Enlarged Electro-tactile Display with Repeated Structure

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ABSTRACT

An electro-tactile display is a possible candidate for a tangible touch panel, because it only requires an electrode substrate that can be made transparent. However, although it needs relatively few components, it does still require several transistors per electrode, and wiring each electrode thus poses practical problems. This study therefore proposes the use of a repeated electrode structure to enlarge the display area of the electro-tactile display, without the need for additional electrical components. Skin impedance measurement, which was previously used for the stabilization of skin sensation, was utilized for sensing finger position, and the tactile pattern was presented only around the finger, enabling a larger presentation area.

KEYWORDS: electro-tactile display, impedance measurement, repeated structure, touch-panel

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptics I/O; H.1.2 [Models and Principles]: User/Machine Systems—Human factors

1 INTRODUCTION

A touch panel able to present tactile sensations is a promising application for tactile displays. In order to present visual as well as tactile information, the tactile display should be transparent and thin, to allow visual information to pass through the device. However, few types of tactile displays currently possess the potential to be both transparent and thin.

One type of thin tactile display vibrates the whole surface. Fukumoto and Sugimura [1] and Poupyrev and Maruyama [2] achieved a clicking sensation by simply vibrating the display surface where it was in contact with the finger. Tangible touch panels utilizing this principle are already available in the market [3]. Nara et al. [4], Takasaki et al. [5] and Winfield et al. [6] proposed using the "squeeze effect", in which the friction coefficient of the plate surface is minimized by vibration in the ultrasonic range. Rapidly turning the vibration on and off allow arbitrary friction to be presented. This type of display can be manufactured relatively easily using a small number of actuators, but the spatial resolution is limited, in principle, by the size of the finger.

Another type of display uses an electro-static effect [7][8]. The electrodes are located under an insulator layer, with which the finger makes contact. When a high voltage is applied to the electrodes, the skin connects to the electrodes by electro-static force. This is a relatively simple method that can achieve high spatial resolution, but the sensation only presents when the finger moves, because users do not detect the electro-static force itself, only the deformation produced by contact between the skin and the electrode, and the relative movement of the finger.

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The other type of display is an electro-tactile display [9][10][11][12][13]. In contrast to an electro-static display, this type of display directly activates sensory nerves via an electrical current. The potential resolution of the display is much higher than that of the vibrating-plate type. In addition, tactile sensation can be presented without the user's motion, in contrast to the electro-static type. An additional touch sensor is not necessary, because finger position can be detected by monitoring the stimulating current. However, the stability of the sensation presents a practical problem when using an electro-tactile display. The author has proposed stabilizing the sensation by measuring skin impedance in real time, using a stimulating pulse [11].

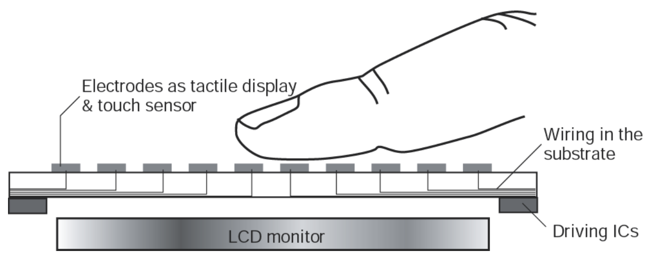

Figure 1. Electro-tactile display as a tangible touch-panel. Electrodes work as both a display and a touch sensor. The substrate is made of a transparent material so that a visual display can be incorporated.

However, although high-resolution, thin, transparent tactile displays can be achieved relatively easily by electrical stimulation, these still require several transistors per electrode, and wiring each electrode is thus a practical problem.

This paper proposes a practical solution to this problem by enlarging the display area for electro-tactile display, without enlarging the circuit size. Assuming that only one finger touches the display (single touch), a display using repeated electrode placements can be constructed.

2 PROBLEM: ELECTRODE DENSITY AND NUMBER

Figure 2 shows the system structure of the previously proposed electro-tactile display [11]. A stimulating pulse is generated by a D/A converter and converted to a current pulse by a voltage/current converter, driven by a high-voltage source (350 V). The voltage is necessary to achieve a 5 mA current flow at any skin state. The current pulse passes through a resistor to measure the voltage and current. This information is used to adjust the pulse width, thus stabilizing the sensation.

