Evaluation of Transmission System for Spatially Distributed Tactile Information

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Abstract. Spatially distributed tactile information is essential for dexterous operation in telexistence. We propose a transmission system for spatially distributed tactile information using a finger-shaped GelForce and an electrotactile display. Both devices are suitable for integration with multi-fingered tele-operation system because these devices are compact. In this study, we evaluate the performance of a one-fingered transmission system for spatially distributed tactile information by conducting recognition experiments. We discuss the efficiency and limitations of the proposed transmission system.

Keywords: finger-shaped force sensor, electrotactile display, spatially distributed tactile information, and telexistence.

1 Introduction

The transmission of haptic information in tele-operation systems is essential for interaction with remote objects. In particular, spatially distributed tactile information is essential for dexterous operation [1]. Thus far, several systems have been developed for the transmission of spatially distributed tactile information [2] [3]. For example, Methil et al. [3] have developed a tele-diagnostic system that can be used to detect tumors in remote patients. Unfortunately, because this system was developed for use as a diagnostic tool for breast pathology, users are unable to grasp objects. The size of the tactile device limits the finger workspace, making it all the more difficult to fabricate a multi-fingered transmission system. Therefore, compact sensors and displays are required to achieve dexterous grasping of remote objects in tele-operation systems.

To achieve dexterous tele-operation, we have developed the following compact tactile devices: a finger-shaped force sensor named as finger-shaped GelForce [4] and an electrotactile display [5]. Because these devices are small in size and light in weight, they can be easily mounted on any multi-fingered tele-operation systems (Fig. 1). Furthermore, the spatial resolution of these devices can be easily improved because of their simple structures. In this study, we fabricated a one-fingered transmission system and evaluated the contact area recognition efficiencies of the system.

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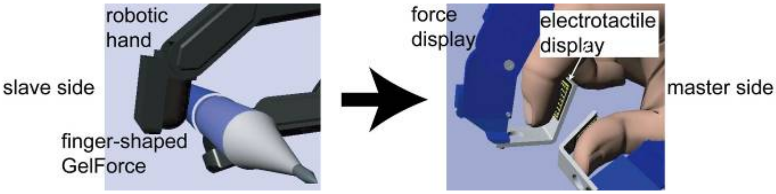

Fig. 1. Transmission system for spatially distributed tactile information using finger-shaped GelForce and electrotactile display

2 Transmission of Spatially Distributed Tactile Information

2.1 Finger-Shaped GelForce

A finger-shaped GelForce sensor [4], which was developed in-house, was used to obtain spatially distributed tactile information. The finger-shaped GelForce consists of a transparent elastic body, red and blue marker matrices, and a color charge-coupled device (CCD) camera that captures the movements of the markers. These movements are used to calculate the distribution of the force vector (magnitude and angle) applied on the sensor surface. Thus, we easily realized a high-resolution sensor that has a design, such as shape and impedance, similar to that of the human fingertip.

We use a human skin gel (Exseal Corp., Young's modulus: 50.0 KPa) for the transparent elastic body of the finger-shaped GelForce to match the impedance of the human finger. We set 15 force sampling points at intervals of 2.5 mm. In this case, the spatial, magnitude, and temporal resolutions of the constructed finger-shaped GelForce are 5.0 mm, 0.15 N, and 16 ms, respectively.

2.2 Electrotactile Display

The developed electrotactile display [5] produce spatially distributed tactile stimulus. It comprises pin electrode matrices and directly activates nerve fibers under the skin by passing electric current through surface electrodes. The current flows from an electrode to adjacent electrodes through the skin. By periodically changing the pin used for stimulation, electrotactile stimuli can be presented at any point. Because the electrotactile display does not require the use of any mechanical actuators, the displays can be easily attached to each fingertip.

In this study, we use an electrotactile display that has 15 electrodes. The diameter of each electrode and the distance between the centers of the electrodes are 1.25 mm and 2.5 mm, respectively. A square wave having a pulse width and maximum pulse amplitude of 20 μs and 5.0 mA, respectively, is used for stimulation. The frequency of pulses applied at the electrode is 30 Hz. The line-width, two-line, and amplitude discrimination thresholds are 2.5 mm, 7.5 mm, and 0.1 mA, respectively.

