Tactile Vision Substitution with Tablet and Electro-Tactile Display

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Abstract. We developed a device that converts visual information on a tablet into tactile information on the fingertip. To achieve this we mount optical sensors and a tactile display on the fingertip. Our first prototype using a vibrator for each finger revealed that it was difficult to recognize the information of the display, mainly because of its low resolution. We addressed this limitation in our second prototype by using electro-tactile stimulation. From our preliminary experiment with a mechanical pin matrix, we decided to use a single index finger. In a subsequent alphabet recognition experiment, we confirmed that it is possible to recognize relatively complex shapes on a tablet with the device. Furthermore, we observed that the learning curve is quite steep, which implies the potential of the device.

Keywords: electro-tactile, tactile vision substitution, visually impaired.

1 Introduction

Understanding information on a computer screen is a challenge for visually impaired people. When the character-based user interface (CUI) was dominant, it was relatively easy to convert the information to voice or braille display. Then, the era of the graphical based user interface (GUI) arrived, where the presented information cannot be easily translated to a temporal sequence. Today, tactile graphics displays that incorporate numerous mechanical pins are widely used to present graphical information.

Now we live in the era of personal portable computing devices. Of these, the tablet has perhaps the ideal user interface for non-blind users because it is “what you see is what you touch”. However, for visually impaired users, information has once again become difficult to access. Tactile graphics displays can be connected but the portability is sacrificed.

This paper addresses this issue, by developing a portable tactile vision substitution system for a tablet. The device is composed of an array of optical sensors and an electro-tactile display for one finger. The optical sensors capture the brightness of the display, and the electro-tactile display presents it directly to the finger. This device is a direct descendant of previous SmartTouch system [1], but it has four times more electrodes,

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which greatly improves its resolution. This enables numerous functionalities. For example, by using the tablet's camera, visually impaired users can take a picture of the surrounding environment and determine its contents by their finger, enabling them to go sightseeing.

The contribution of the paper is twofold. First, we demonstrate that shape recognition using a single optical sensor and vibrator on one finger is quite difficult, but multiple fingers are not required. Second, we use the developed system to perform a relatively complex shape recognition task using alphabets.

2 Related Work

A tactile vision substitution system (TVSS) was first proposed by Collins et al [2]. They used a video camera and vibrators or electrodes on the abdomen or back to let users feel the surrounding environment. This type of TVSS for the 3D environment has numerous descendants, such as the Forehead Retina System [3], which used electrical stimulation on forehead, and the HamsaTouch [4], which used a smartphone camera to capture images and selected the palm as a display site.

TVSS for the 2D desktop environment also has a long history. Optacon [5] was the most successful product, which let users touch written information on paper using a handheld camera and a mechanical pin matrix. Although a mechanical display still requires a large setup, SmartTouch uses electrodes and an optical sensor matrix to shrink its size.

TVSS are now being used with tablets to allow users to feel the information on the surface of the display. Giudice et al. [6] detect finger position on the tablet and vibrate the whole surface. Burch et al. [7] used a combination of an optical color sensor and a vibrator mounted on each finger to enable users to feel the surface of the tablet. However, although the latter work achieved the perception of textures and simple shapes, recognition of complex information remains a challenge.

In the following we describe two prototypes. The first is composed of an optical sensor and a vibrator unit for each finger, similar to previous approaches [7] [8]. The second is composed of a matrix of optical sensors and an electrode unit, similar to the SmartTouch device [1]. While the SmartTouch was composed of a relatively limited number of sensing and display units, and it did not validate the accuracy of the presented information, the system was much improved and evaluation using alphabet recognition task was conducted.