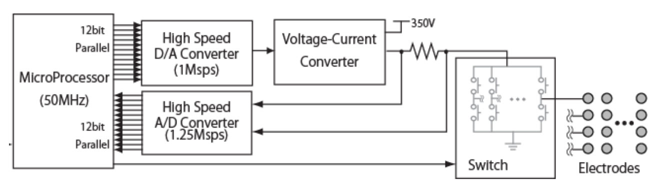

Figure 2. System structure [11].

The transistor switches (HV507, Supertex) controlled by the microprocessor select a stimulating electrode one at a time. As illustrated in Figure 3, a pair of top/bottom switches is connected to an electrode. If the top switch is on, the electrode works as an anode, while if the bottom switch is on, it works as a cathode. The system only requires a single current source, thus significantly reducing the hardware costs. Using this system, only one point is stimulated at a time, and a two-dimensional pattern is produced by scanning.

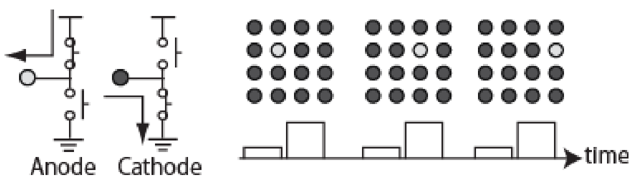

Figure 3. Principle of electrode selection. Each electrode is connected to a pair of switches and can work as either an anode or a cathode. Pattern is produced by scanning [10].

Although this configuration significantly reduces the hardware costs, it still requires several transistors per electrode, which means that N by N electrodes require $O(N^2)$ electrical components. The switch IC must be able to endure a high voltage, and as far as the author knows, there is no alternative commercially available IC. The size of the IC is 18 × 24 mm (including footprint), and it can drive 64 electrodes. In order to enlarge the number of electrodes, it is necessary to use several ICs. Figure 4 shows a previous prototype based on this strategy [10]. To minimize wiring problems, the ICs are placed just at the back of the electrodes.

However, three problems remain. First, because of the size of the IC, the electrode pitch cannot be smaller than 3 mm, which is relatively large for a fingertip tactile display [14][15]. Second, placing the ICs at the back of the electrodes hinders the achievement of a visually transparent tactile display, which is necessary for a touch panel, though it is possible to use a transparent substrate such as indium-tin-oxide. Third, conversely, if the ICs are not placed at the back of the electrodes, the wiring becomes impractically cumbersome. Thus, although a high density can be achieved relatively easily by an electrical tactile display, hardware advancements are still required.

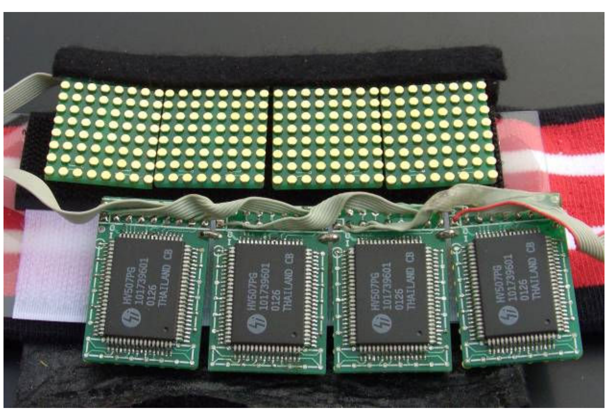

Figure 4. Forehead Retina System [10]. A system with a large number of electrodes can be achieved by high-voltage switching IC.

3 Proposal: Repeated Electrodes Structure

A repeated electrode structure is thus proposed. Figure 5 shows the principle in a one-dimensional case. The structure is composed of groups of electrodes that are connected to each other. In Figure 5, electrodes with the same numbers are connected, comprising three groups. When the finger touches the electrodes, the position of the finger is measured, and stimulation patterns are presented to the electrodes. Electrodes around the finger represent the correct pattern, while the other electrodes present repeated patterns. Because the users only detect the pattern at their fingertips, they do not notice that only the electrodes around their finger work correctly.

There are three necessary conditions associated with this method. First, only single-finger touch is allowed, not multi-finger touch; touching by more than one finger means there would be a possibility of simultaneously touching two or more connected electrodes such that finger position could not be determined. Second, the area size of one group of electrodes should be larger than the finger. Third, the system must measure finger position. Takahashi [16] implemented a similar system using a pen-type tablet as a position sensor. This work has refined this idea by using the electrodes to obtain finger position by measuring impedance.

