# A novel multimodal tactile module that can provide vibro-thermal feedback


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**Abstract.** This paper describes a novel tactile module that can provide both vibratory and thermal feedback onto the skin. The module is composed of two different components; miniaturized vibrator and four units of Peltier devices. The dimension of the vibro-thermal tactile feedback device is $16 \times 32 \times 7$ mm, which is small enough for attaching to fingerpad. We describe basic concept of this module, and the state of current prototype including possible applications.



**Keywords:** Tactile Display · Thermal Feedback · Vibrotactile Feedback · Wearable device


## 1 Introduction

There are enormous numbers of tactile displays proposed so far. Pin-based tactile display is most studied in analogous to visual displays. This type of tactile display uses multiple contractors that are driven with different actuators [8]. Other tactile displays utilize physical phenomena to induce skin deformation such as electrostatics [14], surface elastic wave [10] or to directly activate sensory afferent by electrocutaneous stimuli [7].

In addition to providing mechanical tactile feedback to provoke tactile sensation, thermal displays also attract attentions recent years [6]. They used water circulation [1], Peltier devices [2], or heaters [5]. The thermal display can not only display thermal cues, but they can also produce tactile perception of material properties [6].

It would be beneficial for the research community to have multimodal tactile displays that can present vibratory and thermal tactile cues simultaneously. Based on recent progress of psychology on vibrotactile and thermaltactile perceptions, it is expected that multimodal tactile display may enhance realistic experience while interacting with presented object. Although multimodal tactile sensors have been proposed [9] and commercially available [4], only a few multimodal tactile displays have been proposed [3]. Considering mobile or wearable computing purposes in the usage of multimodal tactile display, the size of hardware should be taken into account.

Here we developed a small-size tactile module that can provide both vibratory and thermal tactile feedback onto the skin, which is small enough for wearable use. We also evaluated our developed device, and further discussed possible application with the device.

## 2 Hardware development

The vibro-thermal tactile unit is composed of two different components: a vibrotactile unit and a thermal tactile unit. We developed these two components separately and then integrated them by closely placed side by side.

**Vibrator unit** Vibrator unit was developed by miniaturizing previously developed actuator called ForceReactor$^{TM}$ AF series short-vibration feedback device [13]. Since previous actuator was relatively large for mobile device use, so that we developed a prototype that has a smaller dimension. The dimension of current vibrator prototype was 10 × 3 × 24 mm, which was slimmed down comparing with previous one (7.5 × 5 × 35 mm). The weight is 6 gram, which is light enough for integrating with developed thermal tactile unit.

**Thermal unit** We chose a Peltier device (KSMH029F, KELK Ltd.) as thermal unit for giving tactile feedback. We used four Peltier devices to provide fast thermal feedback as proposed previously [12]. The size of each Peltier device is 6.0 × 10 × 1.7 mm, which is small enough even we used four Peltier devices in tile patterns as shown in Fig. 1. This configuration enables fast temporal change of temperature, because two of four Peltier devices are used only for cooling and others are used only for warming the skin. The problem of using Peltier devices is that it requires more electricity when one tries to cool down after it is heated, or vice versa. Four-tile configuration can solve this conventional problem and previous study showed that the time to perceive temperature change was improved 36 % on average [12].

### Vibro-thermal module assembly

We assembled the vibrator with the thermal unit into one module. Fig. 1a is the schematic of the module, and Fig. 1b is the appearance of the developed module. Three thermistors were equipped in order to measure the temperature of warming and cooling Peltier devices including housing base, avoiding too much cooling and warming during thermal feedback. The thermistor between Peltier devices works as a reference point for capturing the temperature of contacting skin. The size of assembled module was 16 × 7 × 32 mm and the weight was 10 gram with the housing base.

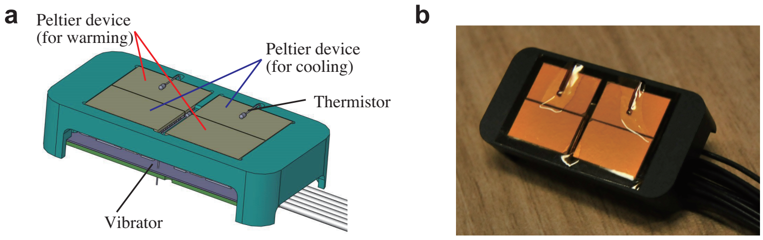


**Fig. 1.** Schematics (a) and developed (b) vibro-thermal tactile display

# 3 Hardware evaluation

## 3.1 Vibratory characteristics

**Hardware** We evaluated frequency response of the developed module. We measured the displacement of the module with a laser displacement sensor (Keyence, LK-H055) from the top of the module. The module was fixed onto the stage with a sponge, in order to imitate light contact with a finger pad. We observed two resonant frequencies around 150 and 500 Hz as shown in Fig. 2a.

