Improvement of Shape Distinction by Kinesthetic-Tactile Integration

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Abstract

The sensation of touch is divided into kinesthetic and tactile sensation. It is important for a touch sensation device to present both types of sensations. We mounted an electrotactile display on a kinesthetic display, and realized a compact display of touch sensation. This system can improve the ability to identify objects. In this paper, we evaluate the effect of integrating kinesthetic and electrotactile sensations for identifying the shape of an object.

1. Introduction

The sensation of touch can be divided into two types based on the receptor that acquires the sensory information. One type is kinesthetic sensation, which is acquired by the proprioceptors that exist in the muscle, tendon, and joint. The other type is tactile sensation, which is acquired by mechanoreceptors that exist at a depth of several millimeters from the skin surface.

The sensation of touch is important for virtual reality environments or telepresence technologies. When we do work that requires us to remain in contact with an object, the presentation of touch sensation significantly influences our working efficiency. Based on the characteristics of human perception, it would be appropriate to present both types of touch sensation. However, many conventional displays of touch sensation present only kinesthetic sensation. To improve actual sensation and the working efficiency, it is necessary to simultaneously present tactile sensation as well.

This concept is realized by mounting a tactile device on a kinesthetic device. A number of technologies can be employed to achieve such a tactile device. The mechanical tactile display is one such tactile device [2] [3] [7]. This display drives a pin matrix and presents tactile sensation by directly deforming human skins. Another type of device is the electrotactile display [4], which directly stimulates the nerves connected to the mechanoreceptors.

Many studies have investigated the use of these tactile devices along with a kinesthetic device. Typical examples include a mechanical tactile display mounted on a kinesthetic display [1] [5] [10]. In another example, Methil et al. [8] used an electrotactile display to present tactile sensation. Some studies showed that presenting both force and tactile sensations can improve the working efficiency. However, the systems that accomplish this are too large to be used as an interface for general-purpose work in virtual reality or telepresence environments. Therefore, a small and light-weight system is desirable.

The purpose of this study is to construct a compact interface that is capable of presenting both kinesthetic and tactile sensations. In order to achieve this, we mount an electrotactile display on a kinesthetic display (Figure 1). This system enables us to distinguish the shape of an object. In this paper, we evaluate the efficiency of the electrotactile display to distinguish the shape of an object.

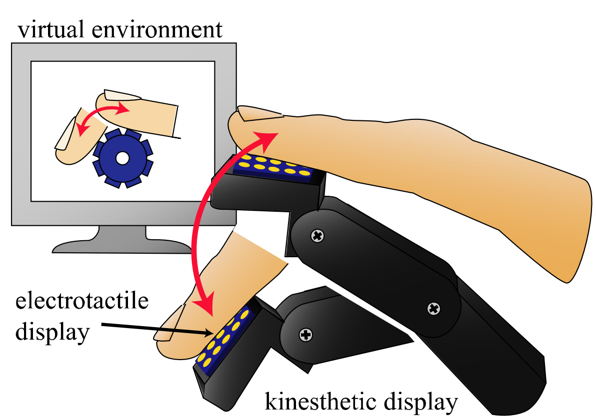

Figure 1. Conceptual diagram of the interface

2. Proposed method

When we hold an object in our hand, we try to ascertain its properties such as its size, shape, weight, position, and posture. Recognizing these properties improves the efficiency of working with the object. However, in order to recognize these properties, we require both kinesthetic and tactile sensations to be presented to us.

The conventional kinesthetic display presents only the reactive force sensation to its users, and makes us perceive a global shape. On the other hand, the electrotactile display makes us perceive a local shape. The electrotactile display consists of pin electrodes (Figure 2). Each pin electrode sends current inside the skin surface and directly stimulates the nerves that are connected to the mechanoreceptors (Figure 3). In this manner, the electrotactile display can present 2-dimentional touch sensation, touch position and distribution.

