Combined virtual bumps and textures on electrostatic friction tactile displays

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***Abstract*—Touch panels are commonly used interfaces in consumer electronics, and tactile feedback on touch panels can improve usability and create new use cases. In this study, we investigated whether virtual macroscopic and microscopic surface features can be recognized when they are presented together using electrostatic friction tactile displays. Participants were able to distinguish between five composite stimuli; however, they tended to struggle distinguishing between a macroscopic bump and dent. The results of this study provides new insights regarding consumer electronics and human interfaces research.**

***Index Terms*—Touch panel, texture, bump, dent**

I. INTRODUCTION

Tactile feedback functions on touch panels provide surface information regarding bumps and textures. Accordingly, combining the audiovisual and tactile feedback makes digital contents more enjoyable [1]. Recently, electrostatic friction displays have been intensively studied by many research groups [2]–[7]. For example, earlier researches demonstrated how virtual macroscopic bumps [2] and how virtual microscopic textures are perceived on touch panels with electrostatic friction feedback functions [3].

However, no existing study has tested bumps and textures in conjunction using electrostatic friction displays. It remains unknown if the bumps and textures are correctly recognized when they coexist. One concern is that macroscopic or microscopic features may perceptually mask each other, or they may mutually interfere consequently, it may be difficult to assess the two surface feature types. The objective of the this study is to clarify human perceptual abilities under combined bump and texture stimuli. We conducted an experiment where participants identified five virtual surface types, a few of which presented a macroscopic bump or dent and microscopic textures in conjunction.

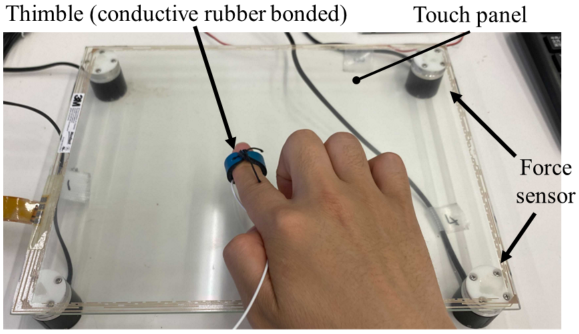

Fig. 1. Electrostatic friction display used in the experiment.

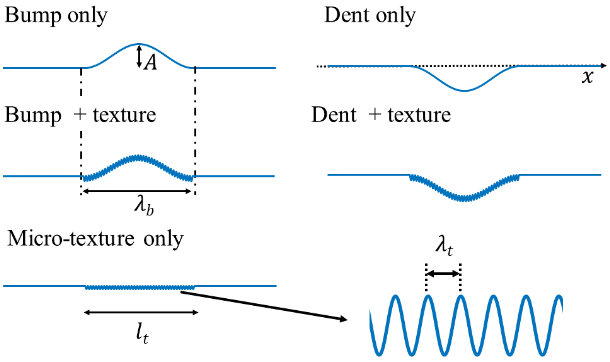

Fig. 2. Five types of virtual surfaces used in experiment, where A, l_t, λ_b, and λ_t are the sinusoidal surface amplitude, micro-texture length, and spatial wavelength of bump and micro-textures, respectively.

II. ELECTROSTATIC FRICTION TACTILE DISPLAY

For the experiments, we used an electrostatic friction display shown in Fig. 1. The display consists of an electrostatic touch panel (SCT3260, 3M Touch Systems, MA) and four force sensors (USLG25, Tec Gihan Co. Ltd., Japan), each of which was affixed beneath a corner to localize the finger on the panel. To unify the frictional conditions between the panel and finger for different participants, the participants were provided a thimble with a grounded conductive rubber piece. An electrostatic friction tactile display modulated friction force between the finger pad and panel in the shear direction by applying a voltage between the conductive rubber and panel. The applied voltage was amplified by a voltage amplifier (HJOPS-1B20, Matsusada Precision Inc., Japan, maximum output: ± 1 kV, response: 75 kHz).

III. EXPERIMENT

A. Participants

Six volunteers participated in this experiment. They were not informed about the research objective prior to the experiment.

