A Study on Fundamental Information Transmission Characteristics of an Air-Jet Driven Tactile Display

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Abstract. There are many people with impaired vision as well as hearing. Tactile displays can be useful to such people for communicating by means of characters and shapes. Many devices for tactile displays such as oscillators and electrocutaneous stimulators have been developed. However oscillators have two drawbacks: physical stress tends to build up in actuators because of long term exposure to oscillations, and they may transmit erroneous information because of unstable contacts between magnetic pins and the skin. Moreover, electrocutaneous stimulators cause discomfort to the user. In this study, we have developed a tactile information presentation technique that uses air jet stimulations and tactile phantom sensations induced by a complex combination of tactile perceptions. The tactile display can transmit information to the skin without physical contact and is free from the restriction of pitch size. In this paper, we have examined its fundamental information transmission characteristics.

Keywords: Tactile Display, Air Jet Stimulation, Phantom Sensation.

1 Introduction

In Japan, there are 20,000 people with impaired vision as well as hearing [1]. Tactile displays can be useful to such people for communicating by means of characters and shapes. In order for the tactile displays to be widely accepted, it has been established that the type of actuators and the pitch size of the actuators are major factors to be considered while designing tactile displays [2][3].

Selecting the appropriate type of actuator for transmitting accurate tactile information has been considered to be a challenge. Many devices such as oscillators and electrocutaneous stimulators have been developed that serve as the principle mechanism of tactile displays. It has been reported that oscillators, however, have two drawbacks: physical stress tends to build up in these actuators because of long term exposure to oscillations [4], and they may transmit erroneous information because of unstable contacts between magnetic pins and the skin [5].

Electrocutaneous stimulators have been reported to induce pain [4]. These stimulators require physical contact between the actuators and the skin; thus, they

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are prone to interference [6]. Consequently, though these actuators have an advantage in that the coupling between the actuators and the skin provides instantaneous tactile information, they also have a disadvantage that they cause discomfort to the user.

Selecting the appropriate pitch size is important for the effective transmission of information. For improving the transmission efficiency, some researchers have attempted using actuators with a high spatial density [3][7], and others have attempted invoking tactile apparent motions [8][9][10]; however, these techniques have been ineffective in overcoming the above mentioned problems, thus far.

In this study, we have developed and demonstrated a tactile information presentation technique that uses air jet stimulations and tactile phantom sensations (PSs) [11] induced by a complex combination of tactile perceptions. Tactile displays that employ air-jet stimulations can be used to present noncontact stimuli so that safety as well as non-interference is assured [6]. Therefore, this presentation technique can potentially compensate for the above mentioned drawbacks to some extent.

A tactile PS is a combination of sensations that is evoked by a stimulus at a certain location where no stimulus is indeed present. This phenomenon typically occurs at a specific location of the skin when two stimuli are provided to the skin at a specific distance from each other. It has been reported that the location of the PS shifts depending upon the ratio of intensities between the two real stimuli; therefore, the location of the PS can be changed by controlling the intensities of the two stimuli. This controllability of the location of the stimulus implies that a limited number of actuators can be used to provide PS-based stimuli at many locations. This leads to a high efficiency in density of stimulus actuators for a tactile display by applying PS-based stimuli.

Thus, the tactile display that uses air-jet stimulations and PS-based stimulus presentation technique can transmit information to the skin without physical contact and is free from the restriction of pitch size. In this study, we have developed a noncontact tactile display and have examined its fundamental information transmission characteristics.

2 Noncontact Tactile Display Using Air-Jet Stimulations

The stimulus presentation unit of our noncontact tactile display consists of 25 nozzles (HB-U1/8VV-00D3, Spraying Systems, Japan) arranged in a 5 × 5 matrix (see Fig. 1(a) for the unit). A schematic diagram of the tactile display is shown in Fig. 2. Compressed air supplied by an air compressor (EC1430H2, Hitachi Koki) is emitted from the nozzles. The amount of air supplied is controlled by using a digital electro-pneumatic regulator (EVD-1900-P08 SN, CKD) and a precision regulator (RP2000-8-08-G49PBE, CKD). The pressure level is controlled with a resolution of 1.0 kPa. A digital I/O board (PCI-2726C, Interface) is used for transmitting control signals from a PC to determine the pressure level in each nozzle.