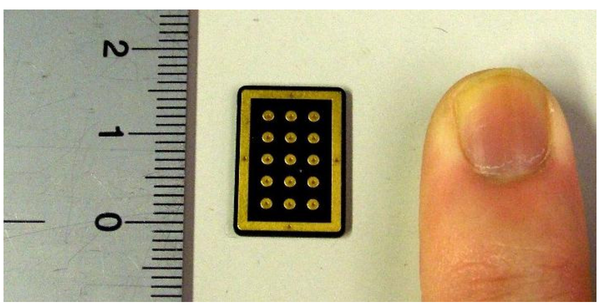

Figure 2. Electrotactile display (Electrodes)

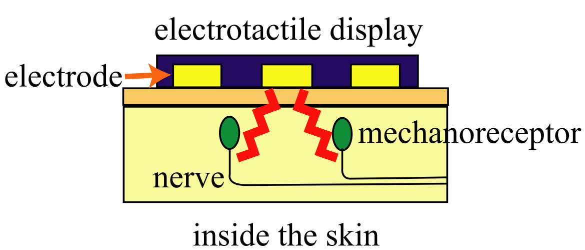

Figure 3. Electrostimulus
Reconstructed from [4]

We hypothesize that by integrating these two displays, many virtual touch sensations can be achieved (Figure 4). For example, line stimulation with a reactive force presents the feeling that an edge of the object has been touched. On the other hand, a uniform field like stimulus with a reactive force presents the feeling that a plane of the object has been touched.

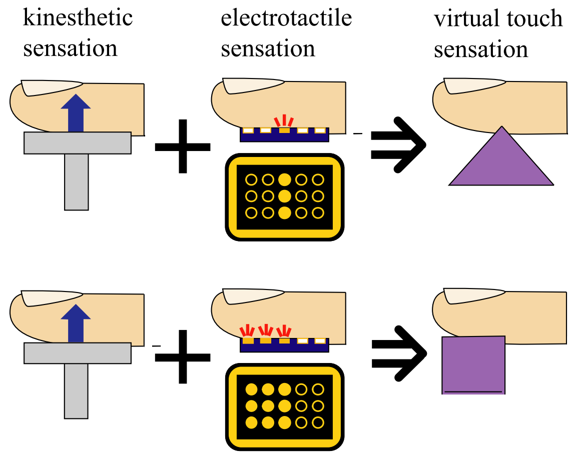

Figure 4. Virtual touch sensation

The advantage of using an electrotactile display is that a compact system can be constructed. The electrotactile display does not require any actuators. Therefore, it can be fabricated with a size and weight that are smaller and lighter, respectively, in comparison to a mechanical tactile display. The compact tactile display is suitable for future integration with a kinesthetic display.

In the following section, we will confirm the efficiency of integrating an electrotactile sensation with a kinesthetic sensation. It is considered that this integration will simplify object shape recognition. Further, we evaluate the shape detection efficiency of the electrotactile display.

3. Experiment 1

3.1. Material and Method

In this experiment, participants were asked to touch an object and identify it. First, in order to familiarize the participants with the experimental procedure, they were made to touch all the objects while conducting electrical stimulation (ES). Then, the objects were presented randomly. The participants touched the object according to the directed procedure and attempted to identify the object. During the experiment, the participants were not allowed to see the objects. Each object was displayed five times in a single trial. Next, the manner of touching and the condition of ES were changed. The number of correctly recognized objects and the time required for recognition was compared.

Figure 5 shows the experimental setup. The participants wore a plastic finger case on their fingertip when they touched the object. The electrode plate used for electrotactile display was in the finger case (Figure 6). Therefore, they were unable to feel any tactile sensation other than the ES or the pressure of the finger case. The thickness of the bottom of the finger case was 2 mm.

