High-Quality Texture Display: The Use of Vibrotactile and Variable-Friction Stimuli in Conjunction

Ken Ito, Shogo Okamoto, Hatem Elfekey and Yoji Yamada

Abstract The sliding of a finger on a material surface results in complex physical interactions. Tactile texture displays have been limited in their ability to capture the aspects of these interactions. As a step forward, we have combined two complementary types of tactile stimuli, vibrotactile and electrostatic, to deliver roughness textures with high realism. These two types of stimuli represent the surface roughness and friction. We then conducted an experiment where participants agreed that the experience of the texture presented by the combined stimuli was more similar to that of an actual specimen than that of textures presented by either type of stimulus. Our experiment indicates that combining vibrotactile and electrostatic friction stimuli, both of these have been studied extensively, results in high-quality tactile contents for surface texture displays.

Keywords Tactile display · Vibrotactile · Electrostatic · Texture · Surface texture display · Variable-friction stimulus

1 Introduction

The tactile texture displays are categorized into vibrotactile and variable-friction stimuli [1–4]. Vibrotactile stimuli actively produce mechanical displacements on a fingertip. Variable-friction stimuli induce tactile sensations by controlling the surface friction between a fingertip and a display device. These two types of stimuli are distinct and complementary: For example, vibrotactile stimuli actively provide the tactile sensation, whereas variable-friction stimuli do so passively. In addition, vibrotactile stimuli are good for the presentation of surface roughness [5, 6], whereas friction stimuli are more suited for surfaces where friction is dominant in terms of textural perception [7].

K. Ito (✉) · S. Okamoto · H. Elfekey · Y. Yamada
Mechanical Science and Engineering, Graduate School of Engineering,
Nagoya University, Furo-Cho, Chikusa-ku, Nagoya 464-8603, Japan
e-mail: itou.ken@a.mbox.nagoya-u.ac.jp

S. Hasegawa et al. (eds.), *Haptic Interaction*, Lecture Notes
in Electrical Engineering 432, DOI 10.1007/978-981-10-4157-0_22

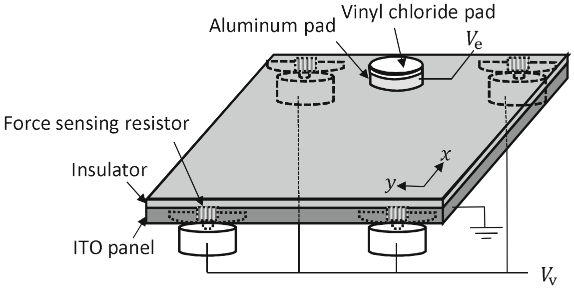


Fig. 1 Overall structure of the proposed tactile display with vibrotactile and electrostatic stimuli

These complementary characteristics suggest that a combination of the two types may result in stimuli of higher quality with each type in isolation. An attempt has been made to combine the stimuli [8]; the researchers, however, did not attempt to present the high-quality textures by simultaneously activating the two types of stimuli. Other approach employed a combination of mechanical and electric current stimuli for the purpose of quality tactile displaying [9].

Using vibrotactile and variable-friction stimuli in conjunction, we were able to deliver a roughness texture with a high degree of realism. Real surfaces possess the properties of surface roughness and friction; high-quality virtual surfaces may be realized by using the two types of stimuli simultaneously. This approach can make full use of the two types of stimuli to eliminate the flaws in earlier methods for improving the quality of surface texture displays and vastly improves the quality of virtual tactile textures.

2 Tactile Texture Display Combining Vibrotactile and Electrostatic Stimuli

Figure 1 shows the tactile display developed in this study. Vibrotactile stimuli on the proposed display were produced by four voice coil actuators (X-1741, Neomax Engineering Co. Ltd., Japan), located at each corner of the top panel. The four actuators were synchronously driven by a current amplifier (ADS 50/5, Maxon Motor AG, Switzerland) and produced mechanical vibratory stimuli along the normal to the top panel. The electrostatic stimuli were produced by electrostatic forces induced by a voltage between the aluminum pad and an ITO panel (V_e). An insulator (kimotect PA8X, KIMOTO Co. Ltd., Japan) was fixed on the ITO plate. The voltage V_e was driven by a high-voltage amplifier (HJOPS-1B20, Matsusada Precision Inc., Japan). Four force-sensing resistors (FSR 400 short, Interlink Electronics Inc., USA) were affixed between each voice coil motor and the top plate. The two amplifiers and four resistors were connected to a data acquisition board (TNS-6812, Interface Corporation, Japan). The position of the finger pad was calculated based on the output from the four force-sensing elements. Thus, the display can present the stimulus based upon the position of the pad. The voltage and current signals were processed at a sampling frequency of 1 kHz.

