8.4" Tactile Touch Display using Segmented-electrode array as both tactile pixels and touch sensors

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ABSTRACT

We developed an electrostatic-tactile touch display using a segmented-electrode array as both tactile pixels and touch sensors. This structure allows presenting real localized tactile textures in any shape. A driving scheme in which the tactile strength is independent of the grounding state of the human body was also demonstrated.

1 INTRODUCTION

An electrostatic tactile device is suitable for smart devices because it can be made transparent using transparent electrodes (e.g., ITO) and a glass substrate. Also, it does not need any moving parts. Several types of tactile touch display systems with electrostatic tactile interfaces have been proposed. One system is composed of a tactile panel, a video projector displaying visual images on the tactile panel, and a camera [1]. The panel is composed of a transparent electrode sheet applied onto a glass plate, in which the electrode sheet is coated with an insulator layer. The camera detects a user's finger. The panel is excited when the location of the user's finger coincides with the location of a visual object like a button. Thus, users can feel tactile feedback at the position of the visual object. However, [1] cannot allow multi-finger tactile interaction because the panel has only one electrode laying over the panel's whole area, resulting in presenting the same tactile sensation over the whole surface at the same time.

We reported a tactile display consisting of multiple X and Y electrodes [2]. The panel consists of a glass substrate, multiple X and Y electrodes made of an indium tin oxide (ITO) on the substrate in a matrix arrangement, and an insulator layer that covers the electrodes. Every electrode is used both as a tactile display and touch sensor. For the electrodes to have two functions, each of them is connected to one of the tactile drivers and to the touchscreen controller via a single pole dual throw (SPDT) switch in accordance with the control signal of the system controller. A real localized tactile sensation is generated by the beat phenomenon in a region where X electrodes excited by a 1000-Hz waveform cross Y electrodes excited by a 1240-Hz waveform. It allows multi-finger tactile interaction.

In this paper, we propose two new configurations for the tactile touch display system. First, we describe an electrostatic tactile touch panel using a segmented-electrode array. Second, we elaborate on a driving scheme for tactile strength stabilization in which the tactile strength is independent of the grounding state of the human body.

2 SYSTEM CONFIGURATION

Figure 1 shows our visuo-tactile touch display. The tactile touch panel consists of a glass substrate, signal lines extended in one direction on the substrate, a first insulator layer that covers the signal lines, electrodes made of ITO on the first insulator layer, and a second insulator layer that covers the electrodes. Each electrode is electrically connected to one signal line through a contact hole. This panel can generate real localized tactile sensations at arbitrary positions by supplying voltage waveforms to intended signal lines. All of the electrodes are used both as a tactile display and touch sensor. For the electrodes to have two functions, every signal line is connected to one of the tactile drivers and to the touchscreen controller via a SPDT switch in accordance with the control signal of the system controller. Every electrode on the panel is driven for both a tactile presentation and touch sensors in a time-division manner. The tactile touch panel is optically bonded on the LCD. Users can enjoy both visual information from the LCD and tactile information from the tactile touch panel at the same time.

Figure 2 shows a plane view and a cross-sectional view of the tactile touch panel. The electrode shields the electric field generated from the signal lines so that the panel does not present unintentional stimuli to a user's finger.