3 Prototype using vibrator unit and sensor unit on each finger

As a first prototype, we developed a device that uses a vibrator and an optical sensor on each finger. We used a linear resonant actuator (LRA) (LD14-002, Nidec Copal Corporation) that can vibrate at 150 Hz with 20 ms latency, and a phototransistor (PT19-21C, Everlight Electronics Co., Ltd.), which has a peak wavelength of 940 nm. The unit was mounted on each finger so that it reacted to the brightness change of the tablet. A microcontroller (mbed NXP LPC1768, ARM Holdings) was used to control the whole system (Figure 1). This system is similar to the structures developed by Burch et al. [7] and Ando et al. [8]. While the primary purpose of the optical sensor–vibrator pair was to present texture information, we also examined whether it is possible to convey more detailed shape information.

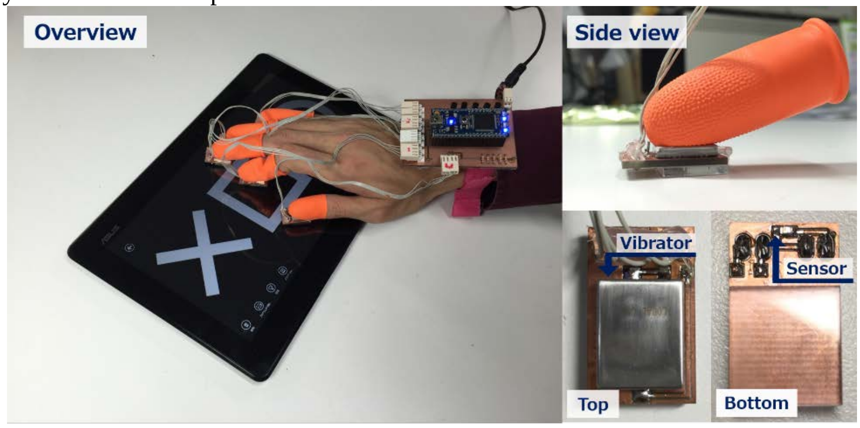

Fig. 1. Overview of the prototype using a vibrator and a sensor unit for each finger.

We conducted a preliminary experiment to verify whether it is possible use the device to recognize the shape displayed on the tablet. We attached the units to all five fingers but we did not explicitly ask participants to use them all. However, we found that it was quite difficult to recognize the shape of the figure with the device, although the LRA responded quickly and the texture was presented to the finger.

We believe that there were two possible causes for this uncertainty. First, there was a size mismatch between the sensor and the actuator. The size of the vibrator was 14.0 mm × 11.2 mm, about 100 times larger than the size of optical sensor (1.6 mm × 0.8 mm). Therefore, users might not have been able to identify the relationship between the sensor position and the display position. Second, there was a lack of local information on the fingertip. In the situation when a bare finger strokes on a relief shape, the relief generates a line or dot pattern on the finger, giving users local directional information. However, the whole finger vibration cannot provide this information, and so the user must scan the whole surface to identify presented shapes.

To resolve these issues, it is necessary to reduce the sensor stimulation area and use multiple stimulators–sensor pairs on a finger to let users feel local shape on the fingertip. This can be achieved with an electro-tactile display that can stimulate with a higher density while keeping the device thin.

We observed that frequency of use of each finger is different among fingers. After getting used to the device, the participants mainly used the index finger and middle finger and the thumb and little finger were barely used. Therefore, the number of fingers to be used will be examined before constructing the next system.

4 Prototype using electro-tactile display

4.1 Experiment 1: identification of necessary number of fingers

To develop a TVSS for a tablet using an electro-tactile display, we conducted an experiment using a mechanical tactile graphics display to identify the number of fingers necessary for effective user sensing.

4.1.1 Procedure

Six participants, all male, aged from 21 to 25 years, participated in this experiment; the authors were not included. We used a DotView DV-2 (KGS Corporation) that can display the graphic as mechanical relief in a pin matrix with a pin resolution of 32×48 and a pitch of 2.4 mm. The participants were blindfolded and were asked to sit in front of the display. Each character of the alphabet was presented once randomly on the display, making 26 characters displayed in total. The participants were asked to identify the displayed alphabet relying on the sense of touch of their bare fingers, as fast and accurate as possible.

