can feel tactile sensation only when (s)he slides his/her finger on the display. By controlling the applied voltage pattern to the electrode, the sensation can be controlled. We investigated the relationship between voltage pattern and the felt tactile sensation with our system.

2.2 Magnitude Estimation Method

Our goal is to obtain guidelines for input signal design on electrostatic tactile display; we have investigated the magnitude of tactile sensation for each frequency and described the evaluation experiment of the magnitude of tactile sensation using magnitude estimation [7].

The magnitude estimation method is an evaluation method for evaluating how much two objects differ. In this experiment, two tactile display devices are prepared; one device presents the reference tactile stimulus to the participant, while the other device presents the tactile stimulus to be compared by the participant. The magnitude of reference tactile sensation was set to 1.0. We asked the participants to compare the magnitude of tactile sensation between the two stimuli. If the tactile stimulus to be evaluated is weaker than the magnitude of reference tactile sensation, the participant answers with a number smaller than 1.0. Conversely, if the tactile stimulus is stronger, the participant answers with a number larger than 1.0.

2.3 Experiment Design

We held an experiment with regard to the feelings of magnitude on electrostatic force display with 10 participants aged 21-23 years old. We explained the informed consent (based on ethical guidelines of University of Tsukuba) to all participants and obtained their consent. After the collection of participants' answers of the magnitude tactile sensation in all waveforms, these answers were normalized from 0.0 to 1.0 by dividing all the values by the maximum value. The participants touched the tactile display using the right index finger, irrespective of their dominant hand. A sine wave of 300 Hz was used as an input waveform for the reference tactile stimulation.

3 EVALUATION EXPERIMENT

In our previous research, we have prepared four types of input waveforms, and 20 frequencies from 10 Hz to 800 Hz of each waveform [8]. From the result of this experiment, the characteristics of the graph were divided at around 100 Hz. The cause of this result was considered to be the frequency component of the waveform. However, the input waveforms used in the previous research were insufficient because the number and trends of the frequency components of prepared waveforms are ad hoc (sine, saw-tooth, rectangular, and impulse function).

3.1 Input Waveforms

In this paper, eight input waveforms which differ in their frequency components (shown in Fig. 1) were prepared to investigate the detailed relationship between the frequency component and the magnitude of tactile sensation. For example, each of the input waveform #2 and #3 has the same number of frequency components, however, the amplitude intensities of the components are different. The relation is also the same as #5 and #6, or #7 and #8. The experiment using the waveforms was conducted with 10 participants in the same experimental environment, that is, the room temperature, the equipment, and the reference tactile stimulation, as the previous research.

3.2 Result

Fig. 2 shows the evaluated result of a magnitude of tactile sensation for each input waveform. The vertical axis of this graph shows the normalized magnitude of tactile sensation. The horizontal axis of Fig. 2 shows the dominant frequency of input waveform. This graph shows the averaged result of the magnitude of tactile sensation answered by all participants. From the result of this experiment, the characteristics of the graph were divided at around 100 Hz. As a boundary, the frequency of 100 Hz divides the peak of the sensitive frequency of each waveform in two patterns. Waveform #7 and #8 have their peaks of sensitivity in lower frequency than 100 Hz, and vice versa.

3.3 Discussion

Fig. 2 shows that the peak frequency of sensitivity seems to change based on the frequency component of the input waveform. Although the graphs of the six perceptual intensities are slightly different, it is difficult to confirm the difference from the graph. This approximation equation was considered based on characteristics common to all the graphs of experimental results. All the graphs are upward convex, and these peaks are around 100 Hz. The graph of the magnitude of tactile sensation is considered to be a graph like a Gaussian function in a semilogarithmic graph. Therefore, we approximate the graph of the magnitude tactile sensation to the following Gaussian function (eq. 1) and find the relationship between frequency component and tactile sensation by comparing parameters for each input waveform.

$$G(f) = a + b\exp\left(-\frac{(\log_{10} f - \log_{10} \mu)^2}{2\sigma}\right) \qquad (\mathrm{eq.\,1})$$