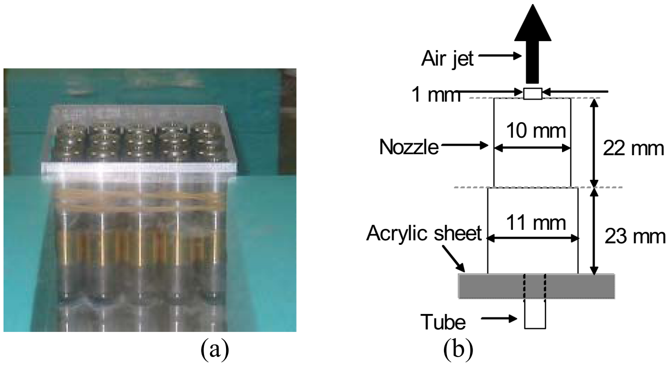

Fig. 1. Noncontact 5 × 5 tactile display. ((a) side view of the stimulus presentation unit, (b) internal structure of the nozzle).

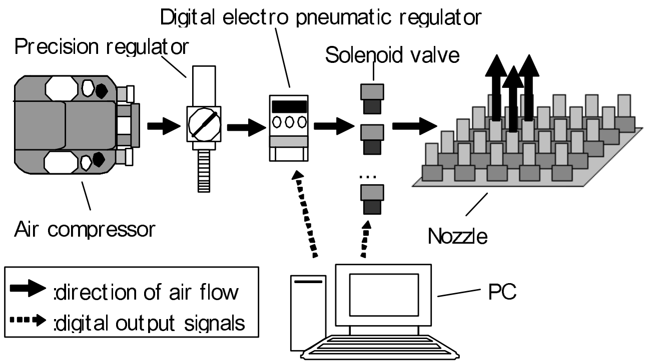

Fig. 2. Schematic diagram of the tactile display

3 PS Generation Scheme and Presentation Patterns

In this study, PSs were generated by using a 3-point simultaneous stimulus presentation pattern. In previous studies [12][13], it was reported that PSs were clearly evoked when mechanical and electrical stimulations were presented by using a 3-point simultaneous stimulus presentation pattern designed on a planar surface. According to a study conducted on the optimum conditions required for the generation of PSs [14], the location of each PS was assumed to be the median point of the weighted intensities of the stimuli at three adjacent locations.

4 Experiment

An experiment was conducted to evaluate the information transmission characteristics of the proposed tactile display.

4.1 Shapes Presented in the Study

In this study, simple graphical symbols were presented via the tactile display. Fig. 3 shows the shapes of the symbols. A total of eight shapes were selected. In the figure, the black square points in each graphical symbol denote the PS generating points and the white circles denote the location of the nozzles.

4.2 Types of Presentation Methods

The methods used to present information via tactile displays are varied. Many researchers have developed their own presentation methods for effective information transmission. The type of information (shape, texture, etc.) to be presented may restrict the type of method used and the transmission characteristics of the tactile display. In this study, three presentation methods were tested for their preciseness in transmitting tactile information: They were one-stroke drawing, path separation, and vertex emphasis methods. In the one-stroke drawing method, stimuli were presented by tracing the shape of the symbol. Fig. 4 shows the stimulus path traced in the case of a trapezoid, i.e., the exact sequence of stimulations generated from the nozzles to present the symbol. As shown in the figure, the stimulus locations shifted in the order 1 through 11 and back to 1. Note that stimuli were not presented during transition between two PS locations, that is, after presenting a stimulus for certain duration at location 1, the next stimulus was provided at location 2. Fig. 5 shows the set of active nozzles corresponding to each stimulus location as the trapezoid was traced.