There were three finger conditions: index finger only (I), index finger + middle finger (I/M), and index finger + middle finger + ring finger (I/M/R). There were two font size conditions: large (about 52 mm in height) and small (about 20 mm in height) (Figure 2). There were 26 × 3 × 2 = 156 trials for each participant. We fixed the condition pairs and repeated 26 trials for each condition. The order of conditions was randomized to avoid anticipation bias.

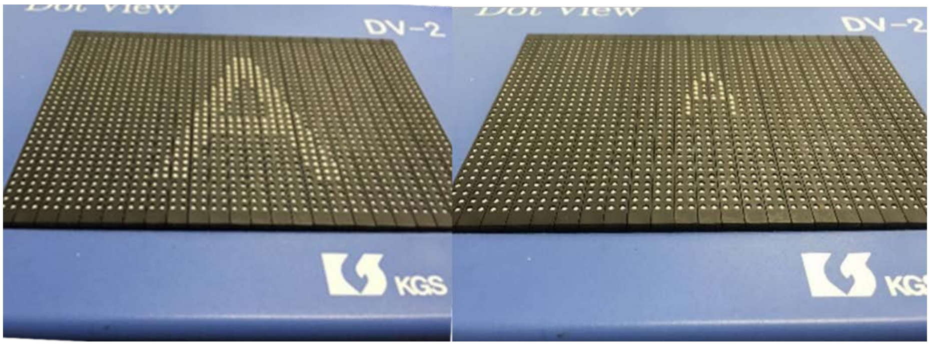

Fig. 2. Displayed character on the tactile display; (left) large condition, (right) small condition.

4.1.2 Results

Figures 3 (left) and 3 (right) show the median answer time and the average correct answer rate for each finger condition, respectively. We performed a two-way within-participants repeated-measure analysis of variance (ANOVA). The within-participants factors were the number of fingers used and the size of the character.

Regarding answer time, the number of fingers was significant (F(2, 930) = 3.00; $p < 0.05$). The relation between the number of fingers and the size of the character identified was also significant (F(2, 930) = 3.00; $p<0.01$), as was the relation between the size of the character and the correct answer rate (F(2, 35) = 3.31; $p < 0.01$).

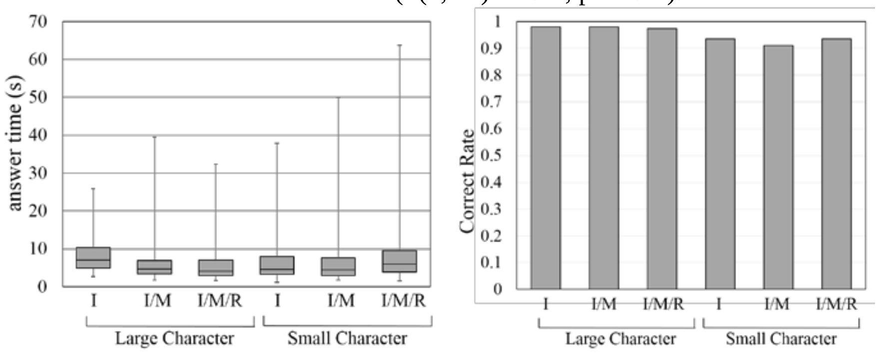

Fig. 3. Answer time (left) and correct answer rate (right) for each finger condition; I: index finger, M: middle finger, R: ring finger.

The number of fingers used made no difference to the percentage of correct answers. The participants identified the character with a high degree of accuracy in all finger conditions. Wrong answers were often observed for particular character pairs, such as O/C and Q/G. Using multiple fingers tended to give shorter answer times for the large character condition, but this tendency was reversed in the small character condition. These results suggest that for shape recognition tasks, the number of fingers only has a small effect on the correct answer rate, and the optimal number of fingers for recognition time depends on the character size. Craig et al. [9] suggested that a searching task with two fingers gives lower performance than with one finger. Lappin et al. [10] pointed out the poor performance with multiple fingers. Our results are generally consistent with these studies.