2.3 Methods for Information Transmission

In the proposed system, spatially distributed tactile information is transmitted from the finger-shaped GelForce to the electrotactile display (Fig. 2). The magnitude and distribution of the force vectors are related to the amplitude and position of the electrotactile stimuli. The electrotactile display can only indicate the magnitude and distribution of the force vectors, not their orientation. The magnitude of the force vector $|f_i|$ is calculated as follows:

$$|f_i| = \sqrt{{f_{ix}}^2 + {f_{iy}}^2 + {f_{iz}}^2} \tag{1}$$

where i denotes the number of force sampling points. When the magnitude of force at a point is less than half its value at adjacent sampling points, we set the magnitude of force at that point to 0.0. This elimination technique seems to virtually improve the spatial resolution of the finger-shaped GelForce from 5.0 mm to 2.5 mm [4]. The amplitude of the electrotactile stimulus at a pin electrode, $|A_i|$, is given as follows:

$$|A_i| = \alpha |f_i| + \beta \tag{2}$$

where i, α and β denote the number of pin electrodes, gain, and bias, respectively. Each value of α and β is pre-examined by a user.

3 Experiment

We evaluate the transmission system for spatially distributed tactile information from the view-point of contact area recognition efficiency.

3.1 Material and Method

Material. We employed PHANToM Omni (SensAble, Technologies) to touch the remote object in the transmission system for spatially distributed tactile information. We mounted the electrotactile display and the finger-shaped GelForce on the end-effectors of the master PHANToM and slave PHANToM, respectively (Fig. 3). The participants had to place the tip of their index finger on the electrotactile display and move the end-effector of the master PHANToM to control the finger-shaped GelForceon the slave PHANToM. In this experiment, we used the simplest symmetric position servo type control algorithm for robotic master-slave control, which can be represented by the following equations:

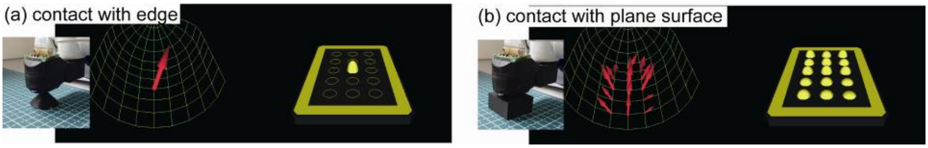

Fig. 2. Transmission of spatially distributed tactile information. Contact with (a) edged object and (b) flat object. The lengths of the arrows represent the magnitude of the measured force, whereas the size of the sphere represents the amplitude of the electrostimulus.

Fig. 3. Experimental setup: one-fingered transmission system for spatially distributed tactile information employing PHANToM master-slave system

$$f_s = (x_m - x_s)K_p \qquad f_m = -f_s \tag{3}$$

where f_s and f_m denote the forces of the slave and master systems, respectively; x_s and x_m, the positions of the slave and master systems, respectively; K_p, the gain. We limited the participant's finger movement to a single direction (along the y-axis, as indicated in Fig. 3). Participants were instructed to push the object, but not to stroke the surface of the object or to change the contact position.

Method. Participants conducted three recognition experiments: position, width and angle. In the position experiment, the participants touched the edge of a circular cone at an arbitrary position (Fig. 4a). The circular cone is made from plastic and its diameter and height are 20.0 mm and 10.0 mm, respectively. The contact position of the cone was selected randomly from five positions, namely, the center of the sampling point, 2.5 mm away from the center and toward to left, toward the right, forward, and backward. Subsequently, participants reported the position in which they made contact with the cone. In the angle experiment, the participants touched at rectangular prism that was oriented at 0°, 45°, 90°, or 135° (Fig. 4b). The rectangular prisms are made from plastic, and they have a width and length of 2.5 mm and 20.0 mm, respectively. The angle of orientation of the prism was selected randomly. Then, the participants reported the orientation of the prism that they touched. In the width experiment, the participants touched closely-arranged rectangular prisms (Fig. 4c) using the transmission system. The number of prisms was randomly selected as 1, 2, 3, and 4, and therefore, their total widths were 2.5 mm, 5.0 mm, 7.5 mm, and 10.0 mm, respectively. Then, participants reported on the number of prisms they had touched.

