Augmentation of Material Property by Modulating Vibration Resulting from Tapping

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Abstract. We present a new haptic augmented reality system that modulates the perceived stiffness of a real object by changing the perceived material with vibratory subtraction and addition. Our system consists of a stick with a vibrotactile actuator and a pad with an elastic sheet. When a user taps the pad, the innate vibration resulting from the tapping is absorbed by the elastic surface. Simultaneously, the vibrotactile actuator provides the intended vibration, which represents a modulated perceived material property such as rubber, wood, or aluminum. The experimental results showed that the participants were able to discern the three materials by tapping.

Keywords: haptic augmented reality, material, stick-type interface, stiffness modulation, vibrotactile sensation

1 Introduction

Haptic augmented reality (haptic AR) is an emerging haptic research area where a user can touch an augmented or untouchable environment [1, 2]. The system generally consists of a haptic display and a sensor to measure the environment.

Stiffness, which is one of the most fundamental haptic properties, has been successfully modulated by a haptic AR system. Nojima et al. proposed SmartTool, which is composed of a stylus with an active force feedback device and a sensor attached at the tip of the tool [3]. The active force feedback provides a reactive force according to the information detected by the sensor, which lets the user touch and know an untouchable boundary, such as the interface between oil and water, as if the interface got a stiff wall. Jeon and Choi proposed a haptic AR system that modulates the stiffness of a real object [2]. The system is composed of an active force feedback device and force sensor to measure the reaction force from the surface of the real object and control the device.

However, both systems require an active force feedback device, which is generally expensive and complicated. Therefore, in contrast to visual and audio AR systems, it is difficult to apply their systems to daily life, such as for entertainment.

This paper thus proposes a new haptic AR system to modulate the perceived stiffness of a real object, but with a simple implementation that focuses on a “tapping by a stick” situation. The paper first begins with a review of previous work on stiffness representation by simulation of material vibrations resulting from tapping and stylus-type haptic AR devices. Next, we describe our proposal, which modulates the perceived stiffness of a real object by changing the perceived material via vibratory subtraction and addition. We then present a material identification experiment to demonstrate the efficacy of our proposal. Finally, the paper ends with the conclusion and a description of potential applications.

2 Previous Work

2.1 Haptic Simulation of Tapping Object

When tapping the surface of a hard object, we can discern the material by using haptic cues without requiring visual or acoustic ones. The haptic sensation consists of a kinesthetic sensation (i.e., reactive force from the surface of the object) and vibrotactile sensation (i.e., cutaneous mechanical deformations and vibrations).

Various methods have been proposed to present kinesthetic and vibrotactile sensations. Wellman and Howe proposed mounting of a vibrator on an active force feedback device [4]. Okamura et al. presented both kinesthetic and vibrotactile stimuli solely through an active-force feedback device [5]. Both groups employed the following decaying sinusoidal waveform to simulate the vibration resulting from tapping:

$$Q(t) = A(v)\exp(-Bt)\sin(2\pi ft) \quad (1)$$

The vibratory acceleration Q is determined by the amplitude A as a function of the impact velocity v, decay rate of sinusoid B, and sinusoid frequency f, where A, B, and f are dependent on the type of material. Okamura et al. used their vibration model to simulate three materials (rubber, wood, and aluminum) and demonstrated that users could successfully discern the materials. However, both proposals require an expensive haptic display.

Hachisu et al. proposed a technique using pseudo-haptic feedback to provide kinesthetic sensation instead of an active-force feedback device [6, 7]. Pseudo-haptic feedback is a haptic illusion where visual cues create a haptic sensation without a physical haptic stimulus [8]. However, full substitution of kinesthetic sensation by this illusion is still not possible.

2.2 Stylus-Type Haptic AR Devices

The Haptic Pen [9] and Ubi-Pen [10] are both stylus-type devices with embedded vibrators and tactile actuators. In these devices, the kinesthetic sensation is naturally presented by real contact, whereas the vibrotactile sensation is added to present the geometrical properties on the touch panel.