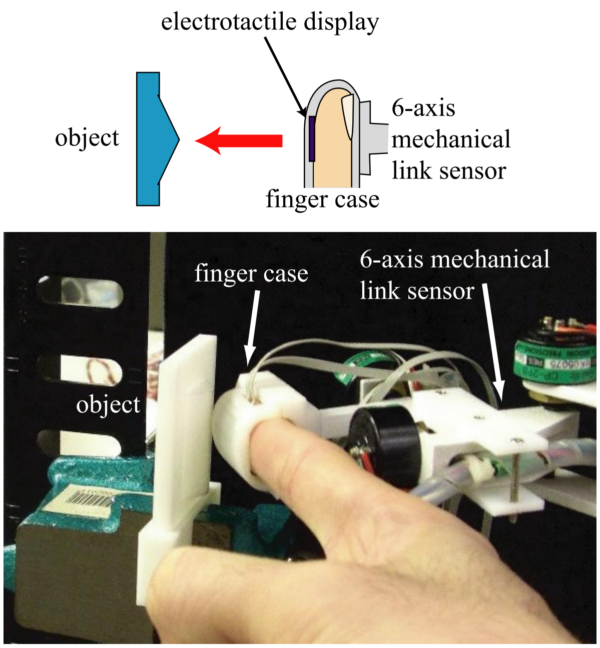

Figure 5. Experimental environment

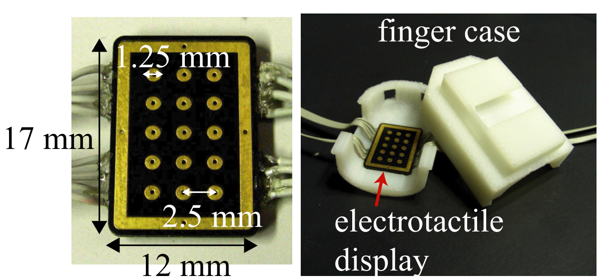

Figure 6.
(Left) Electrodes for electrotactile display
(Right) Finger case

The size of the electrode plate used in this experiment was 12 mm × 17 mm and it consisted of a 3 × 5 electrode matrix. The surrounding electrode was used as an electrical ground. The diameter of each electrode was 1.25 mm, and the distance between the centers of the electrodes was 2.5 mm. The pulse width was 40 μm, and the pulse frequency was 60 Hz. The strength of the stimulus could be controlled by the participants.

The position of the fingertip was measured by using a 6-axis mechanical link sensor (ADL-1, Shooting Star, Inc.). Based on the position information, contact between the finger and object was judged, and the tactile pattern was determined. For example, when all the bellies of the fingertip are in contact with a flat surface, a current is sent from all the pin electrodes. When the middle of the fingertip contacts an edge, the middle line of pin electrodes matrix sends a current. The ES is presented when the fingertip made contacts with the object.

It must be noted that in this setup, “real” kinesthetic sensation was presented by actual contact, and tactile sensation was presented by using the object’s VR model in a PC. This condition is a type of “mixed reality.”

It is difficult to prepare all the shapes of a 3D object. Therefore, we selected some typical shapes as representative of 3D objects, and conducted experiments using them. An identical method was used by Shimojo et al.[9]. For this preliminary experiment, we prepared three objects with the following characteristics: flat surface, curved face, and edge (Figure 7). The objects were prepared from plastic resin. It is difficult to touch and recognize a large object using the index finger. Therefore, we determined the size of the object from the fingertip moving range of the index finger when fixing the root.

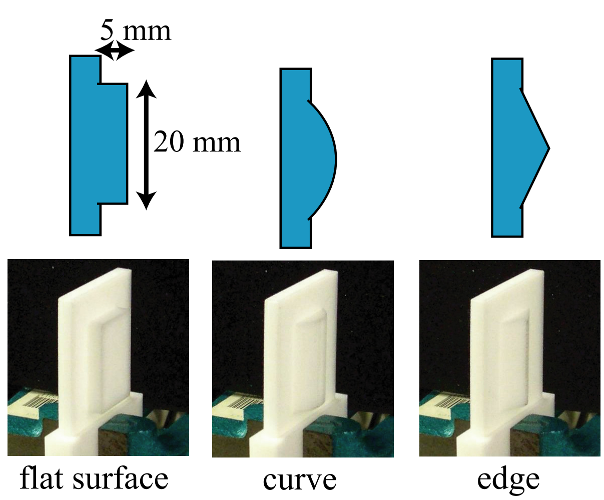

Figure 7. Objects that participants touched
(Above) Dimensions, (Below) pictures

In the case of shape recognition, the manner of touching influences the accuracy and time of recognition. In this experiment, we divided the manner of touching into two modes – pushing and tracing. One was pushing and another sliding (Figure 8). In the pushing mode, the participants only pushed the object vertically. In the tracing mode, the participants were permitted to slide their fingertip horizontally and trace the surface of the object.

