Tactile Presentation using Mechanical and Electrical Stimulation

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Abstract. In our study, we developed the FinGAR (Finger Glove for Augmented Reality), which is a tactile display that uses a combination of electrical and mechanical stimulation. The device can selectively stimulate four channels of tactile sensation, based on pressure, low-frequency vibration, high-frequency vibration, and shear stretching, to achieve high-fidelity tactile sensation. The FinGAR was designed to be lightweight, to have a simple mechanism, to be easy to wear, and to ensure that it does not affect natural finger movement. By combining FinGAR with a virtual reality system, users are able to touch and play with virtual objects.

Keywords: FinGAR, electrical stimulation, mechanical stimulation, virtual reality, augmented reality

1 Introduction

Numerous studies have attempted to reproduce tactile sensation via presentation of skin deformation [2], pin matrix pressure [3], vibration [4,5], or electrostatic force [6]. Each study succeeded in reproducing some degree of tactile feeling, but in a relatively small range. In principle, it may be possible to reproduce any tactile sensation if we could drive the skin with sufficient spatial (up to 1.5 mm at the fingertip) and temporal (0 to 1 kHz) resolution; however, the skin has a large mass and damping action, and it is difficult to develop the versatile micromachines required for tactile displays.

Tactile information is provided by four types of mechanoreceptors in the skin [1], which respond to four channels of sensation. These mechanoreceptors are Merkel cells for pressure, Meissner's corpuscles for low-frequency vibrations, Pacinian corpuscles for high-frequency vibrations, and Ruffini's endings for shear deformation (see **Fig. 1**). If we could activate these receptors selectively and combine the four channels, we could then reconstruct any tactile sensation. This is similar to primary (red-green-blue, or RGB) colors in vision, which are based on the physiological existence of three types of cone cells in the retina.

To achieve both selective stimulation and a simple mechanical design, we proposed a combination of electrical and mechanical stimulation and developed a small, lightweight tactile display called FinGAR (Finger Glove for Augmented Reality). Electrical stimulation with an electrode array presents pressure and low-frequency vibrations with

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spatial resolution, and mechanical stimulation is used to present high-frequency vibrations and skin deformation. We also developed a virtual reality application in which the user can touch and play with objects while receiving tactile sensation on their thumb, index and middle fingers.

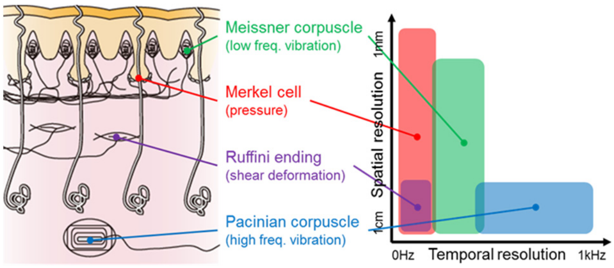

Fig. 1. Mechanoreceptors in skin and their spatiotemporal characteristics

Our virtual reality system was exhibited at SIGGRAPH 2016 Emerging Technology and more than 1000 participants experienced our demonstration [7]. This paper describes our system, the presentation algorithm and some noteworthy comments that we obtained from participants during the demonstrations.

2 FinGAR and Virtual Reality Application

The design and a photograph of a hand wearing the device are shown in **Fig. 2**. The device design is described in detail in [7]. A DC motor (Maxon 118386) with a 16:1 gear head ratio was used to drive an arm that contacts the finger-pad and stretches the skin. The DC motor was also found to serve as a high fidelity vibration unit [8]. The setup can thus provide shear deformation and vibration sensations simultaneously. A 4×5 array of electrodes made from a film substrate was attached to the end of the mechanical arm to provide high-resolution pressure and vibration sensations to the finger-pad. Using this combination, we can achieve four-channel stimulation with suitable spatial and temporal resolution.