3 Proposal

3.1 Concept

To deal with the high cost issue of kinesthetic feedback, we apply the real reactive force generated by contact with a real object like previous stylus-type haptic AR devices. We also modulate the perceived stiffness by adding a decaying sinusoid vibration at the moment of contact. However, the addition of the vibration is not enough for modulation because the innate vibration still exists.

We previously proposed the idea of subtracting the vibrotactile sensation by simply using an elastic sheet and then presenting the intended vibration through a vibrotactile actuator embedded in the stick (details are described in the following section) [11].

Furthermore, to achieve real-time superposition of the vibrotactile actuation on the real contact, we use conduction to detect contact between the stick and the surface of a real object; this is simply implemented by using an I/O port on a microcontroller.

3.2 Implementation

Stick. The stick and its internal configuration are shown in Fig. 1. The head is made of acrylonitrile butadiene styrene (ABS) resin, and its surface is covered with conductive coating material; it is connected to a power-supply voltage from the microcontroller. The handle is made of aluminum and has an embedded voice-coil type vibrotactile actuator (Tactile Labs Inc., Haptuator [12]). The length and weight of the stick are 200 mm and 90 g, respectively.

Fig. 2 shows the frequency response of the stick. The data was collected by providing a sinusoidal input (1 Vrms; from 10 Hz to 500 Hz in increments of 10 Hz) to the actuator and measuring the acceleration at the handle using an acceleration sensor (Kinonix Inc., KXM52-1050).

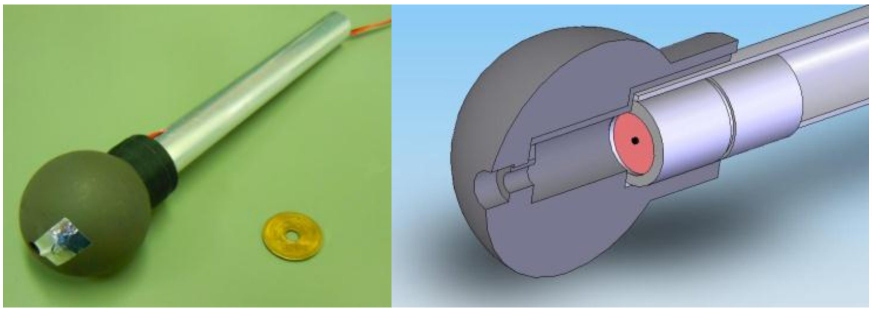

Fig. 1. Stick: The left image shows the exterior, and the right shows the internal configuration. The voice-coil type actuator is embedded.

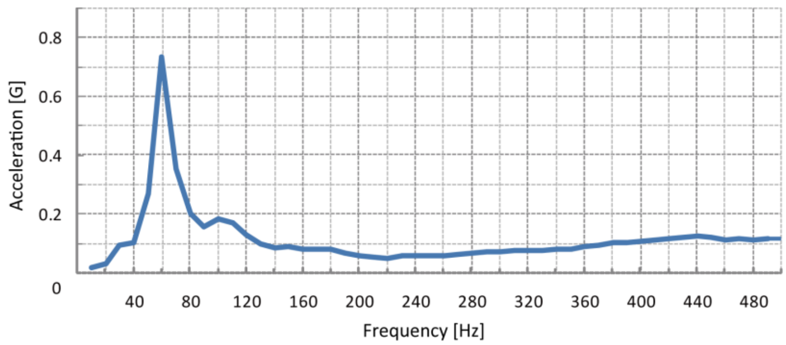

Fig. 2. Frequency response of the stick to various input frequencies

Pad. The pad is composed of an elastic sheet and a thin conductive sheet on top. The conductive sheet is made of aluminum, and its thickness is less than 0.05 mm. The conductive sheet is connected to an I/O port of a microcontroller (NXP Semiconductors, mbed NCP LPC1768) and to a signal ground through a pull-down resistor. The elastic sheet is made of styrene elastomer, which is generally used for impact and vibration absorption. The thickness of the elastic sheet is 3 mm.