**Psychological characteristics** We also evaluated psychological characteristics of the developed vibrator.

In the experiment, we measured individual difference of vibrotactile sensitivity for different frequencies. We measured equal-loudness contour in this experiment. Participants were asked to adjust the intensity of comparison vibrotactile stimulus to intensity of standard stimulus with a ten-key control pad. We used a 400 Hz of sine wave as standard stimulus. Comparison frequency was one of ten vibrotactile frequencies (40, 80, 120, 160, 200, 240, 280, 320, 360, 400 Hz). Once participants judged adjusted intensity of comparison stimulus is the same as standard stimulus, they terminated one trial and moved on next trial. The order of presented frequency of vibrotactile stimulus was randomized for each participant. Total number of trials were fifty (ten kinds of vibrotactile frequency $\times$ five trials each) and averaged duration for the experiment was about thirty minutes. Five participants attended this experiment.

Figure 2b shows averaged amplitude of tactile stimuli that gave equal perceptual intensity with 400 Hz vibrotactile stimuli. X-axis is the presented vibrotactile frequency and Y-axis is the intensity of stimuli in dB unit that gave equal perceptual intensity.

The data showed apparent lower peak at around 150 Hz, which is due to the resonance of the vibrator. This would be due to the frequency response of vibroator itself which had a steep resonant peak at 150 Hz as shown in Fig. 2a. This data also implies that the frequency response of mechanical stimulator could affect perceptual intensity of vibrotactile stimuli.

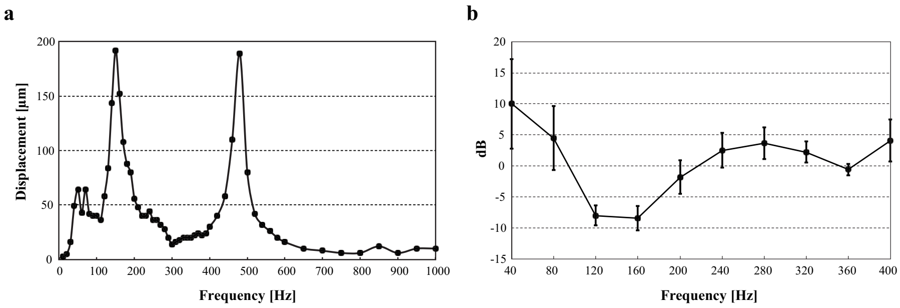


**Fig. 2.** Frequency response of (a) mechanical vibrator and (b) its equal-loudness contour estimated by human participants.

### 3.2 Thermal characteristics

We evaluated thermal characteristic of the developed module. We measured the temperature of warming and cooling Peltier devices using built-in thermistors as indicated in Fig. 1. In addition, we measured the temperature of bottom side of vibro-thermal module to observe the trend of heat diffusion in developed module.

In the evaluation experiment, we continuously input current to pairs of warming and cooling Peltier devices respectively in order to alternately increase or decrease their temperature. The duration of applied current was 1.5 seconds, and the interval between warming and cooling input was 3.5 seconds. In this experiment, the contact side of warming Peltier devices were always warmed up, and never cooled down by applying current in opposite directions. Similarly, cooling Peltier devices were always cooled down. Once the temperature of module bottom reached at 30 °C, we stopped current input to the Peltier devices. The room temperature was 22 °C, and the sampling rate was 2 Hz in this experiment.

Based on the result shown in Fig. 3, we observed expected increase and decrease of temperature in both warming and cooling Peltier devices, however, we also observed the temperature increasing trend in all thermistors. This was due to the heat diffusion from both warming and cooling Peltier devices. In the beginning of the experiment, the temperature of bottom side of the module increased rapidly until the actuation of warming Peltier devices stopped around 100 seconds, and kept increasing its temperature slowly (Fig. 3). The former temperature increase would be due to the heat diffusion from warming Peltier devices, and the latter would be from bottom side of cooling Peltier devices.

## 4 Discussion

In this study we developed vibro-thermal tactile display in a small size by assembling small vibrotactile display and four Peltier devices into one module. The size of the module is small (32 mm in maximum length) and light (10 gram weight) so that this could be useful for mobile or wearable devices.

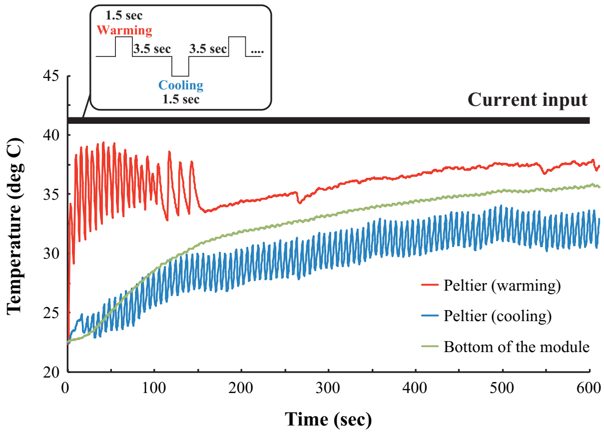


**Fig. 3.** Temperature profile of termotactile unit in developed module

Based on the evaluation experiment, the performance of vibrotactile presentation was good in relatively lower frequeny bandwidth (120-160 Hz). This may be good characteristics for vibrotactile display, because human has relatively higher sensitivity in this frequency range.