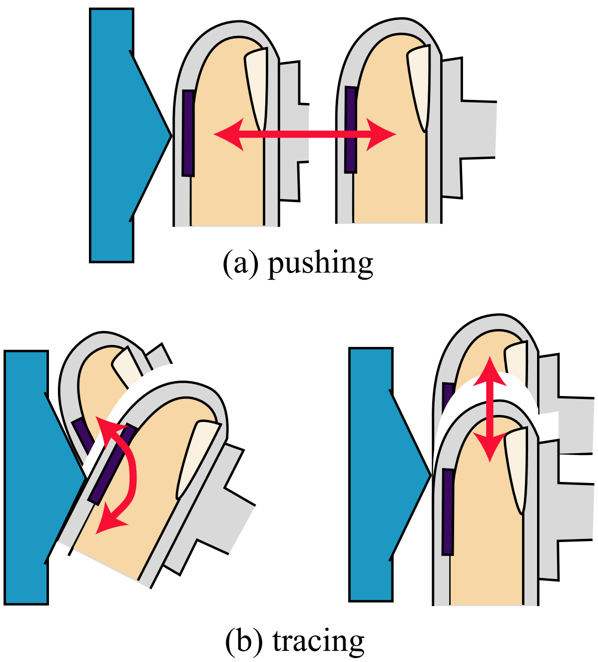

Figure 8. Two modes of touching

The participants included four males and one female in the age group of 22-25. They were healthy graduate students volunteered for the experiments. They were asked to name the object they were touching (from three choices). The experiment conditions were as follows:

1. Pushing with ES
2. Pushing without ES
3. Tracing with ES
4. Tracing without ES

A total of four trials was designated as 1 set and each participant performed three sets.

3.2. Results

Figure 9 and Figure 10 show the experimental result of all participants. The horizontal axes represent the abovementioned experimental conditions. The vertical axes represent the correct answer ratio or recognition time. The recognition time is the average time required to recognize one object. Each bar represents the result for one of the participants. Each horizontal line represents the average of participants in each experimental condition.

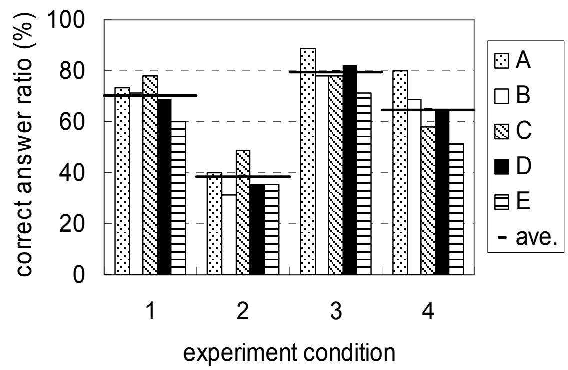

Figure 9. Correct answer ratio

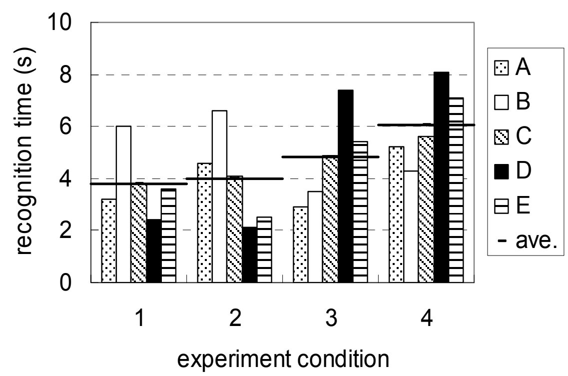

Figure 10. Recognition time

3.3. Discussion

From the result, it was confirmed that a correct answer ratio with ES was higher than that without ES, and a recognition time with ES was shorter than that without ES. Further, this was hardly related to the participant and mode of touching. Therefore, it was inferred that the integration of the electrotactile display improves the efficiency of shape recognition. However, this was a preliminary experiment, and hence, only three different shapes were used, and the size of the object was also fixed. In the future, we will investigate in greater detail.

From the differences arising due to the experiment conditions, it can be seen that the recognition time was short under condition 2 as well as the condition 1. In this experiment, we asked participants to answer the shape correctly and quickly. Therefore, some participants answered a shape before they recognized an object completely.

