# Softness-Hardness and Stickiness Feedback Using Electrical Stimulation While Touching a Virtual Object

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### Abstract

With the advantages of small size and light weight, electrical stimulation devices have been investigated for providing haptic feedback in relation to virtual objects. Electrical stimulation devices can directly activate sensory receptors to produce reaction force or touch sensations. In the current study, we tested a new method for inducing electrical force sensation in the fingertip, presenting haptic feedback designed to alter softness, hardness and stickiness perception. We developed a 3D virtual reality system combined with finger-motion capture and electrical stimulation devices. The system can provide visual feedback and the sensation of illusory force that moved the index finger by forward-flexion or backward-extension using tendon or cathodic stimulation. In the demo, participants can experience the sensation of softness, hardness and stickiness of a virtual object.

**Keywords**: Softness-hardness perception, stickiness perception, electrical stimulation, virtual touch.

**Index Terms**: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

## 1 Introduction

Fully immersive virtual reality requires a high quality tactile device for reproducing sensations such as softness-hardness and stickiness. To be used in free-space virtual environments, devices must also be wearable. Many wearable tactile devices for virtual reality have been proposed [1], but most are vibrotactile systems, which are limited in terms of the object properties they can represent. To present the sensation of softness-hardness or stickiness of a virtual object to the fingertips, in addition to the sensation of the contact area [2], a haptic device must also produce a force sensation that reacts on the skin of the fingertip, inducing forward-flexion or backward-extension. Several previous studies have used asymmetric vibration to produce illusory force sensations in the finger [3]. However, the use of a mechanical actuator increases the size of the device.

To produce a small device with high responsiveness and energy efficiency, systems using electrical stimulation have been extensively studied. This method directly activates sensory receptors using an electrical current. Most previous studies of electrical stimulation have presented tactile sensation to the palm or fingertip [4], or force feedback sensation to the elbow or wrist [5][6]. However, previous studies have not presented force feedback sensation to the finger.

In this study, we tested a system for presenting haptic feedback to induce the sensation of softness-hardness and stickiness of a virtual object in the fingertip using electrical stimulation. As shown in Fig. 1, the electrode array mounted on the fingertip for stimulation was dense, small, and lightweight. We proposed a method for generating the illusory sensation of force, moving the fingertip by forward-flexion or backward-extension.

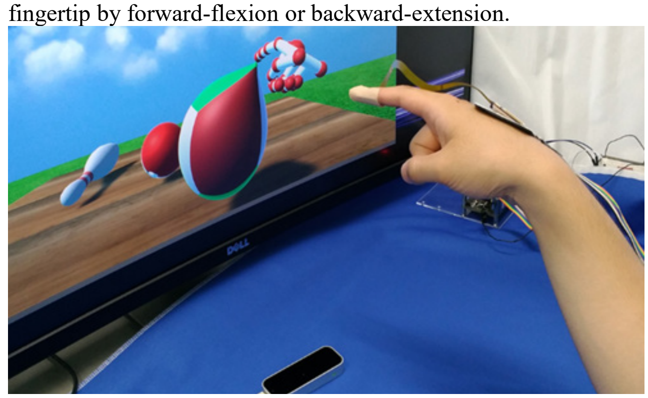

Figure 1: A 3D virtual reality system using electrical stimulation to present force feedback sensations of softness-hardness and stickiness to the index finger while pressing or releasing a virtual ball.

## 2 System

We used an electrical stimulation kit, as shown in [4], to control the intensity of electrical current. There were two types of electrodes (Fig. 2). The first was an electrode array placed on the fingertip. All of these electrodes were connected to the pins of a high voltage shift register (HV507, Supertex Inc.), enabling selection of the electrode for stimulation. The second was a large electrode (50 mm × 50 mm, NPP 40222, BODYMED) placed on the back of the hand. A switch (MOSFET 2SK1313, Renesas Electronics) was used to connect this electrode to ground or high impedance. We used the pulse waveform of an electrical current to stimulate sensory nerves and produce haptic feedback sensation on the fingertip of the index finger. As shown in Fig. 3, the pulse width of electrical current was 100 μs, there were two pulses per burst with an interval of 5 ms, and a refresh frequency ranging from 20 to 50 Hz. The pulse height could be adjusted from 0 to 5 mA.

We use cathodic electrotactile stimulation to present an illusory force sensation pushing the fingertip by backward-extension. As shown in Fig. 4 (left), the electrode at the stimulation point contacted the ground, while the others were connected to high voltage. Such a stimulation method has been previously reported to mainly activate Merkel cells that respond to pressure sensation on the fingertip [7][8]. In contrast, we used tendon electrical stimulation for presenting the sensation of force moving the finger by forward-flexion. In this method, all electrodes at the fingertip were connected to high voltage, while electrodes on the back of the hand were connected to the ground (Fig. 4 (right)). The electrical current flowing from the fingertip to the back of the hand activated the tendon sensory nerves inside the finger to produce the sensation of force. This is our proposed method of electrical stimulation for presenting force feedback to induce the sensation of stickiness.