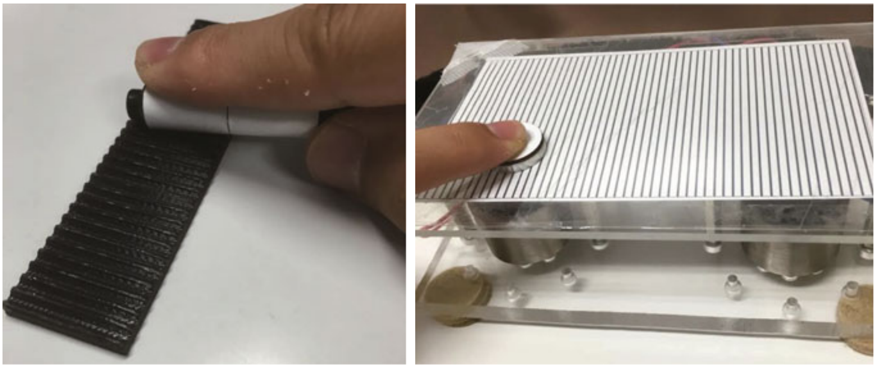
3 Experimental Procedure

3.1 Tasks

In this experiment, a rank task was applied to assess the performance of the combined texture stimuli. Participants experienced three stimuli: vibrotactile, electrostatic, and vibrotactile plus electrostatic. They compared three types of stimuli with a specimen (shown in Fig. 2), and ranked the three types of stimuli in terms of realism. If a participant ranked a stimulus as first, the stimulus was felt like the specimen the most. Because our display could not distribute stimuli in the contact area, the participants scanned the specimen with a round tip probe, as shown in Fig. 2a. The spatial wavelength of the specimen was 3 mm, and the top of the specimen was 1 mm above the bottom. The participants could experience the specimen and three stimuli as many as they wanted.

3.2 Participants

Six volunteers (all students, non experts, right handed, average age 23) participated in this experiment. They were not informed of the objective of the research.



(a) Roughness specimen (b) Display part

Fig. 2 Roughness specimen to be compared with virtual textures. Participant in the experiment scanned the surface with a round tip probe

3.3 Roughness Texture Stimuli

We used vibrotactile and electrostatic roughness texture stimuli. The presentation algorithm for each stimulus is simple. It has been used in numerous earlier studies. Those studies, however, used only one of the two stimuli (vibrotactile and electrostatic).

The roughness texture stimuli presented a roughness grating scale with a sinusoidal surface asperity, with a spatial period of $\lambda = 3\,\text{mm}$. The resultant drive force F_v for the vibrotactile actuators was determined by (1), as below:

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

where $x(t)$ and A are the position of the finger pad and the gain of the force, respectively. The A value were 2.0 and 1.7 N for the vibrotactile and vibrotactile plus electrostatic stimuli conditions, respectively. The voltage instruction to the electrostatic actuator was determined by

$$V_\text{e}(t) = B \cos 2\pi \frac{x(t)}{\lambda} \tag{2}$$

where $x(t)$ and B are the position of the finger pad and the voltage gain respectively. The friction force was determined using

$$F_\text{e}(t) = \mu(W + kV_\text{e}^2(t)) \tag{3}$$

where μ, W, and k are respectively the coefficient of friction between the finger pad and the surface of the panel, the load normal to the panel, and a constant that determine the electrostatic force. k was mainly influenced by the electrode surface area, and the dielectric constant and thickness of the insulator. As a result, the variable-friction force F_e was 0.45–0.89 N for the electrostatic condition when the pressing force W was 1 N. Further, F_e was 0.45–0.79 N for the vibrotactile plus electrostatic condition, with $W = 1$ N. The phases of the stimuli for surface displacement and friction were separated by $\pi/2$ [10, 11]. The force and voltage gains for each stimulus condition were empirically best tuned for each condition such that each texture stimulus was perceived as most similar to the actual roughness specimen shown before the virtual stimulus was presented.