The path separation method was different from the one stroke drawing method in that air jet emission was stopped at each corner, indicating that each straight path deviated at the corners. In Fig. 4, four paths are followed to trace the trapezoid: 1 to 4, 4 to 7, 7 to 9, and 9 to 1. The basic concept of the vertex emphasis method was similar to that of the path separation method; both starting points and ending points were emphasized to recognize the path easily. While a no-stimulus interval was used to indicate the vertex location in the path separation method, stimuli with a high intensity were used to indicate the vertex locations in the vertex emphasis procedure. The intensity of the stimulus generated at each corner was determined from the inner angle of two paths intersecting at that corner. The intensities of the stimuli in the case of the vertex emphasis method were set according to the following equation:

$$I = \theta + 350 . \qquad (1)$$

Where I : Intensity of stimulus [kPa]
θ: Inner angle between two paths [°]

According to this equation, if two paths intersect at an inner angle of 90°, the stimulus intensity at the vertex becomes 440 kPa.

In all the methods, the duration of stimulus presentation ranged from 100 ms to 500 ms, as determined by each subject prior to the experiment so that the stimuli could be perceived very clearly. The optimum duration of stimuli presentation was different for each individual.

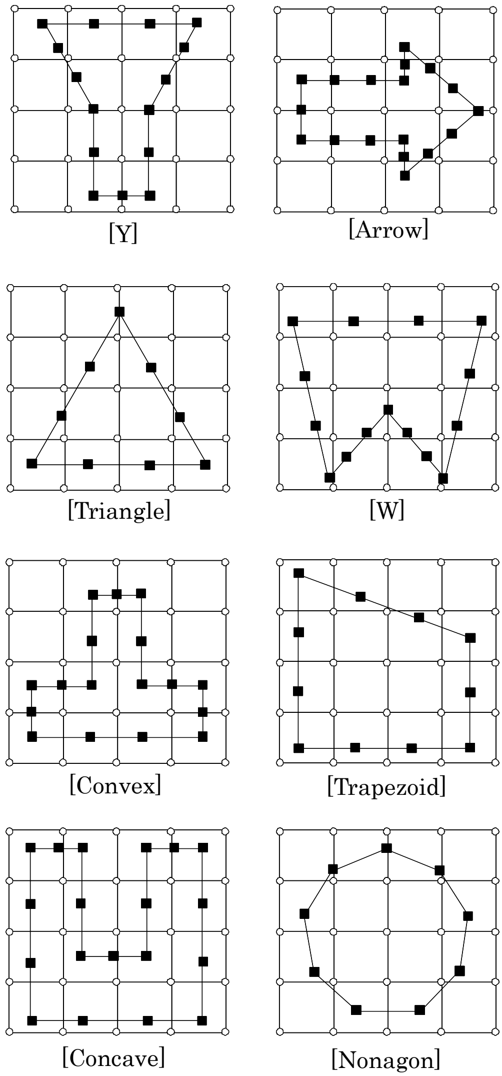

Fig. 3. Shapes of graphical symbols presented in the study. Note that all PS generating points (*black squares*) are linked for the purpose of legibility. No tracing stimuli were presented between two PS generating points throughout the experiment.

4.3 Sequence of Events during Experiment

Fig. 6 shows the sequence of events followed during the experiment. Two trials, each consisting of a set of stimuli corresponding to a shape, were carried out in the following manner. A set of stimuli were presented in the first trial. After the second set of stimuli was presented, the subjects identified the shapes as perceived by them. The subjects had been notified of the list of graphical symbols visually, but not tactually, prior to the experiment. Table 1 summarizes the other experimental conditions.

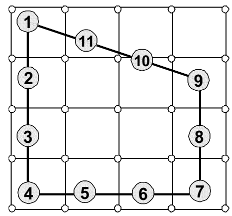

Fig. 4. Stimulus path traced in the case of trapezoid. Each *numbered circle* corresponds to the location of the PS. Numbers in circles indicate the order of stimulus presentation. Each PS-generating stimulus consisted of simultaneous weighted air-jet emissions from three nozzles.

