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Softness Presentation via Friction Force Control on Electrostatic Tactile Panel Display

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***Abstract*—This study proposes a softness presentation method for when the finger slides on a hard touch panel. Herein, an electrostatic tactile display was made to present a friction stimulus, the frequency of which was changed by virtue of the normal force and speed of the finger. Such a stimulus imitates the stick-slip phenomenon that occurs between soft materials. In the experiment where four types of stimulus conditions were ranked, one of which was a control condition with no active friction stimulus, the new stimulus and previous method that presented a constant low-frequency friction were subsequently determined to be the softest among the four stimulus condition types.**

I. Introduction

Substantial demand exists for the presentation of tactile feedback on a touch panel. Many studies have introduced methods for texture presentation; however, softness presentation on a hard touch panel is challenging because the panel surface itself is hard. For achieving perception of softness, earlier studies focused on the pushing motion that can be reasonably employed to explore material softness. However, because the touch panel is inherently hard and does not deform by virtue of a finger's force, pushing against it is not particularly meaningful. Therefore, different approaches should be studied when a hard touch panel is involved. To date, only a few studies have attempted to present softness on a hard panel.

Some studies have presented softness by using low-frequency vibrotactile stimuli [1]–[3]. In our previous study [4], we found that low-frequency friction stimuli present the sense of softness when the finger slides on a touch panel. Ours was the first study to present softness while the finger slid along a hard panel. Furthermore, the rubbing motion is also frequently used for exploring soft objects, in addition to pushing. Arakawa and Okamoto demonstrated that surface friction influenced the softness perceived when a finger was made to slide on the surface [5]. Hence, softness presentation using friction stimuli can be a practical solution in the case of a finger sliding along a hard panel.

Friction between the finger and a soft object is affected by not only the normal contact forces but also the finger speed [6], [7]. Therefore, effective softness perception can be achieved upon employing dynamic change of the friction on the panel according to the finger force and motion. In this study, we investigated the effects of a new method for controlling the friction force between the touch panel and finger for presenting softness and achieving perception of it.

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(a)

(b)

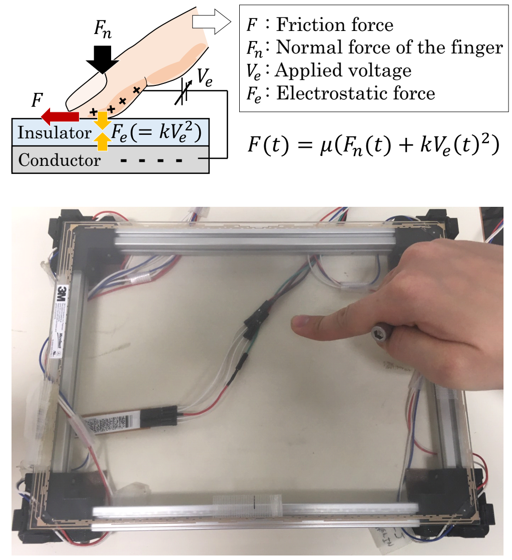

Fig. 1. Structure of electrostatic tactile display. (a) Principle of electrostatic tactile feedback. (b) Photograph of electrostatic tactile display. Participants were instructed to grip the ground rode to improve the effectiveness of electrostatic feedback.

II. Electrostatic Tactile Display and Friction Stimuli

A. *Equipment*

The device manipulated the friction force between the finger and touch panel by controlling the attractive electrostatic force induced by the applied voltage between the finger and the touch panel. A change in the friction force influenced the tangential deformation of the skin as the finger slid along the panel.

A commercially available touch screen (SCT3250EX, 3M Touch Systems, MN) was modified for presenting the electrostatic friction stimulus. A load cell (FSS015WNSX, TE Connectivity, Switzerland) was located under each corner of the touch screen to calculate the load and the position of the finger. The outputs of the load cells were sampled at 250 Hz. The applied voltage was controlled at 2 kHz for smooth stimulus presentation. Further, the voltage was amplitude-modulated with the carrier frequency of 4 kHz. A similar equipment was also used in [8].