Fig. 2. FinGAR and photograph of device when worn on three fingers

Fig. 3 and **Fig. 4** show the objects available in the virtual reality application and a view of a user touching and playing with the virtual objects, respectively. Participants wear the device on their thumb, index finger, and middle finger, and hold an optical mouse with their ring finger and pinky finger. The virtual hand is controlled via the mouse. Participants can touch puzzle lines, a pencil, a book cover, a ball, and the edge of a hole by keeping their hand on the mouse and moving it.

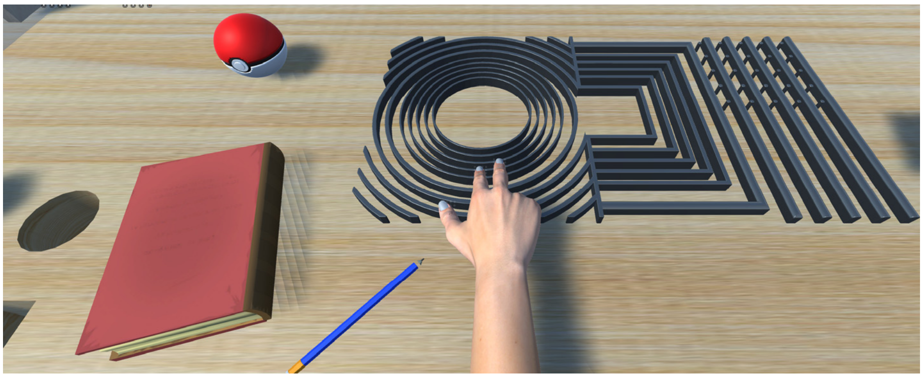

Fig. 3. Virtual objects in touching application

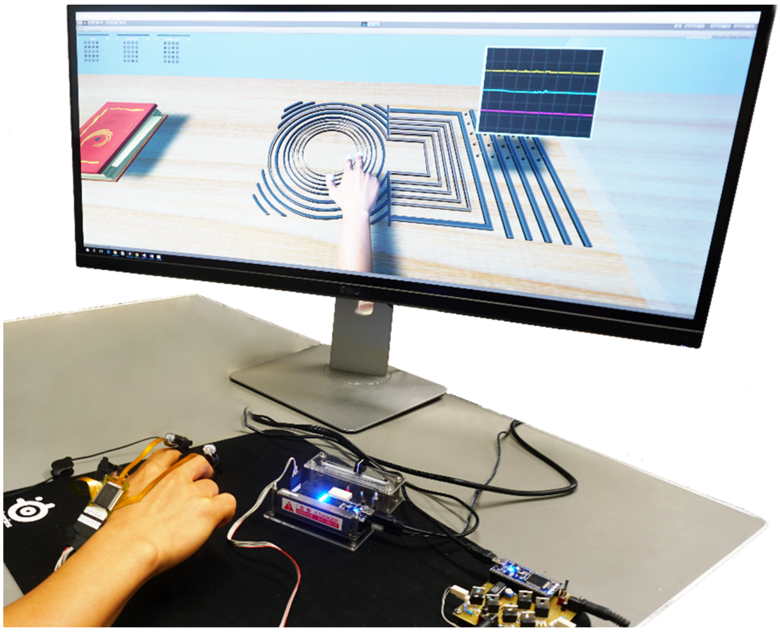

Fig. 4. View of user touching virtual objects

To reconstruct the realistic feeling of touching the objects, we designed the following algorithm based on consideration of the finger tracing speed, the contact surface and the roughness of the object.

- Mechanical stimulation algorithm

Because the DC motor can be used as a high fidelity vibration unit, our mechanical stimulation setup can provide skin deformation and low- and high-frequency vibration sensations with sufficient temporal resolution. To provide a combination of these sensations, we designed the signal input ($V_{DCinput}$) of the DC motor as follows:

$$V_{DCinput} = \min\left(k \times Depth_t + A_t(v) \times Tri(2\pi f t)\,, V_{DCinput\,,max}\right) \tag{1}$$

$$A_t(\mathrm{v}) = \min(C \times \sqrt{v}\,, A_{t\,,max}) \tag{2}$$

where k and C are constants, and $Depth_t$ is the touched object depth at the finger position. Tri, A_t, and f are a triangular waveform function, its amplitude, which depends on the finger velocity v, and frequency, respectively. For stability, the values of $V_{DCinput}$ and A_t were limited to no more than $V_{DCinput\,,max}$ and $A_{t\,,max}$, respectively.