4.2 High-density TVSS for finger

Based on the preliminary experiment, we developed a high-density TVSS for a tablet using an electro-tactile display and a matrix of optical sensors for one finger (Fig. 4). Although the electro-tactile display still has some disadvantages, such as stability and quality of sensation, it is also thin, high density, clear, permits localized sensation and is low cost [1][4][11][12].

Fig. 4. Electro-tactile stimulation device for a single finger.

The electro-tactile display is composed of 63 (7 × 9) electrodes with 2-mm center intervals. The sensor is composed of the same number of optical sensors (PT19-21C, Everlight Electronics Co., Ltd.), arranged just beneath the electrodes (Figure 5). As the two-point discrimination threshold of the finger is known to be 1.5mm at the fingertip and 3 mm at the finger pad [13], the electrode intervals of 2 mm are sufficient for the finger pad. We used a 10.1-inch tablet (T100TA-DK32G, ASUS) for all experiments. The optical sensors detect the brightness distribution of the tablet and the electro-tactile stimulation is actuated when the brightness reaches a certain threshold. The control loop was 68 Hz, pulse frequency was 35 μs, maximal pulse height was 10 mA, which could be freely adjusted by participants using a slide volume; most participants chose a pulse height of less than 5 mA. For these settings line direction could be clearly determined. For the next experiment, we set the thickness of the line displayed on the tablet to around 2 mm so that it could be recognized by the optical sensor.

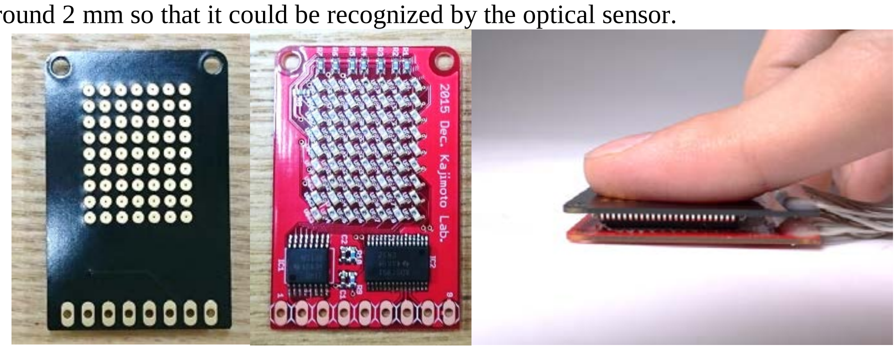

Fig. 5. High-density TVSS. (Left) electrodes, (center) sensors, (right) combined, side view.

4.3 Experiment 2: Alphabet identification task using high-density TVSS

4.3.1 Procedure

Six participants, all male, aged from 21 to 25 years, participated in this experiment (Fig. 6); the authors were not included. Each character was displayed on the tablet randomly, making 26 trials in total to complete the alphabet. The participants were blindfolded and asked to respond to the displayed character as fast and accurately as possible. There were two character size conditions, large (52mm) and small (20mm), as per Experiment 1. The index finger was used in all recognition tasks in the experiment. There were 52 (26 × 2) trials for each participant. Three participants conducted the large character condition first, followed by the small character condition, and the others conducted the experiment in reverse order, to avoid order bias.

Fig. 6. Overview of the experiment.

4.3.2 Results

Figure 7 shows the median answer time and the average correct answer rate. Figure 8 shows the median answer time for each trial number from 1 to 52, where the character size was mixed. We performed a t-test on the data. There was a significant difference in answering correctly for the two character sizes ($p < 0.05$).