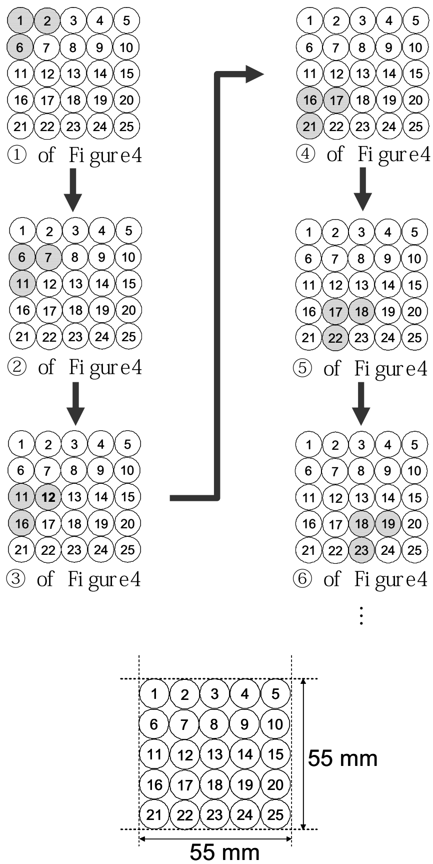

Fig. 5. Set of active nozzles corresponding to each stimulus location as the trapezoid is traced. Air-jet stimulations were emitted from the shaded nozzles to generate the PSs. The exact locations of the PS are shown in Fig. 4. Intensity of the air-jet for each nozzle was different from each other, based on the weighted midpoint to generate PS at designated position. This figure shows the exact arrangement of the nozzles in the tactile display developed in this study.

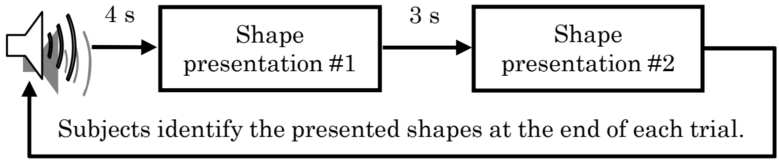

Fig. 6. Sequence of events during each trial

Table 1. Experimental Conditions

Subject	Five healthy males
Body location for the stimulus presentation	Center of the palm
Distance between the skin and nozzle	5 mm
Total intensity of the 3-point air-jet stimulations	350 kPa
Presentation duration	100–500 ms, adjusted according to the optimum duration for each subject
Number of presentation methods	3
Number of shapes presented	8
Number of trials in a block	4

5 Results and Discussion

Fig. 7 shows the correct responses rates along with the average correct response rates of each subject for the three different presentation methods. Fig. 8 shows the correct response rates categorized by shape. As shown in Fig. 7, the correct response rate was the highest in the case of the path separation method. The path separation method appeared to be the most effective tactile stimulus presentation method within the range of the experimental conditions. On the other hand, the one-stroke drawing and vertex emphasis methods were not as effective. Subjective responses revealed that the shapes were not perceived clearly when stimuli were presented by the one-stroke drawing method. The edge information was distorted in the case of the one-stroke drawing method, and the loss of information resulted in low correct response rates. In the case of the vertex emphasis method, the subjects responded that the intensities of the air-jet stimuli presented at the vertices were sometimes very high and they obscured the tactile information of the adjacent locations. Identifying each path separately is important to be able to interpret a symbol accurately, and the vertex emphasis method offers an advantage in this aspect; however, depending on the intensity of the stimulus, the stimulus itself may obscure the location information of the adjacent feature.