4 Experimental Results

Figure 3 shows the ranks assigned to each stimulus condition by the individual participants. We used the Wilcoxon Rank Sum Test to evaluate two pairs of stimuli; the combined and vibrotactile conditions, and then, the combined and electrostatic

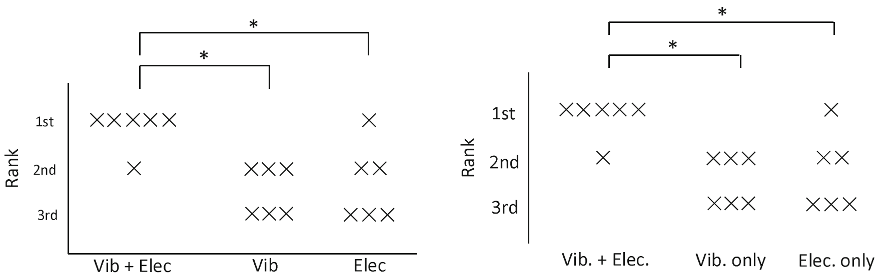


Fig. 3 Experimental result: frequencies of ranks for each stimulus ($*$ indicates $p < 0.05$)

conditions. There were significant differences in two pairs ($p < 0.05$, after Bonferroni correction). These results showed that we could produce high-quality textures by combining Vibrotactile stimuli and electrostatic friction stimuli.

5 Conclusions

We developed a tactile display that can present vibrotactile and variable-friction stimuli to improve the quality of tactile displays. We conclude that the combination of the stimuli results in a more realistic rendering of textures compared to that afforded by vibrotactile and variable-friction stimuli individually.

Acknowledgements This study was in part supported by MEXT Kakenhi (15H05923), SCOPE (142106003).

References

1. Asano, S., Okamoto, S., Yamada, Y.: Vibrotactile stimulation to increase and decrease texture roughness. IEEE Trans. Hum. Mach. Syst. **45**(3), 393–398 (2015)
2. Okamoto, S., Yamada, Y.: Lossy data compression of vibrotactile material-like textures. IEEE Trans. Haptics **6**(1), 69–80 (2013)
3. Nakamura, T., Yamamoto, A.: A multi-user surface visuo-haptic display using electrostatic friction modulation and capacitive-type position sensing. IEEE Trans. Haptics (2016)
4. Chubb, E.C., Colgate, J.E., Peshkin, M.A.: ShiverPaD: a glass haptic surface that produces shear force on a bare finger. IEEE Trans. Haptics **3**(3), 189–198 (2010)
5. Asano, S., Okamoto, S., Yamada, Y.: Toward quality texture display: vibrotactile stimuli to modify material roughness sensations. Adv. Robot. **28**(16), 1079–1089 (2014)
6. Yamauchi, T., Okamoto, S., Konyo, M., Tadokoro, S.: Real-time remote transmission of multiple tactile properties through master-slave robot system. In: Proceedings of the 2010 IEEE International Conference on Robotics and Automation, pp. 1753–1760 (2010)
7. Bau, O., Poupyrev, I., Israr, A., Harrison, C.: Teslatouch: electrovibration for touch surfaces. In: Proceedings of Annual ACM Symposium on User Interface Software and Technology, pp. 283–292 (2010)

8. Pyo, D., Ryu, S., Kim, S.-C., Kwon, D.-S.: Haptic interaction on a touch surface. In: Lecture notes in Electrical Engineering, vol. 277. Springer (2015)
9. Yem, V., Okazaki, R., Kajimoto, H.: Fingar: combination of electrical and mechanical stimulation for high-fidelity tactile presentation. In: Proceedings of ACM SIGGRAPH Emerging Technologies, pp. 13–14 (2016)
10. Robles-De-La-Torre, G., Hayward, V.: Force can overcome object geometry in the perception of shap through active touch. Nature **412**, 445–448 (2001)
11. Fujii, Y., Okamoto, S., Yamada, Y.: Friction model of fingertip sliding over wavy surface for friction-variable tactile feedback panel. Adv. Robot. **30** (2016)