HamsaTouch: Tactile Vision Substitution with Smartphone and Electro-Tactile Display

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Abstract
This paper documents the development and evaluation of a novel tactile vision substitution system (TVSS) for the people with visual impairments. The system is composed of an electro-tactile display with 512 electrodes, the same number of optical sensors beneath each electrode, and a smartphone with a camera and an LCD. The smartphone acquires the surrounding view, conducts image processing and displays the image on the LCD. The image is captured by the optical sensors and converted to a tactile image by the electro-tactile display. While the concept of the TVSS is classic, combining the commonly available mobile device and electro-tactile display enables a low cost yet powerful and compact system. Furthermore, optical communication architecture enables an open development environment.

Author Keywords
electro-tactile display, optical communication, reading aid, smartphone, tactile vision substitution system, visually impaired

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces - Haptic I/O.

Introduction

Since the development of the first tactile vision substitution system (TVSS) in the 1960s, there have been numerous attempts to present surrounding visual information to a tactile channel for the people with visual impairments. The system consists of a camera and tactile display. However, the developed systems have not prevailed in the blind community to date, for several reasons, summarized by the following two points.

The first is cost. While the number of people with visual impairments is large and increasing [1], it is not large enough to expect economies of scale, which typically leads to expensive systems with non-state-of-the-art device elements.

The second issue is the way of presentation. Our surrounding environment is complex and three dimensional (3D). If we simply do image processing such as edge enhancement, we obtain many features that are not comprehensible for a tactile channel that has much less capacity than a visual channel. We need to reduce information; filtering out further objects and concentrating on closer obstacles seems a promising approach, which requires depth sensing. Therefore, this issue is strongly related to sensing capability, which is partly the cost issue.

This paper documents the development and evaluation of a novel TVSS named HamsaTouch (Figure 1), which tries to resolve these issues with the following three frameworks. The first is to use a commonly available smartphone as a camera and image processing device, the second is to use simple optical data transmission using an LCD and phototransistors, and the third is to use an electro-tactile display.

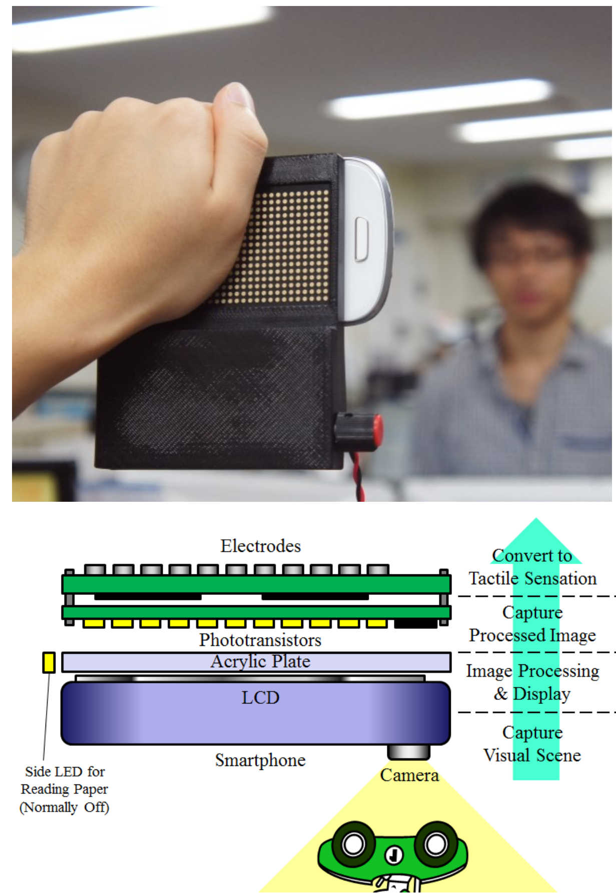

Figure 1 (Top) Overview of HamsaTouch. Image captured by the smartphone is converted to tactile pattern. (Bottom) Cross-section of HamsaTouch and its information processing procedure.

The cost of hardware is reduced by using a smartphone, and we can always use a state-of-the-art image sensor and processing unit by replacing the smartphone, which could be done by the end users. The software cost is reduced by using optical data transmission, because we only need to process the image and display it on the LCD. The adoption of an electro-tactile display contributes to the reduction in hardware cost and size, because it only requires electrodes and a switching circuit.

At present, we do not have a solution to the depth sensing issue. However, by employing a smartphone, we can expect future adoption of a depth camera. Furthermore, we can use simple image processing to address this issue, which will be discussed in the future work section.

RELATED WORK

The first tactile vision substitution system was developed by Bach-y-Rita et al., and was composed of a camera and vibrators on the stomach or back [2]. Simple image processing, such as edge enhancement was employed.

Recently, a few research groups developed a haptic aid for the people with visual impairments using a smartphone as a sensing device [3], [4]. Akhter et al. developed a vision substitution system, using a smartphone as a parallax-based 3D sensing device [3]. Vera et al. developed a virtual white cane using a smartphone as a depth sensor combined with a laser pointer [4]. These studies share the common concept of using a smartphone as a cheap image processing unit. Our work inherits the concept, and attempts to refine it with an electro-tactile display and an optical transmission technique.