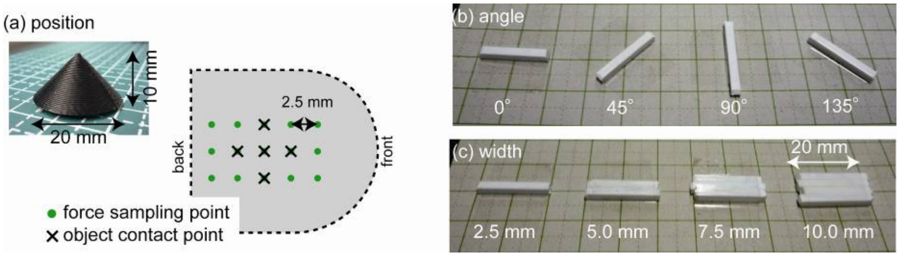

Fig. 4. Conditions of object for each position, width, and angle recognition experiment

One male and two female participants in the age-group of 23-26 volunteered for the experiments. In each discrimination experiment, each experimental condition was performed ten times. Throughout the experiment, there was no visual or audio feedback for the participants.

3.2 Result

The experimental results are shown in Fig. 5. In the position experiments, the averaged correct answer ratio was 0.75. Using ANOVA, we determined that there is no significant difference in the results obtained for the different contact positions on the circular cone ($F(4,14)=1.33$, $p=0.34$). In the angle experiments, the averaged correct answer ratio was 0.74. There is no significant difference in the results obtained for different orientation of the rectangular prism ($F(3,11)=2.37$, $p=0.17$). Finally, in the width experiments, the averaged correct answer ratio was 0.53. There is a significant difference in the results obtained by changing the widths of the rectangular prisms ($F(3,11)=6.51$, $p<0.05$). Furthermore, the results of multiple comparisons demonstrate that there are significant differences in the results when the widths of the prisms are 2.5 mm and 7.5 mm ($t(11)=4.11$, $p<0.05$).

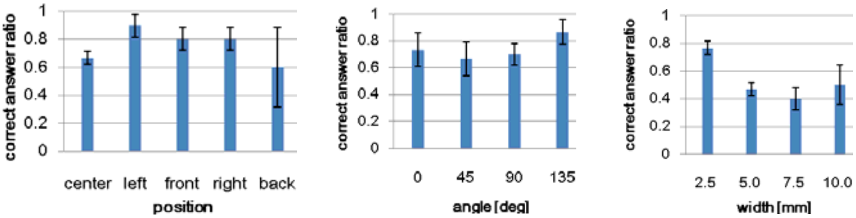

Fig. 5. Experimental results. The graphs on the left, at the center, and on the right represent the results of the position, angle, and width experiments, respectively. The horizontal axis represents the experimental condition, whereas the vertical axis represents the ratio of correct answers. The bars represent the averages of all participants. The error bar represents standard deviation.

3.3 Discussion

In this evaluation, we employed a finger-shaped GelForce and an electrotactile display. These devices have similar spatial resolutions as those employed in previous studies. From the spatial resolutions of these devices, we expected that participants would correctly discriminate the 2.5 mm differences more than 75% of the time. The results of the experiment involving the position and angle demonstrate that the proposed system is capable of effectively determining the contact position and orientation of the object. Therefore, we expect that an improvement in the spatial resolutions of our tactile devices would result in the improvement in the efficiency of the transmission system.

However, it appeared that participants were unable to discriminate the 2.5 mm difference in the width experiment. A previous study [5] showed that the participants can discriminate this difference using the electrotactile display. Therefore, we assume that the measurement error of the finger-shaped GelForce causes a decrease in the accuracy of the transmission system. It is believed that the measurement error can be decreased by increasing the resolution of the CCD camera [4].

4 Conclusion

In this study, we fabricated a one-fingered transmission system for spatially distributed tactile information using a finger-shaped GelForce and an electrotactile display. The results of the contact area recognition experiment showed that our system is efficient for transmission for spatially distributed tactile information.

However, the transmission of other haptic information such as compliance or texture is also essential for tele-operation systems. Therefore, in the future, we would aim to conduct a comprehensive evaluation of our system as a haptic transmission system. Then, we will design a multi-fingered transmission system and evaluate its efficiency from the viewpoint of achieving dexterous grasping.

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