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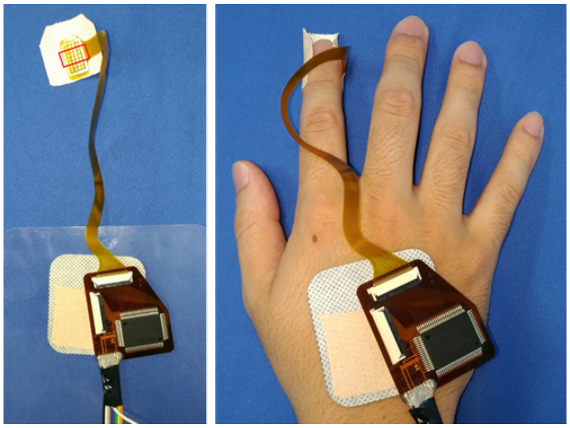

Figure 2: Electrodes for electrical stimulation (left) and overview of a wearable electrical stimulation device. The electrodes inside the red box are the points of cathodic electrotactile stimulation.

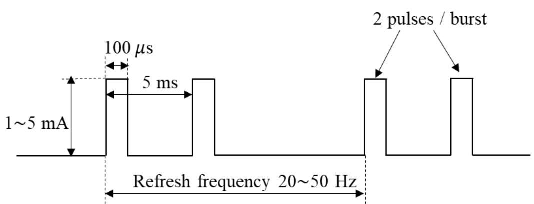


Figure 3: Pulse waveform for electrical stimulation

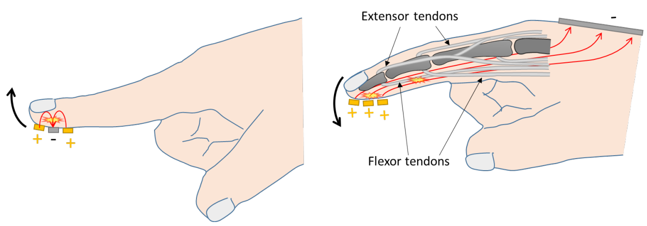


Figure 4: Cathodic electrotactile stimulation (left) and tendon electrical stimulation (right) for presenting illusory sensation of force moving the finger by backward-extension and forward-flexion.

We determined the strength of force feedback (the intensity of electrical current) on fingertip to be proportional to the distance between the virtual surface before deformation to the position of the finger measured by the motion capture device (Fig. 1 and Fig. 5).

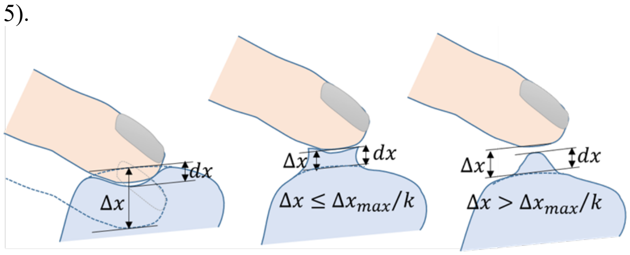


Figure 5: Deformation of a virtual object when pressing with a finger (left), releasing with stickiness (middle) or after releasing (right)

The surface of the virtual object started deforming when the finger applied force for pressing the object, or releasing the object with stickiness. The amount of deformation can be expressed by the following equation.

$$dx = \begin{cases} \frac{\Delta x}{k} & \text{(for pressing)} \\ \Delta x & \text{(for releasing with stickiness)} \\ \frac{\Delta x_{max}}{k} e^{-c \times t} \cos(\omega t) & \text{(after releasing)} \end{cases} \quad (2)$$

where $dx$ is the distance of a point on the surface for deformation, while $k$ and $c$ represent the spring and damping coefficient of the virtual object, and $t$ is time. $\Delta x_{max}$ is a constant value to limit the amount of deformation while releasing (Fig. 5 (right)). ω is the frequency of virtual surface vibration. Fig. 6 showed the deformation of a virtual ball that we used for our demo experience.

Figure 6: Visual interaction with object deformation while pressing (left), releasing with stickiness (middle), and surface vibration after releasing (right).

## 3 Demo Experience

As shown in Fig. 1, participants can experience the sensation of softness-hardness and stickiness feedback when they touch a virtual ball shown in the monitor. For safety, before demo experience we adjust the pulse height of electrical current for finding sensation threshold and pain threshold of each participant. During the demo, we change the intensity of electrical current or/and the amount deformation of virtual object for participants to perceive the different intensities of softness-hardness and stickiness.

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