System and Principle. Our proposed devices are implemented in a system consisting of the microcontroller, an audio amplifier (Rasteme Systems Co., Ltd., RSDA202), the stick, and the pad (Fig. 3).

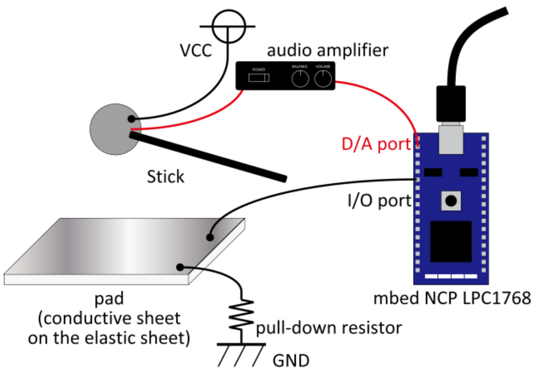

Fig. 3. System configuration

When the head of the stick contacts the surface of the pad, the pad first absorbs the vibration resulting from the collision. At the same time, the voltage of the I/O port changes from low to high. This allows the microcontroller to detect the collision instantly. Then, the microcontroller outputs the decaying sinusoid waveform from its D/A port to the actuator in the stick through the audio amplifier. Finally, the user feels the stiffness modulated by subtracting and adding vibrations. The refresh rate of the D/A port is 10 kHz.

Note that our system employs the decaying sinusoid model as described in equation 1. However, at present, the strength of the impact is not considered, i.e., the initial amplitude is set to be constant.

4 Experiment

We verified the efficacy of our proposal by testing whether participants could discern the materials.

4.1 Experimental Setup and Procedure

In this experiment, we used three pads on an acrylic board, as shown in Fig. 4. Three vibration models (rubber, wood, and aluminum) were applied to each pad in random order. We also prepared real samples of each material for comparison. The size of the pads and real samples was 50 mm × 50 mm × 3 mm. We employed Okamura's parameters [5] as the vibration models, as shown in Table 1. As mentioned in the previous section, our current system fixes the initial amplitude.

The participants were asked to select the perceived materials for each pad from three candidates (rubber, wood, and aluminum). They were informed that there was no overlap. They were allowed to tap the pads and the real samples freely during trials but were asked to do so lightly; this was because our current system cannot handle intense vibrations, and we wanted them to discern the materials via vibrotactile rather than kinesthetic cues. The participants were unaware of the correct answer. There was no limit on the time taken to respond. Each participant performed this identification experiment three times.

Twelve participants—eleven men and one woman—aged between 20 and 35 (mean = 24.4; SD = 3.8) took part in the experiment. All participants were right-handed. None of them was familiar with the research.

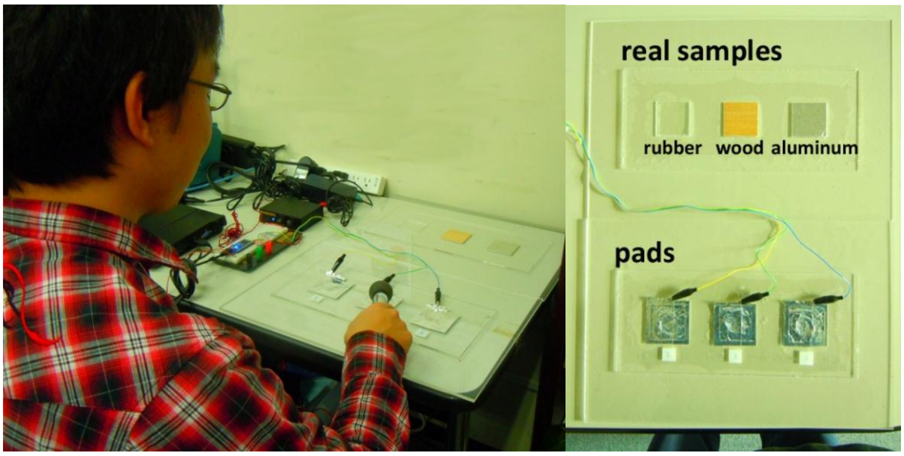

Fig. 4. Setup for the experiment

Table 1. Vibration parameters

	A [m/s^2]	B [s^{-1}]	f [Hz]
Rubber	1.0	60	30
Wood	0.7	80	100
Aluminum	1.3	90	300

4.2 Results

One participant's data was eliminated due to his comment that he tried to identify the material by the reactive force (kinesthetic sensation) and ignored the vibrotactile sensation.