As the size of the tactile display limited its daily use, numerous attempts were made to use electrical stimulation instead of vibration [5], [6], [7]. Electrical stimulation enables small, flexible and low cost tactile pattern presentation so that the stimulation site was not limited to the stomach or back but could be used on the forehead [5] or tongue [7].

While the sensation elicited by electro-tactile stimulation was considered unstable compared to mechanical vibration, waveform optimization [8], and impedance based control [9], [10] enabled durable and not unpleasant electrical stimulation. The electrical tactile display was also applied as a touch-panel to achieve tactile feedback [11]. Our work is based on these technologies.

Optical data transmission itself is quite a common technology, but using a visual display as a parallel optical signal was, as far as we know, first developed by Sugimoto et al., and named Display-Based Computing [12]. They first used a projector or an LCD to control numerous robots with high positional accuracy. Nojima et al. used a similar method to control numerous “hairs” on a tablet, actuated by shape memory alloys [13].

As far as the speed of communication is concerned, equivalent data transmission is possible using wireless transmission. We adopted this technology for HamsaTouch for three reasons. One is its simple architecture, which clearly divides the image processing part and display part, leading to low software costs.

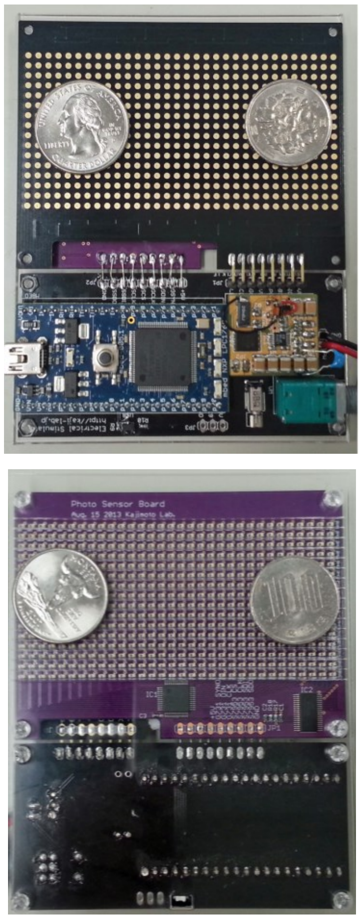

Figure 2 Top and bottom view. The top contains 512 electrodes, and the bottom contains the same number of phototransistors.

Another is its low legal barrier. Inspection is required for a wireless device, which is not a significant cost for the huge smartphone market but is actually quite a burden for a smaller market. The third is that we can use the device without a smartphone as a paper-reading device, similar to Optacon [14].

One of our authors has developed a finger-mounted tactile vision conversion system named SmartTouch [15], composed of 4 by 4 electrodes and the same number of phototransistors beneath each electrode, which is a technical predecessor to this work.

SYSTEM

Hardware

Figure 3 illustrates the hardware structure. The system uses a microcontroller (mbed NXP LPC1768, NXP Semiconductors NV), which drives a high-speed D/A and A/D converter for electrical stimulation, and multichannel analog multiplexer and A/D converter for photo sensing.

The stimulating pulse is generated by the D/A converter and converted to a current pulse by a voltage/current converter, driven by a high-voltage source (300 V). The current pulse passes through a resistor to measure the voltage and current. This means that the system can measure the electrical impedance of each electrode, which can be used for stabilizing sensation and for touch-sensing.

Eight 64-channel half-bridge switches (HV507, SuperTex Inc.) drive 512 electrodes (32 by 16), which are located on the top of the device. At any one moment, a single electrode is set as an anode and all the other electrodes work as cathodes. A two-dimensional pattern is produced by high speed scanning.

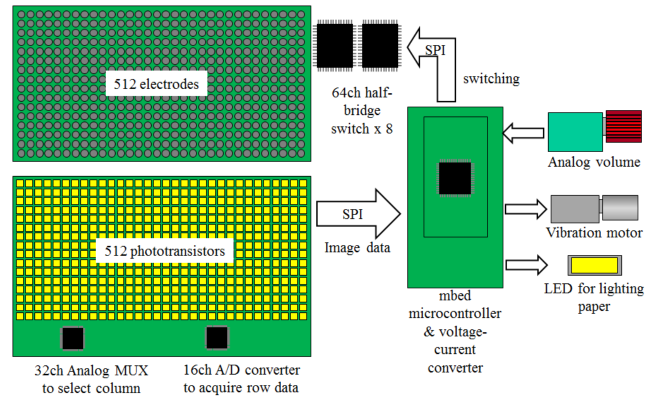

Figure 3 Hardware structure.

512 phototransistors are aligned just beneath the electrodes. A 32-channel analog multiplexer drives each row, and a 16-channel A/D converter acquires row data, sending it to the microcontroller.