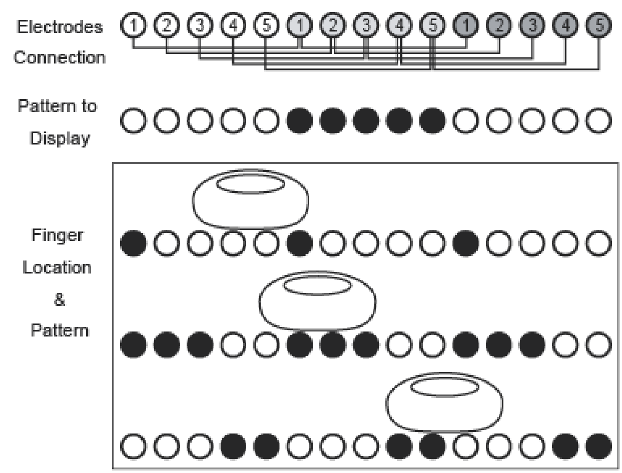

Figure 5. Principle of repeated structure of electrodes.

3.1 Electrode Design

As explained in section 2, our electro-tactile display system is able to measure electrode-skin contact impedance during stimulation. The primary purpose of this measurement was to stabilize sensation, but the current system uses this feature to measure finger position.

Figure 6 shows the electrode placement design. White circles represent ordinary electrodes that have repeated structure. In the figure, every four electrodes with the same number are connected. Black circles represent "independent" electrodes that are not connected to the other electrodes, and can therefore be used as finger position sensors.

The electrodes are divided into four areas, each containing 7 × 7 electrodes. The electrodes pitch is 2 mm, so the single area size is 14 × 14 mm, which was determined based on the fact that in most cases, the finger contact area does not exceed this size.

The distance between independent electrodes (black circles) is no less than 8 mm. The basic principle of finger-position calculation is as follows. First, independent electrodes that have lower than threshold impedance are selected. This indicates that those independent electrodes are in contact with the finger. Second, the center of the mass of the selected independent electrodes is calculated. Figure 7 shows several potential situations, and demonstrates that finger position can be measured to an accuracy of ≤ 4 mm. Although it is possible that the finger will not contact any independent electrodes, finger motion estimation from past data will help to resolve this problem in the future.

Figure 8 shows how to present a large pattern. Finger position is measured, and a 7 × 7 dot correct pattern is presented only around the finger.

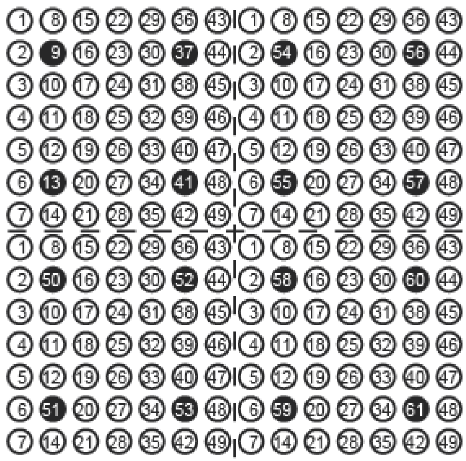

Figure 6. Electrode placement. White circles represent repeated electrodes and the numbers indicate connections. Black circles are independent electrodes that measure finger location. There are 14 × 14 = 196 electrodes in total.

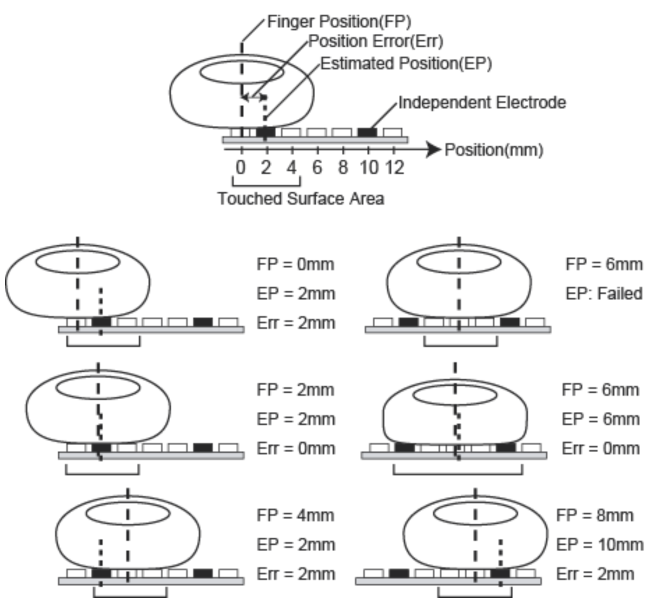

Figure 7. Finger position, estimated position and position error.