The answer rates for three vibration models on the pads are listed in Table 2. The correct answer rates (cells highlighted in yellow) were higher than 70%. In particular, aluminum was successfully identified in most of the trials (90.9%). Most errors occurred by confusion between rubber and wood.

As shown in Table 3, the correct identification rate (i.e., the correct identification of all three materials by a participant) was 72.7%. The rates increased as the trials progressed, and most of the participants correctly identified all three materials by the third trial (90.9%).

Table 2. Results of the experiment: Answer rates for three vibration models. Yellow cells represent the correct answer rates.

	Vibration models		
Answer	Rubber	Wood	Aluminum
Rubber	81.8%	18.2%	0.0%
Wood	18.2%	72.7%	9.1%
Aluminum	0.0%	9.1%	90.9%

Table 3. Rates for the correct identification of materials
(i.e., correct identification of all three materials by a participant)

Fist trial only	Second trial only	Third trial only	Overall
54.5%	72.7%	90.9%	72.7%

4.3 Discussion

The overall correct rate for material identification was lower than the results from Okamura's experiment (83.3%) [5], which employed an active-force feedback device. On the other hand, the rate of the third trial was similar to Okamura's result (85.7%). The tendency for errors owing to confusion between rubber and wood was also reported by Okamura. These observations show that it is possible to represent perceived material properties by employing the decaying sinusoid model in a haptic AR environment as well as a virtual one.

After the experiment, three of the participants reported that they were able to identify the materials through a vibrotactile cue, but the absence of a repulsive sensation induced an uncomfortable sensation. This was because the elastic sheet of the pad absorbed the impact as well as vibration. Employing an elastic sheet with a high coefficient of restitution might be one solution to providing a repulsive force. However, this solution may induce a similar uncomfortable sensation when the user taps the pad for the rubber model. To deal with this difficulty, as future work, we would like to vibrate the pad as well as the stick in order to control the repulsive force.

In addition, we must consider the materials of the conductive sheet and head of the stick because they are also related to the default haptic cue. Thus, it is necessary to adopt the optimal materials for the stick and pad.

Interestingly, two of the participants reported that they felt a magnet-like force that attracted or repelled the stick when tapping the pad. This phenomenon was only observed when the rubber model was adopted. Currently, we cannot explain why this force sensation was generated. Future work will involve investigation of the behavior between the stick and pad using a high-speed camera.

5 Conclusion

This paper describes a haptic AR system that focuses on tapping, which modulates the perceived stiffness of a material by subtracting and adding vibrations. The system consists of a microcontroller, audio amplifier, stick, and pad. We carried out an experiment to demonstrate the efficacy of our proposal. The experimental results showed that the participants were able to discern the three materials that we simulated. Notably, almost all of the participants correctly identified all three materials in the third (final) trial (90.9%).

The current system employs Okamura's parameters for the decaying sinusoidal waveform [5], which was obtained with a different haptic device. Therefore, the parameters should be obtained with our system for optimization. Furthermore, as described in the previous section, optimization of the materials (elastic sheet, head of the stick, etc.) is another part of future work.

We have considered several applications for the stick-type haptic AR system. Touching and feeling the image of a visual AR is one possibility, which can be achieved by superimposing the visual image on the conductive sheet with a projector (in this case, the aluminum sheet should be replaced by another sheet that will work both as a screen and as a conductive sheet). Enhancing the touch interface with tactile feedback is another possibility. This can be achieved by employing a transparent electrode sheet as the conductive sheet on top of the multitouch interface. This can be applied to musical instruments, especially chromatic percussions such as the xylophone and glockenspiel, as proposed in [11] (Fig. 5).