The sine waveform is commonly used to present vibration sensations. However, preliminary tests showed that triangular waveforms seem to be better in providing friction and roughness sensations for our device, possibly because it contains natural high-frequency harmonic components. We can change the frequency of triangular waveforms to convey different roughness sensations in a shape. The frequency may be affected by finger velocity, but it was fixed for each material in our current setup.

- Electrical stimulation algorithm

While electrical stimulation can provide pressure and low-frequency vibration sensations by varying the electrical current's polarity [エラー! 参照元が見つかりません。], we did not use all of its functions in our application. The main purpose of using this stimulation is to provide shape information (e.g., lines, circles, or corners) and the strength of the roughness depends on the shape-tracing speed of the user's finger. We used anodic current because it is safer and easier to adjust its intensity when compared with cathodic current. To convey the shape sensation, only the electrodes within the contact area were stimulated; however, when the contact area increased (e.g., when touching the book cover), some of the electrodes were randomly turned off.

3 Demonstration Results and Discussion

Fig. 5 shows our demonstration experience at SIGGRAPH 2016 Emerging Technology. One of the authors stood or sat near the participants to instruct them on how to wear the device and touch objects, and then listened to their comments. More than 1000 people participated in our demonstration and almost all participants were surprised at the realistic sensations stimulated using our device.

Fig. 5. Demonstration experience at SIGGRAPH 2016 Emerging Technology

The most common comments obtained from the participants are listed below.

- Puzzle lines

The participants perceived the most realistic sensation when touching this structure. They could sense the shape of each line, friction and roughness. Some participants stated that it was made from metal, while others could not determine the material of the lines. To produce a smooth surface sensation, we set the triangular wave frequency to a high value of 150 Hz. The participants could perceive the line shape through electrical stimulation but it was hard for them to feel a corner shape. This may be due to the spatial resolution limitations of the electrode array.

- Pencil

Interestingly, participants sensed the scrolling of a hexagonal pencil when they pushed it with their fingers. In terms of shape touching sensation, however, it seemed to be less realistic. We considered it to be necessary to adjust the contact areas of the electrodes to allow clear perception of each edge of the hexagon.

- Book cover

The participants felt a rough cover made from fabric. The fabric sensation can be produced via electrical stimulation with spatial distribution. The triangular waveform frequency was set at 100 Hz to make the cover feel rougher than the puzzle line.

- Ball

Similar to the pencil, the participants could sense the round shape of the ball. Some said that it was soft while others said that it was smooth. Many participants perceived a sensation of smoothness rather than softness. The triangular waveform frequency was set at 30 Hz.

- Edge of a hole

This seemed less realistic but participants could sense the edge shape.

4 Conclusion

We have developed a new fingertip-type tactile display called FinGAR, in which we combine mechanical and electrical stimulation to provide high-fidelity tactile presentation. FinGAR is small, lightweight, easy to wear, and does not affect natural finger movement. We also developed a virtual reality environment in which users can touch and play with objects such as puzzle lines, a pencil, a book cover, a ball, and the edge of a hole. More than 1000 participants at SIGGRAPH 2016 experienced our system. Based on their comments, we have concluded that our device can present sensations of roughness, friction, fabric texture, and object shape (e.g., puzzle lines, hexagonal pencil, or roundness of a ball).

We have two steps for future work. First, we will use cathodic current for electrical stimulation to present the pressure sensation of gripping or holding objects. Second, to reproduce tactile sensation more realistically, we will conduct psychological experiments to determine how to best combine the mechanical and electrical stimulation.

Acknowledgments

This research is supported by the JST-ACCEL Embodied Media Project.

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