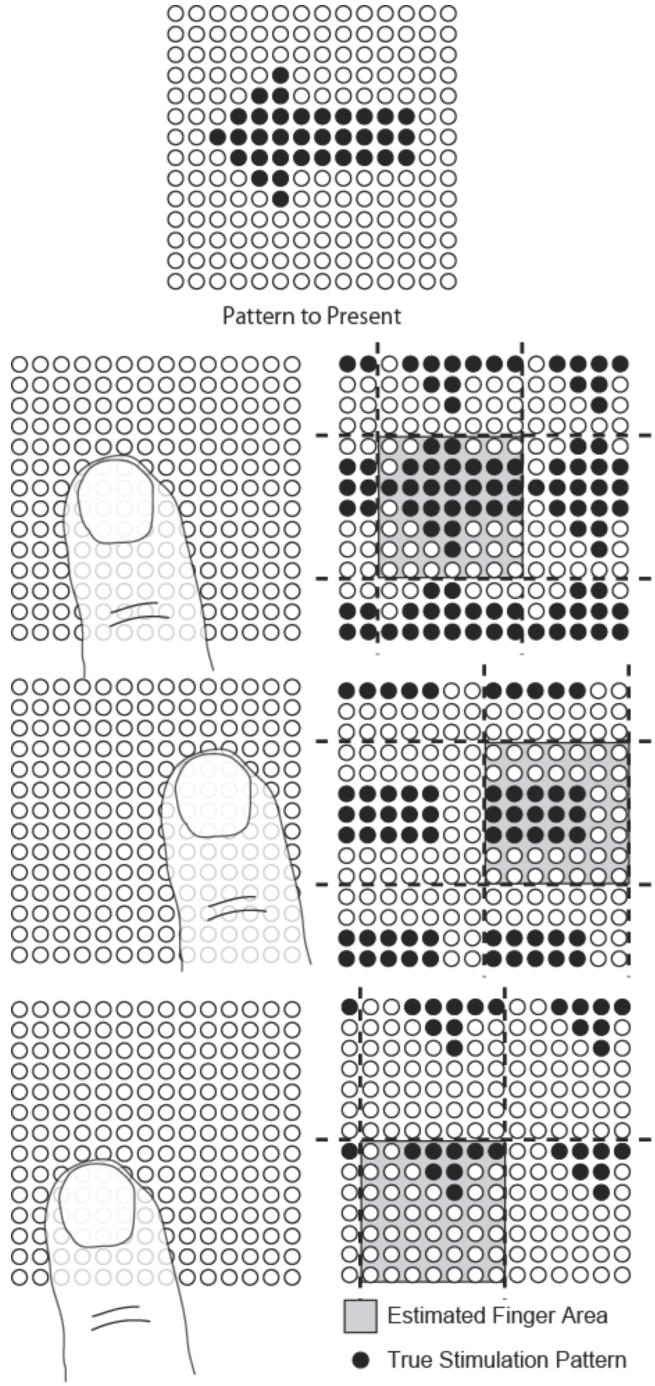

Figure 8. To present a large pattern (top), finger position is measured and repeated pattern is presented. The pattern is correct only around the finger.

3.2 Fabrication of the Electrodes

Figure 9 shows the manufactured electrodes. A printed circuit board manufacturing process was used, with gold-coated electrodes to prevent rust. Wiring among electrodes was achieved using a six-layered substrate.

A previously proposed driving circuit was used [11]. Although there are only 64 pairs of electrical switches, 196 stimulating points were virtually achieved.

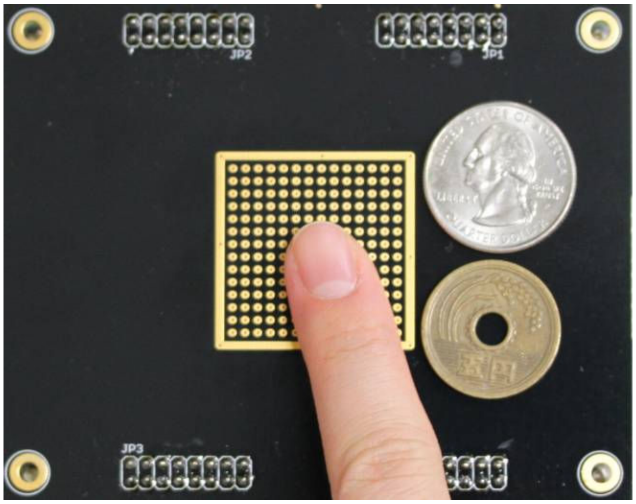

Figure 9. Electro-tactile display with repeated electrodes structure.