The blue bar in Fig. 2, Fig. 3 and Fig. 4 show the parameters when all the graphs are approximated to eq. 1. Parameter "a" is close to 0 in the most input waveform. The parameter "μ" the peak frequency of sensitivity, changes as the tendency of the amplitude intensity of the frequency component changes. As you can see in left sides of Fig. 1, the power of components in waveform #3, #6, and #8 are decreasing according to the frequency change. On the other hand, those of waveform #2, #5, and #7 are increasing. In each pair of the waveforms which have the same number of frequency components such as the green frame in Fig. 1, the value "μ" of the waveform in the power-increasing group is lower than that of the decreasing group. Increasing parameter "σ" widens the deviation of the graph, so there is a wide frequency band that is strongly felt. For example, waveform #7 has a large "σ". The reason for these results is considered to be related to the frequency components and the frequency responses of mechanoreceptors (Pacini, Meissner, Merkel, etc.). When the dominant frequency is 20 Hz, input waveform #7 has a frequency component of 180 Hz with large amplitude. Such a frequency component will stimulate mechanoreceptor even if the dominant frequency of the input waveform is low, thus the parameter "μ" decreases and the parameter "σ" increases in waveform #7.

Thus, we set up a hypothesis that the magnitude of tactile sensation could be predicted with the frequency component.

4 Prediction Model of Magnitude of Tactile Sensation

There is highly reactive frequency band for each mechanoreceptor. The magnitude of tactile sensation is decreased when frequency of waveform is out of that frequency band. We considered the magnitude of tactile sensation is able to be estimated by multiplying characteristic of mechanoreceptor and the frequency component. Thus, we made a prediction model equation (eq. 2) to predict the magnitude of tactile sensation.

$$R(f) = \sum M(f_n)\, C(f_n) \quad , \quad (f_0 = f\,) \qquad (\text{eq. }2)$$

$R(f)$ shows the predicted magnitude of tactile sensation. $C(f_n)$ shows the frequency component of input waveform. $M(f_n)$ shows the base of the magnitude of tactile sensation by mechanoreceptor for each input frequency f. When input waveform is sine wave, the predicted magnitude $R_{sin}(f)$ has only $M(f_n)$, so $M(f_n)$ can be replaced by $R_{sin}(f)$ (eq. 3).

$$R(f) = \sum R_{sin}(f_n)\, C(f_n) \quad , \quad (f_0 = f\,) \qquad (\text{eq. }3)$$

Our proposed model can predict the magnitude of tactile sensation for any input waveform when the magnitude value whose input waveform is sine wave is known. We calculated the magnitude of tactile sensation by using our proposed model for input waveform, and approximated it to the following Gaussian function. The orange bar in Fig. 2, Fig. 3 and Fig. 4 shows the parameters of approximated result in all input waveform.

We compared acquired parameter by the evaluation experiment and predicted parameter by our proposed model. Table 1 shows this comparison. Regarding parameters “a” and “b”, acquired parameter and predicted parameter are almost the same. We consider that these parameters can be predicted by our proposed model. However, this does not work for parameter “μ” and parameter “σ”. As you can see in Table 1, it is shown that the correlation coefficient of parameter “μ” is high. We consider that “μ” is predicted by our model. The parameter “σ” has a low correlation; we consider that it is not predicted by our proposed model now. Thus, our model needs to take further experimental environment (e.g. moisture, permittivity of insulator, etc.) into account in order to predict parameter “σ”.

We plan to perform more precise experiments under several different experimental environments.

5 CONCLUSIONS

In this paper, we focused on evaluating the magnitude of tactile sensation. Our evaluation was performed using the magnitude estimation method. We prepared eight input waveforms based on the frequency component. The tendency of the magnitude graph was different between low frequency and high frequency. We approximated the magnitude of tactile sensation to a function based on a Gaussian function to compare all graphs of the magnitude of tactile sensation, and hypothesized the relationship between frequency component and the magnitude of tactile sensation by comparing the parameters of the Gaussian function. Thus, we propose a model where the magnitude of tactile sensation could be predicted with the frequency component. We found that experimental value can be almost predicted by calculating the magnitude of tactile sensation with our proposed model. We consider that our model needs to take further experimental environment (e.g. moisture, permittivity of insulator, etc.) into account in order to predict accurately.

In the near future, we plan to perform more precise experiments under several different experimental environments.