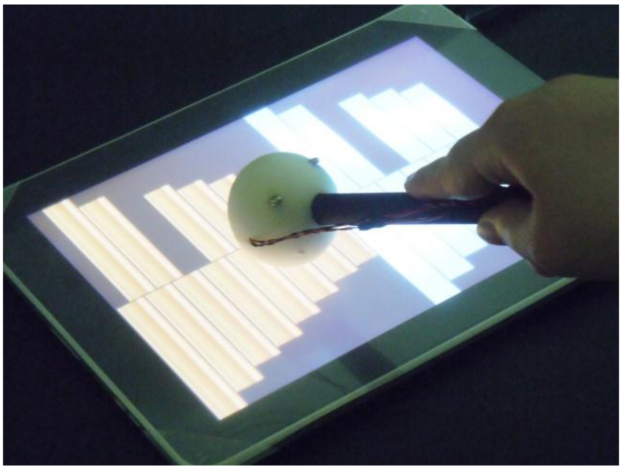

Fig. 5. Example application. Enhancing the touch interface enables haptic interaction with musical instruments (xylophone and glockenspiel) on a tablet PC [11]

References

1. Bayart, B., Kheddar, A.: Haptic Augmented Reality Taxonomy: Haptic Enhancing and Enhanced Haptics. Proceedings of EuroHaptics, 641–644 (2006)
2. Jeon, S., Choi, S.: Haptic Augmented Reality: Taxonomy and an Example of Stiffness Modulation. Presence 18, 87–408 (2009)
3. Nojima, T., Sekiguchi, D., Inami, M., Tachi, S.: The SmartTool: A System for Augmented Reality of Haptics. Proceedings of IEEE Virtual Reality Conference, 67–72 (2002).
4. Wellman, P., Howe, R.D.: Towards Realistic Display in Virtual Environments. Proceedings of the ASME Dynamic Systems and Control Division 57, 713–718 (1995)
5. Okamura, A.M., Cutkosky, M., Dennerlein, J.: Reality Based Models for Vibration Feedback in Virtual Environments. IEEE/ASME Transactions on Mechatronics 6, 245–252 (2001)
6. Hachisu, T., Cirio, G., Marchal, M., Lécuyer, A., Kajimoto, H.: Pseudo-haptic Feedback Augmented with Visual and Tactile Vibration. Proceedings of IEEE International Symposium on VR Innovation, 327–328 (2011)
7. Hachisu, T., Cirio, G., Marchal, M., Lécuyer, A., Kajimoto, H.: Virtual Chromatic Percussions Simulated by Pseudo-haptic and Vibrotactile Feedback. Proceedings of ACM International Conference on Advances on Computer Entertainment Technology 2011, 20 (2011)
8. Lécuyer, A.: Simulating Haptic Feedback using Vision: A Survey of Research and Applications of Pseudo-haptic Feedback. Presence 18, 39–53 (2009)
9. Lee, J.C., Dietz, P.H., Leigh, D., Yerazunis, W.S., Hudson, S.E.: Haptic Pen: A Tactile Feedback Stylus for Touch Screens. Proceedings of User Interface Software and Technology, 291–294 (2004)
10. Kyung, K.U., Lee, J.Y.: Ubi-Pen: A Haptic Interface with Texture and Vibrotactile Display. IEEE Computer Graphics and Applications 29, 56–64 (2009)

11. Hachisu, T., Sato, M., Fukushima, S., Kajimoto, H.: HaCHIStick: Simulating Haptic Sensation on Tablet PC for Musical Instruments Application. Proceedings of User Interface Software and Technology, 73–74 (2011)
12. Yao, H.–Y., Hayward, V.: Design and Analysis of a Recoil-Type Vibrotactile Transducer. Journal of the Acoustical Society of America 128, 619–627 (2010)