Under condition 4, the participants were able to recognize the object almost correctly even without ES. The kinesthetic sensation presents the global shape, and shape recognition efficiency is improved by moving the finger[6]. Therefore, it is considered that the kinesthetic sensation is sufficient to recognize an object in this condition.

If the kinesthetic sensation is sufficient to recognize an object, why is the efficiency of shape recognition improved by integrating electrotactile stimulus? As a contradiction to this question, let us assume that the electrotactile sensation is a transient stimulus. In vision sensation, a human being is said to be sensitive to changes in his surroundings. Such sensitivity occurs with touch sensation as well. It is considered that the participants reacted sensitively to the electrotactile stimulus, and the shape recognition efficiency was improved. In the next section, we will investigate this hypothesis.

4. Experiment 2

4.1. Material and Method

If the electrotactile sensation is a transient stimulus, a number of shape sensations are presented by the electrotactile stimulus. For example, when the kinesthetic display presents a sensation of an "object with an edge" while the electrotactile display presents that of a "curved object", a human being would perceive the latter. In this experiment, we investigate the participant's responses presenting stimulation that confirmed kinesthetic or electrotactile sensation.

The participants traced the object surface in the manner shown in Figure 8 (b). The objects they touched are an edge and a curve (Figure 7). These are selected as a special example of an identical form. Two stimulation modes were tested for electrical stimulation. The first mode stimulated a "curvature"; the second, an "edge". The experiment conditions were as follows.

1. Touching curved face with curve ES
2. Touching curved face with edge ES
3. Touching edge with curve ES
4. Touching edge with edge ES

In this experiment, these four trials is one set, and two sets were performed. Based on the kinesthetic and tactile sensations perceived by participants, they identified the object type as "curved face" or "edge." In this experiment, participants had to answer within 5 s. Other experiment environment conditions in the experiment were the identical to those in the previous experiment.

4.2. Results

The average response ratio of the "curve" is shown in Figure 11. For example, if participant always recognized the object as a curved face, in accordance with condition 1, the response ratio becomes 1.0. The horizontal axis represents the experimental conditions. The vertical axis represents the response ratio of the "curve." Each dot represents the participants' answer ratio, and each bar represents their average. The error bar represents the standard error.

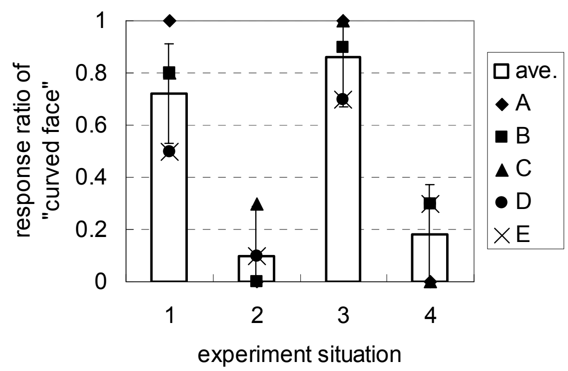

Figure 11. Response ratio of "curves"

4.3. Discussion

In this experiment, there was a tendency that the participants respond to the object judging from the ES. Therefore, the response ratio of the "curve" is high under condition 1 and 3 and low under 2 and 4. This result supports the hypothesis that the electrotactile sensation is a transient stimulus. Therefore, it is suggested that the electrotactile stimulus is efficient in presenting shape sensation, and the result of experiment 1 is natural. In addition, we would suggest that any touch sensation using a typical object shape can be presented by integrating an electrotactile display.

5. Conclusion

In this paper, we proposed a touch sensation display that presents both kinesthetic and electrotactile sensations. It is considered that this system will improve the efficiency of object shape recognition and evaluate it. The results revealed that electrotactile display can improve the ability to distinguish three simple objects. Furthermore, we showed the possibility that the electrotactile stimulus is efficient for representing shape sensation.

In future studies, we will evaluate the efficiency of integrating the electrotactile sensation with kinesthetic sensation in greater detail. We acquired the information on the improvements in the shape recognition by conducting experiments with three objects. Out next step is to experiment with more type of objects and changing the object size. From these experiments, we will clarify the properties required to construct the kinesthetic-tactile integrated display and the possibility of integration. Finally, we hope construct a simple and compact tactile display.

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