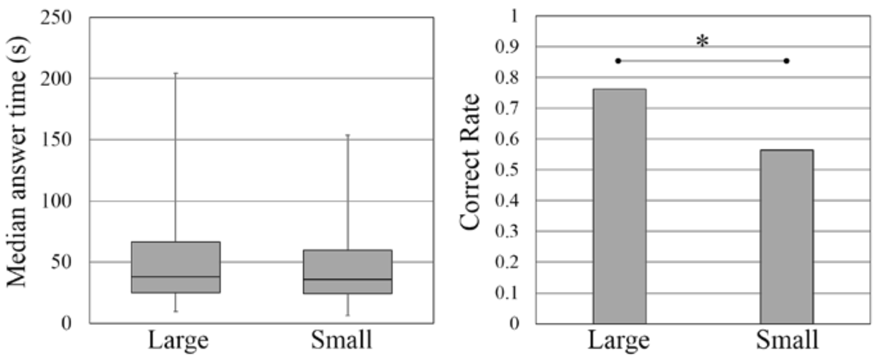

Fig. 7. Results of the alphabet identification task for the two character sizes.

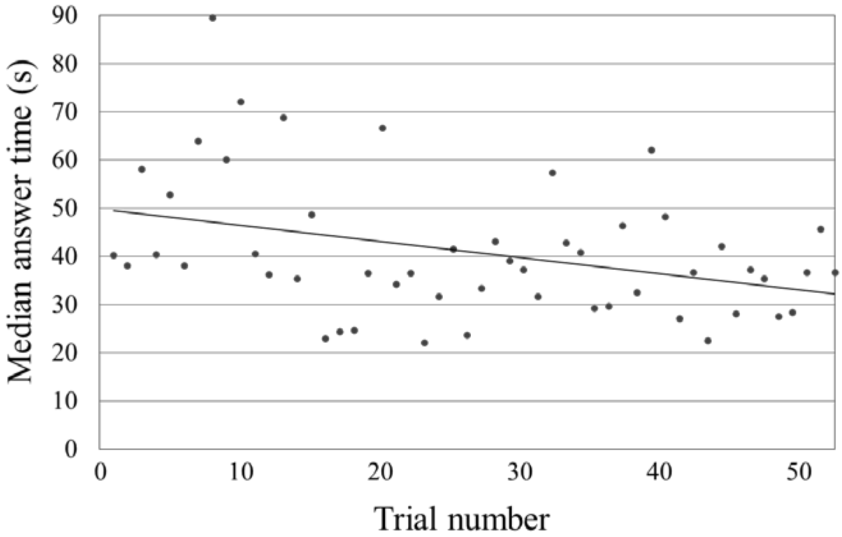

Fig. 8. Answer time for each trial number.

The correct answer rates were 76.2% for the large characters and 56.4% for the small characters, which are significantly higher than the chance rate (1/27=3.8%) but lower than the answer rates in the previous experiment using mechanical tactile display. The answer time was also longer than in the previous experiment. However, we observed a learning curve in this experiment; answer time was 50 s at the beginning but dropped to 30 s by the end of the experiment (Figure 8.). Some participants commented that they came to recognize the character clearly in the second half of the trials. We also conducted a preliminary experiment with a participant who carried out the experiment using the electro-tactile display on a daily basis. His answer rate was 94% and his median answer time was 12.4 s, which was comparable with the results from the mechanical display. From these observations, we submit that further training with the device will improve recognition accuracy. In our current algorithm, we simply stimulated based on display brightness. However, a more sophisticated algorithm, such as with edge enhancement, could be used to simulate mechanical interaction between skin and the relief.

5 Conclusion

We developed and evaluated a tactile vision substitution system for people with visual impairments. Employing an electro-tactile display, the device can convert optical information with high density to a small area of the fingertip. The design was based on preliminary experiments with a mechanical pin matrix, which demonstrated that a single finger device is sufficient for shape recognition. The experiment with the new device showed a much higher character recognition rate than the chance level. Nonetheless, our results also suggested areas for improvement. Specifically, a training regimen is needed for the user to learn to use the device, and a more sophisticated algorithm is required for the conversion from optical sensory input to mechanical actuator output. These will be addressed in future work.

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