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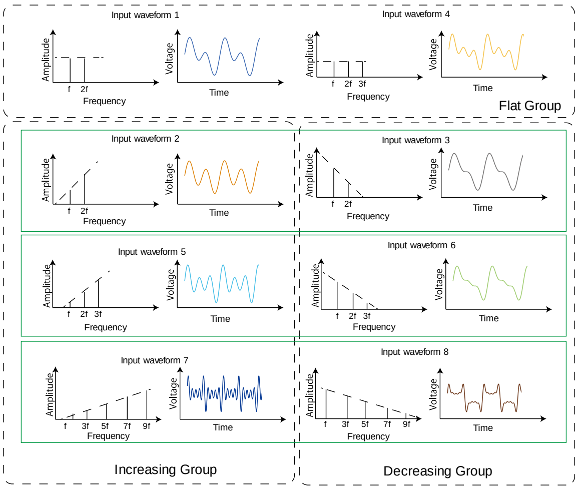

Fig. 1 Input waveforms

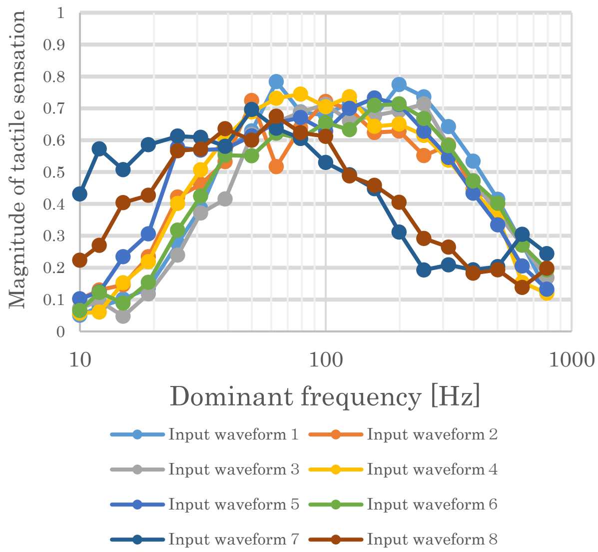

Fig. 2 Result on magnitude of tactile sensation

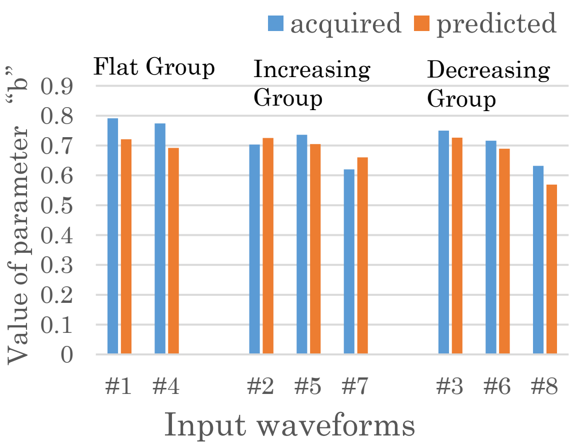

Fig. 3 Result of parameter “b” for acquired value and predicted value

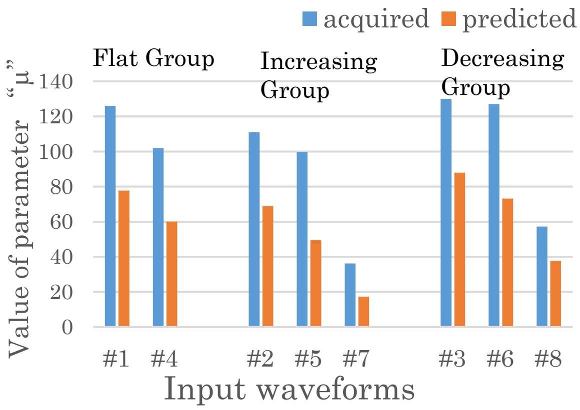

Fig. 4 Result of parameter “μ” for acquired value and predicted value

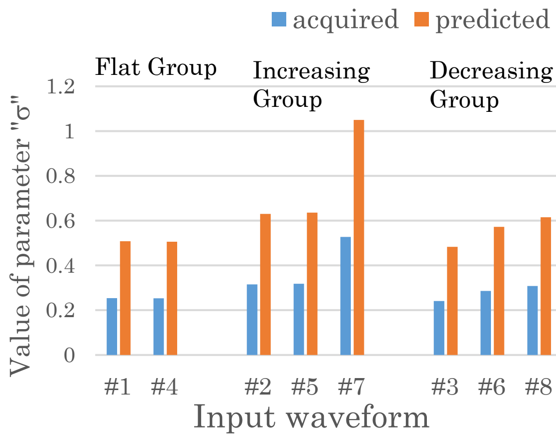

Fig. 5 Result of parameter “σ” for acquired value and predicted value

Table 1 Comparing experimental parameter and predicted parameter

	average error	correlation coefficient
a	0.00	0.657
b	0.0450	0.728
μ	39.8	0.968
σ	0.172	0.297