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B. Friction stimuli

The four different stimuli were prepared for the experiment. One of them was the test stimulus whereas the others were the comparison stimuli. Stimulus A was the constant low-frequency stimulus also employed in our previous study [4] and was determined using

$$V_e(t) = A \sin 2\pi \frac{x(t)}{2\lambda} \tag{1}$$

where A, $x(t)$, and λ represent the amplitude of voltage, the position of the finger, and the spatial frequency, respectively. The A value was adjusted to lie within 96–132 V for individual participants because the fingertip conductivity depends on the individuals. λ was 12 mm. The temporal frequency was determined by the ratio of λ to the finger speed, and it approximately ranged from 5 to 30 Hz according to the finger movement.

According to earlier studies [1], [4], the frequency is an important parameter for the presentation of softness. In the case of the stick-slip phenomenon, the frequency of frictional vibration changes according to the normal force and sliding speed of the finger [7]. Therefore, we designed stimulus B such that its frequency depended on the normal force and finger movement. The stimulus was determined using

$$V_e(t) = A \sin 2\pi \frac{f(t)}{2} x(t) \tag{2}$$

$$f(t) = f_l + (f_h - f_l)\frac{F_n(t)}{F_{n,\max}} \tag{3}$$

where f_h, f_l, F_n, and $F_{n,\max}$ are the maximum and minimum frequencies, normal force, and predetermined maximum normal force, respectively. F_n was bounded to $F_{n,\max}$. f_h and f_l were set to 12 Hz and 2.5 Hz, respectively. These parameters were determined by the authors, and their optimization was not the objective of the present study. As a result, the frequency of the stimuli ranged from 5 to 40 Hz according to F_n and movement of the finger.

Stimulus C did not present any electrostatic friction. This condition was prepared to be a control condition.

Stimulus D presented a high frequency roughness texture. This stimulus was included to test the suggestibility of experimental participants.

III. Experiment

A. Participants

Eight males and one female Japanese university students in their 20s participated in experiment. They were all right-handed, and none of them was aware of the objectives of the study.

B. Tasks

The four types of stimulus were presented to the participants in a randomized order. The participants were then asked to rank the provided stimuli according to the order of softness perceived from them. Two trials were conducted for each individual over a span of 10 to 15 min. The participants slid their right index fingers along the panel, and they could switch the stimuli freely using a key board. The participants wiped their fingers with a cloth before the experiments. They were made to listen to pink noise through headphones to mask the frictional sounds generated.

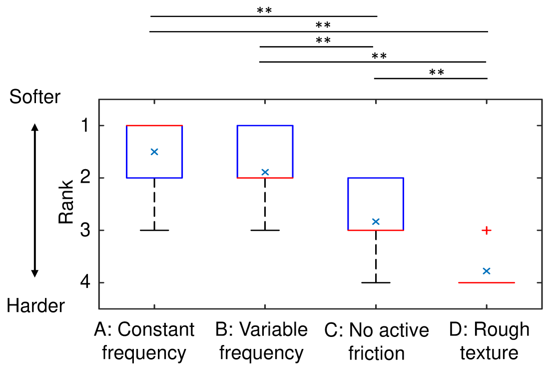

Fig. 2. Box plots of ranks among nine participants. The blue x marks indicate the average rank of each stimulus. ** indicates the significance level of 0.01 found by pair-wised Friedman tests.

IV. Results

Fig. 2 shows the result of the experiments. The horizontal axis indicates the type of stimulus, and the vertical axis indicates the rank of perceived softness. The ranks assigned to the four types of stimuli were significantly different ($\chi^2 = 39.28$, $p < 0.01$, Friedman test). The post-hoc tests (pair-wised Friedman test without p value correction) indicated the differences between all the stimulus pairs except for stimuli A and B.

Stimuli A and B were ranked higher than the other two stimuli, and there was no significant difference between the two. Therefore, the new stimulus, the frequency of which was changed according to the normal force and finger speed, was as effective in presenting softness as the previously proposed stimulus A, the frequency of which was constant.

V. Conclusion

This study investigated a new method for controlling the friction force for presenting softness on a hard touch panel. The electrostatic friction stimulus, the frequency of which depended on normal force and finger speed, was found to be as effective as the constant low-frequency stimulus used in [4]. Therefore, Although further studies are required to elucidate the principles and optimize the stimulus, this new method will expand the possibilities for softness presentation on hard touch panels.

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