4 Finger-Position Estimation

The accuracy of finger position estimation was evaluated. Finger position was measured by both visual analysis of photographs and by impedance information.

4.1 Method of Estimation

Finger position was calculated based on the center of mass of the impedance information as follows:

$$\frac{\sum_{i=1}^{N} Ramp(R_{th} - R_i) \times \mathbf{x_i}}{\sum_{i=1}^{N} Ramp(R_{th} - R_i)} \quad (1)$$

where R_i the resistance of the i_{th} independent electrode, $\mathbf{x_i}$ is the position vector of the electrode, R_{th} is the threshold resistance, and N is the number of independent electrodes. *Ramp(x)* is a ramp function defined as follows:

$$Ramp(x) = \begin{cases} 0 & x < 0 \\ x & otherwise \end{cases} \quad (2)$$

4.2 Experiment and Results

A black dot was marked on the fingernail so that the real finger position could be measured by photographs (Figure 10). Participants were asked to touch 25 different locations on the electrode substrate, as shown in Figure 11. This instruction was not strict, and only aimed to ensure that the participants touched the whole surface of the electrodes evenly. The experiment was conducted with five participants (four male and one female, aged 22-35 years).

The results are shown in Figure 12. The top graph indicates the lateral direction and the bottom graph the longitudinal direction. The horizontal axis represents the real finger position measured by photographs and the vertical axis represents the estimated finger position.

Estimated finger position along x and y axes did not exceed ±11 mm, which was the position of the independent electrodes at the edge. There was an obvious offset, especially in the longitudinal direction, due to the fact that the position of the mark on the fingernail did not accurately represent the center of the contact area. This offset was disregarded in order to determine the accuracy of the position estimation. The maximum position estimation error was obtained by subtracting the estimated position from the real position.

Figure 13 shows the maximum position estimation error for each participant. Although section 3.1 concluded that the maximum error should be ≤ 4 mm (twice the electrode interval), it was actually around 5 mm, possibly because of finger deformation.

There were no failed measurements (i.e. inability to detect finger contact) in this preliminary experiment, suggesting that the distance between the independent electrodes was sufficiently small.

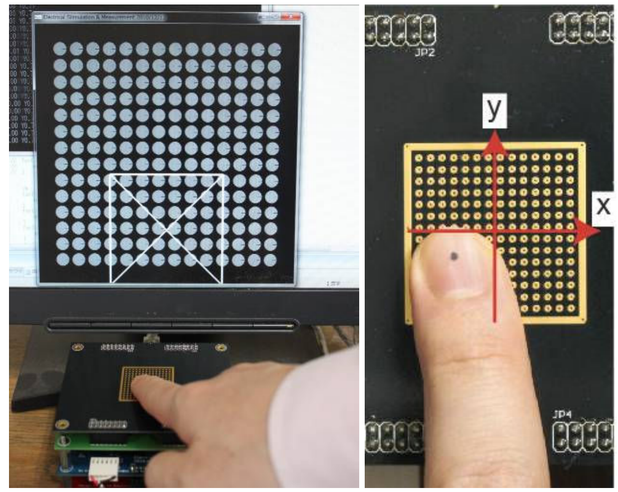

Figure 10. Finger-position evaluation. Real finger position was measured from photographs, while the estimated position was determined by impedance measurements.

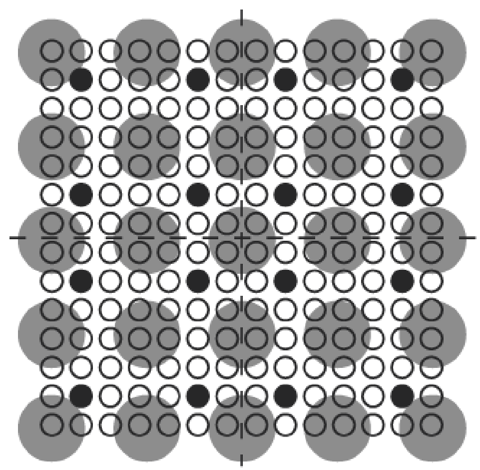

Figure 11. Twenty-five different locations on the electrode substrate.