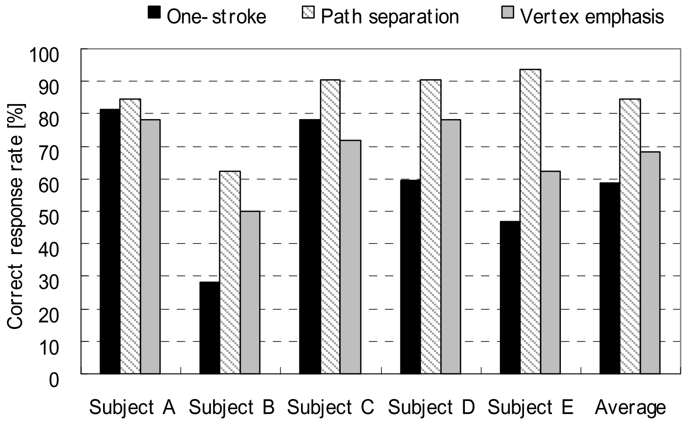

Fig. 7. Correct response rate of each subject

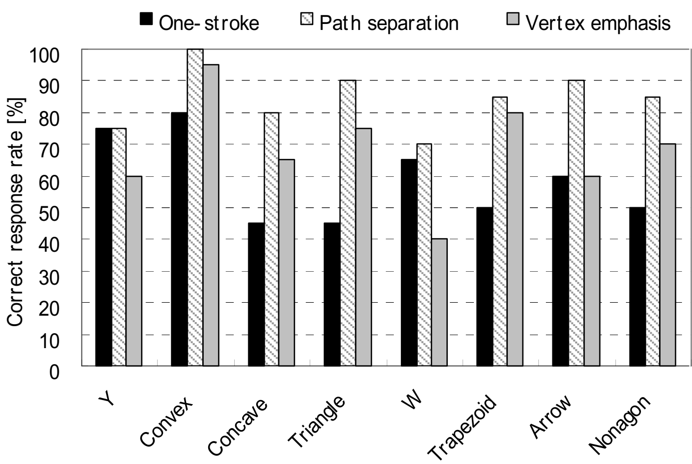

Fig. 8. Correct response rates categorized by shape

Wake et al. [15] evaluated correct response rates by using a 17 × 17 pins TVSS (television substitution system). In their experiment, the subjects were visually impaired and the number of shapes to be identified was increased on the basis of the subjects' performance. First, five shapes were randomly presented by using the TVSS, and after the subjects analyzed the first experimental block, the number of shapes was increased to eight by adding three new shapes. The subjects then analyzed this second experimental block consisting of eight different shapes. By the end of the seventh experimental block, the number of shapes was increased to 17. The average correct response rate was 80.0% in the case of the first experimental block, and it ranged from 78.6% to 87.5% in the case of subsequent blocks. Our study, on the other hand, was different from their study in terms of the type of actuators used (pins were used in their study), type of symbols presented, number of subjects, location of stimulus presentation (entire back region was used in their study), etc.; therefore, the results of the two studies cannot be compared quantitatively. However, the trends of the two studies in terms of the subjects' performances were rather similar, especially in the case of the path separation method when the average correct response rate in our study was 84.38%. With regard to the spatial resolution of the tactile display, a 5 × 5 actuator matrix was used in our study, which was considerably smaller than that used by Wake et al. [15] (17 × 17), implying that PSs can compensate for a large number of actuators. This presents the possibility of transmitting tactile information by the proposed PS-based technique.

6 Conclusion

In this study, we developed the noncontact tactile display that uses air-jet stimuli to present information of two-dimensional shapes by the PS-based technique. Although the number of subjects was limited, the correct response rate was 58.75% in the case of the one-stroke drawing method; 68.13%, vertex emphasis method; and 84.38%, path separation method. The subjective response data obtained during the experiment has provided the basis for further studies. For example, the intensity of a stimulus may affect the clear recognition of a vertex as well as cause unclear perception of location information around the stimulus. In general, the possibility of transmitting information by using the developed tactile display was confirmed and the fundamental information transmission characteristics of the tactile display were studied. Future researches will focus on finding the optimum distance for PS generation and improving the stimulus presentation methods.

Acknowledgment

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