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B. Stimuli

The relationship between the shear frictional force $F_e(t)$ and applied voltage $V_e(t)$ is determined according to the law of electrostatic force and Coulomb friction as follows:

$$F_e(t) = \mu\{W + kV_e^2(t)\} \tag{1}$$

where $\mu, W,$ and k are the coefficients of friction, load of the finger, and electrostatic force constant, respectively [8]. In the experiment, we presented five types of virtual surfaces: macroscopic bump only, macroscopic dent only, micro-texture only, macroscopic bump and micro-texture, and macroscopic dent and micro-texture as shown in Fig. 2. The shear force caused by the bump is a function of its gradient. Thus, the applied voltage $V_e(t)$ could be expressed as follows:

$$V_e(t) = \sqrt{A\sin(\frac{2\pi x(t)+\theta}{\lambda_b}) + \frac{A}{4}\sin(\frac{2\pi x(t)}{\lambda_t}) + \frac{5}{4}A} \tag{2}$$

where A and θ were the sinusoidal surface shape amplitude and phase (0 for bump, π for dent) used to adjust the bump shape, respectively. Moreover, $x(t)$ denotes the finger position on the panel. λ_b and λ_t are the spatial wavelength of the bump and micro-textures, respectively. The first term was utilized when presenting a macroscopic bump; accordingly, the second term was applied when presenting a micro-texture.

Different virtual surfaces were presented during the training session and main experiment. During the training session, we set parameters $l_t = 20$ mm and $\lambda_t = 1.5$ mm for the micro-texture. For presenting only macroscopic bumps, $\lambda_b = 25$ mm. For presenting the bump and texture in conjunction, $\lambda_b = 20$ mm. During the main experiment, $l_t = 20$ mm, $\lambda_t = 1.0$ mm, and $\lambda_b = 20$ mm were set as experimental parameters. These virtual stimuli were presented near the center of the panel.

C. Tasks

During the training session, the participants experienced five virtual surfaces and were told which surface they had touched. The training session continued until the participants were able to correctly identify the randomly presented virtual surfaces ten times in a row. The average number of training trials was approximately 30.

During the main experiment, the participants identified arbitrarily presented stimuli. The participants selected one of the five options in a forced-choice manner. They could explore the stimuli as many times as they wanted during each trial. The number of trials was 50, and each stimulus was presented 10 times in total.

D. Analysis

First, we performed a chi-square goodness-of-fit test to determine if the means of answer proportions for individual stimuli match the chance. The null hypothesis was that there is no significant difference between the means of correct answer proportions and chance probability (0.2). Then, we performed z-tests to investigate whether the mean of correct answer proportions exceeded the chance probability for each stimulus.

TABLE I
MEANS $\pm 95\%$ CONFIDENCE INTERVALS OF ANSWER PROPORTIONS ** INDICATES $p < 0.01$.

	Answer				
	Texture	Bump	Dent	Bump + texture	Dent + texture
Texture	0.85 ** ± 0.18	0.03 ± 0.06	0.05 ± 0.09	0.01 ± 0.32	0.05 ± 0.04
Bump	0.01 ± 0.03	0.65 ** ± 0.24	0.18 ± 0.21	0.10 ± 0.12	0.05 ± 0.06
Dent	0.00 ± 0.00	0.21 ± 0.18	0.66 ** ± 0.19	0.01 ± 0.03	0.10 ± 0.13
Bump + Texture	0.03 ± 0.04	0.06 ± 0.06	0.00 ± 0.00	0.73 ** ± 0.15	0.16 ± 0.14
Dent + Texture	0.03 ± 0.04	0.00 ± 0.00	0.10 ± 0.19	0.21 ± 0.15	0.65 ** ± 0.17

E. Results

Table I lists the means of the answer proportions and their 95% confidence intervals. The correct answer proportions for the five virtual stimuli ranged from 65–85%. The null hypothesis that these values were equal to 0.2 (20%) was rejected (χ^2-test, $p < 0.01$). Furthermore, the mean of correct answer proportions for each stimulus was significantly greater than the chance level (z-test, $p < 0.01$).

IV. DISCUSSION

The experimental results demonstrated that combined virtual bumps and textures were correctly recognized. However, regardless of the presence or absence of texture, the bump and dent were occasionally confused. For example, the presence or absence of micro-textures and those of macroscopic bumps were correctly recognized at 83%. However, the bumps and dents were correctly assessed only 67% of the time on average. Although the friction, which is a function of the surface gradient, is a cue in identifying bumps, the lack of an actual surface gradient hampers the correct recognition of bumps.

V. CONCLUSION

This study demonstrated that macroscopic and microscopic surface features can be recognized when they are presented in conjunction using electrostatic friction displays. To the best of our knowledge, such results have not been reported in the literature. The obtained results will broaden the possible use cases for electrostatic friction tactile displays. Electrostatic friction displays can present more complex surface features than ever considered including macroscopic and microscopic patterns. On the other hand, the difficulty in distinguishing between a macroscopic bump and dent should be resolved.

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