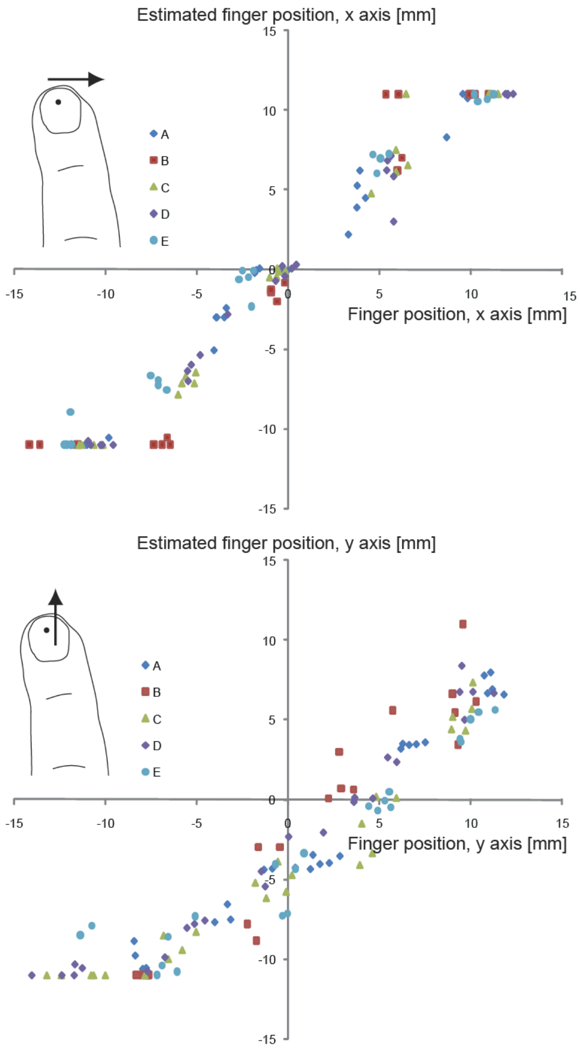

Figure 12. Result of fingertip location estimation.

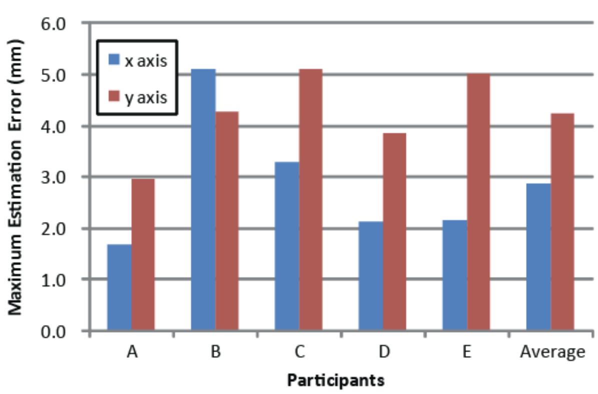

Figure 13. Maximum estimation error of finger position.

5 Conclusion

The electro-tactile display represents a possible candidate for a tangible touch panel, because it only requires an electrode substrate that can be made transparent using current technology. However, although it requires relatively few components compared to other stimulation methods, it still requires several transistors per electrode, thus presenting a practical wiring problem.

In this paper, a repeated electrode structure was proposed to enlarge the display area of the electro-tactile display without adding electrical components. Skin impedance measurement, which was previously proposed for stabilizing skin sensation, was utilized for finger-position sensing and the tactile pattern was presented just around the finger, enabling a large virtual presentation area. It should be emphasized that this proposal utilizes very basic characteristic of electricity; electrodes are multiplied simply by electrical connection. Although this proposal seems very simple, it cannot be easily implemented using other types of tactile display, such as mechanical vibration.

The major limitation of the proposed system is that it can only support one-finger touch, and cannot be applied to tactile interfaces using multi-finger touch. Despite this limitation, the proposed system could still have wide application.

Future studies will include the acquisition of optimal design parameters, such as the area size of one group of electrodes and the interval between independent electrodes, as well as the fabrication of a tangible touch panel using a transparent substrate.

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