The performance of thermaltactile presentation in the developed module seemed to be equivalent to previous study (Sato et al. [11]). An issue we realized was that we needed to improve the performance of heat exhaustion of the module. This issue is always with thermal tactile displays, however, we plan to overcome this difficulty by using materials that can easily absorb heat from the housing base.

Vibro-thermal tactile display would increase the possibility of presenting material property in tactile modality. As discussed in previous literature, temperature information is highly associated with recognizing materials through skin sensations. Combining with vibrotactile presentation, we may increase the variety of tactile materials using our developed module. In our preliminary trial, we added cooling temperature presentation while watching a cup poured water with vibrotactile feedback. Our participants told that it was realistic tactile experience, or even reported that their finger felt as if it were wet. This may be perceptual illusion or physically wet because of dew formation, and this empirical phenomenon is worth studying in future experiment.

We also realized that we needed to develop a system that can easily edit vibro-thermal tactile stimuli. Currently we controlled vibrotactile and thermaltactile display from different software, but an integrated system for editing tactile stimuli may increase the usability of the module that we developed. This is also an item of the list for future development of this series of study.

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## References


1. Ho, H.N., Jones, L.A.: Contribution of thermal cues to material discrimination and localization. Perception & Psychophysics 68(1), 118–128, http://dx.doi.org/10.3758/BF03193662
2. Ho, H.N., Jones, L.A.: Development and evaluation of a thermal display for material identification and discrimination. ACM Trans. Appl. Percept. 4(2) (Jul 2007), http://doi.acm.org/10.1145/1265957.1265962
3. Hribar, V.E., Pawluk, D.T.: A tactile-thermal display for haptic exploration of virtual paintings. In: The Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility. pp. 221–222. ASSETS '11, ACM, New York, NY, USA (2011), http://doi.acm.org/10.1145/2049536.2049577
4. Jimenez, M., Fishel, J.: Evaluation of force, vibration and thermal tactile feedback in prosthetic limbs. In: Haptics Symposium (HAPTICS), 2014 IEEE. pp. 437–441 (Feb 2014)
5. Jones, L., Berris, M.: The psychophysics of temperature perception and thermal-interface design. In: Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2002. HAPTICS 2002. Proceedings. 10th Symposium on. pp. 137–142 (2002)
6. Jones, L.A., Ho, H.: Warm or cool, large or small? the challenge of thermal displays. IEEE T. Haptics 1(1), 53–70 (2008), http://doi.ieeecomputersociety.org/10.1109/TOH.2008.2
7. Kajimoto, H., Kawakami, N., Tachi, S., Inami, M.: Smarttouch: electric skin to touch the untouchable. IEEE Computer Graphics and Applications 24(1), 36–43 (Jan 2004)
8. Killebrew, J.H., Bensmaïa, S.J., Dammann, J.F., Denchev, P., Hsiao, S.S., Craig, J.C., Johnson, K.O.: A dense array stimulator to generate arbitrary spatio-temporal tactile stimuli. Journal of neuroscience methods 161(1), 62–74 (3 2007), http://www.sciencedirect.com/science/article/pii/S0165027006005073
9. Kim, J., Lee, M., Shim, H.J., Ghaffari, R., Cho, H.R., Son, D., Jung, Y.H., Soh, M., Choi, C., Jung, S., Chu, K., Jeon, D., Lee, S.T., Kim, J.H., Choi, S.H., Hyeon, T., Kim, D.H.: Article stretchable silicon nanoribbon electronics for skin prosthesis. Nature Communications 5 (2014)
10. Nara, T., Takasaki, M., Maeda, T., Higuchi, T., Ando, S., Tachi, S.: Surface acoustic wave tactile display. IEEE Comput. Graph. Appl. 21(6), 56–63 (Nov 2001), http://dx.doi.org/10.1109/38.963461
11. Sato, K., Maeno, T.: Haptics: Perception, Devices, Mobility, and Communication: International Conference, EuroHaptics 2012, Tampere, Finland, June 13-15, 2012. Proceedings, Part I, chap. Presentation of Sudden Temperature Change Using Spatially Divided Warm and Cool Stimuli, pp. 457–468. Springer Berlin Heidelberg, Berlin, Heidelberg (2012)
12. Sato, K., Maeno, T.: Presentation of rapid temperature change using spatially divided hot and cold stimuli. Journal of Robotics and Mechatronics 25(3), 497–505 (6 2013)
13. Wakuda, H., Kawauchi, T.: Bodily sensed vibration generator system (Jun 3 2004), https://www.google.ch/patents/US20040104625, uS Patent App. 10/717,070
14. Yamamoto, A., Ishii, T., Higuchi, T.: Electrostatic tactile display for presenting surface roughness sensation. In: Industrial Technology, 2003 IEEE International Conference on. vol. 2, pp. 680–684 Vol.2 (Dec 2003)