Figure 2 shows the top and bottom view of the device. The tactile spatial resolution defined as the so-called two-point discrimination threshold is around 1.5 mm at the tip of the finger, 3 mm at the other parts of the finger, and 8 mm on the palm [16]. We set the electrode density to 2.54 mm to cover most parts of the hand. This covers a 81.28 mm by 40.64 mm area, which is close to the size of a 4-inch LCD adopted by numerous smartphones (ex. iPhone4, Apple Inc.: LCD size 74.8mm by 49.9 mm). Total sensing and stimulation loop was around 50 to 100 Hz depending on the number of stimulation points.

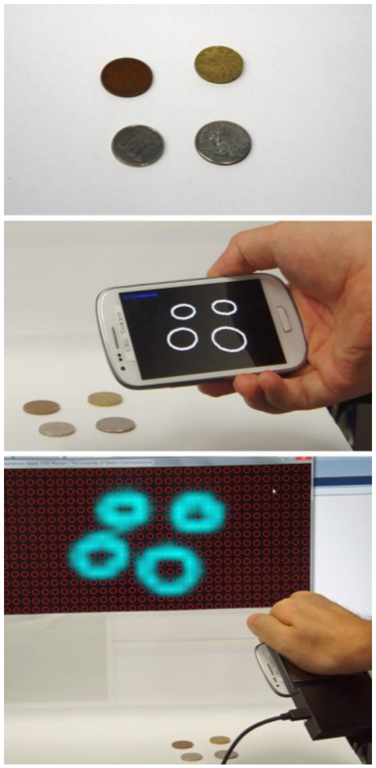

Figure 4 Environment, processed images by the smartphone, and 32 by 16 electrical stimulation patterns.

Image Processing
We used an Android-based smartphone (Galaxy SIII mini, 1 GHz Dual-core ARM Cortex-A9, Samsung Electronics) as an imaging unit. An OpenCV4Android [17] was used for image processing. As a first attempt, simple edge detection using Canny filter and dilation operation for thickening the edges was applied. Refresh rate was 25 to 30 fps. Figure 5 shows the environment, processed image, and the 32 by 16 pattern obtained by phototransistors (Figure 4).

Evaluation
We conducted an experiment to see if the whole system works properly as a tactile vision substitution system. Experiment setup is shown in Figure 5. Participants were asked to sit in front of a 27-inch LCD monitor, blindfolded, hold the device with their dominant hands, and contact the electro-tactile display with their palms. They orally answered displayed visual patterns by using the device. The patterns were vertical bar, horizontal bar, cross-shape, and circle, all were fit to 100 mm square size. Distance between the participants' body and the LCD was around 700 mm, but they were allowed to move their arms freely.

We recruited five laboratory members as participants excluding authors, all right-handed male aged 22-25. They had basic knowledge of electro-tactile sensation but naïve to this device. 16 trials (4 conditions × 4 times) were conducted in random order for each participant.

Correct answer rates were 90% for vertical bar, 90% for horizontal bar, 35% for cross-shape, and 65% for circle, 70% in average. Cross-shape was misinterpreted most because it contains bars and corners, and we did not particularly ask participants to observe the whole structure. Most participants could quickly and confidently answer the vertical and horizontal bars, while in few exceptional cases they moved the device too large and observed the edges of the LCD.

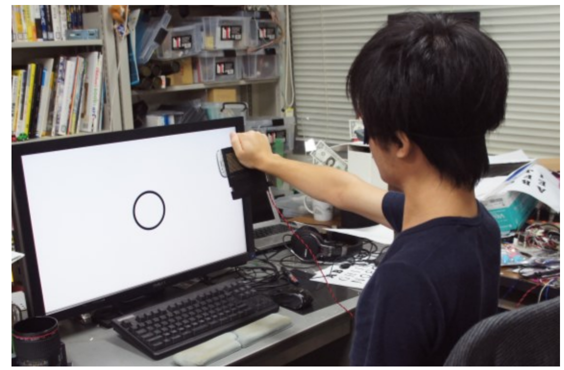

Figure 5 Experiment setup.

	Presented patterns			
Answer	|	—	+	○
|	90%	0%	5%	15%
—	0%	90%	45%	0%
+	0%	10%	35%	20%
○	10%	0%	15%	65%

Figure 6 Answer rates for the four presented patterns.

Conclusions
We developed and evaluated a novel tactile vision substitution system for the people with visual impairments, consisting of an electro-tactile display, optical sensors, and a smartphone. The hardware cost is reduced by using the smartphone, and we can adopt a state-of-the-art imager by replacing this part, including a future 3D sensing unit. The software cost is also reduced by using optical data transmission,

because of its simple architecture. In other words, we attempt to interface between the people with visual impairments and ongoing technological advances.

Future work

Our future work will include more sophisticated image processing, such as depth reconstruction. In our previous attempts to mount a tactile display and a camera on the forehead [5], we observed that users frequently "shifted" their heads left and right to obtain distance, using motion parallax (i.e. a closer object moves faster). This observation reconfirms the importance of distance information, and at the same time, implies motion analysis such as optical flow calculation might be a good substitute for 3D depth sensing.

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