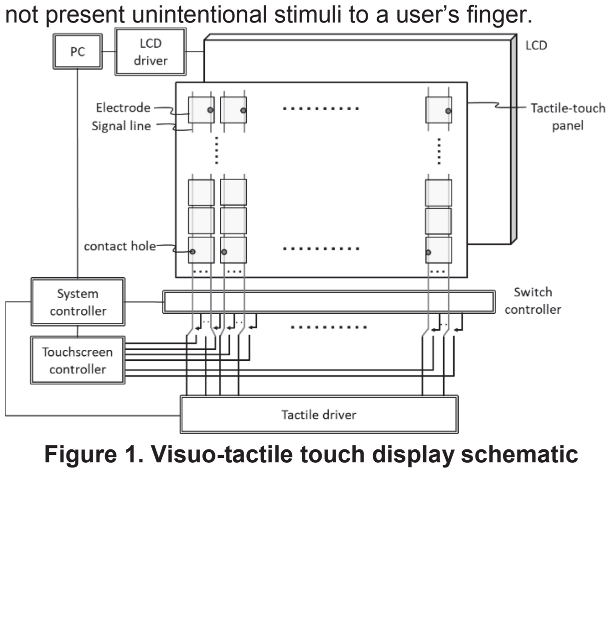
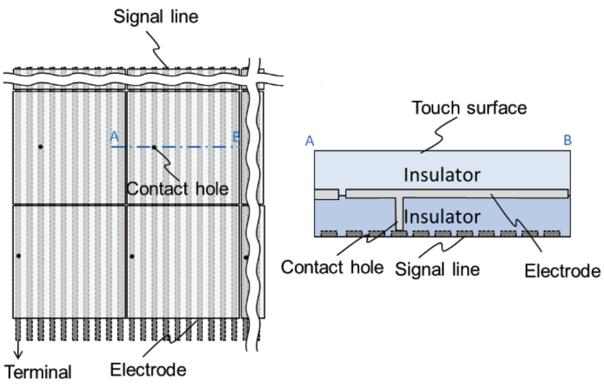


Figure 1. Visuo-tactile touch display schematic



(a). Plane view (b). Cross-sectional view

Figure 2. Plane view and cross-sectional view of tactile touch panel with segmented-electrode

3 DRIVING SCHEME FOR TACTILE STRENGTH STABILIZATION

We have experienced that the tactile strength fluctuates depending on the grounding state of the human body. Actually, [1] uses a ground bracelet to present stable and strong tactile strength to users. Stable tactile strength without a ground bracelet is desired. In this section, we first present the reason for tactile strength fluctuating in [1] in 3.1. Then, we propose a driving scheme for tactile strength stabilization in 3.2. After that, our experimental results demonstrating its effect are shown in 3.3.

3.1 ANALYSIS OF FLUCTUATIONS IN TACTILE STRENGTH

The electrostatic force F_e induced between finger P_f (voltage: V_f) and electrode P_e (voltage: V_e) as shown in Figure 3a is obtained from the formula for the electrostatic force of the parallel capacitor. The F_e is

$$F_e = \frac{\varepsilon S_f}{2d^2} (V_e - V_f)^2, \quad (1)$$

where d is the insulator thickness, ε is the dielectric constant, and S_f is the finger touch area.

The R shown in fig. 3 is the impedance between the fingertip and ground at the frequency of V_e.

If R is very small, V_f is zero. By substituting voltage waveform $V_0 \sin 2\pi ft$ for V_e (f: frequency, t: time), F_e is

$$F_e = \frac{\varepsilon S_f}{4d^2} V_0^2 (1 - \cos 4\pi ft). \quad (2)$$

If R is very large, V_f is the same as V_e. Thus, F_e is zero.

$$F_e = 0 \quad (3)$$

(3) means that if the human body is completely in an electrically floating state, the tactile panel does not present any tactile sensation. (2) and (3) explain the reason for [1] needing a ground bracelet.

3.2 PRINCIPLE OF TACTILE STRENGTH STABILIZATION

Figure 3(b) shows the multiple electrode model. We divided the electrodes into two groups. The electrodes in the first group were designated as P_{e1}, in which the voltage is V_{e1}, and the electrodes in the second group were designated as P_{e2}, in which the voltage is V_{e2}. If the contact area overwrapped two electrodes as shown in Figure 3(b), the finger P_f faced two electrodes driven by the voltage V_{e1} and V_{e2} each. We set the phase difference Φ between V_{e1} and V_{e2} as $V_0 \sin 2\pi ft$ for V_{e1} and $V_0 \sin(2\pi ft + \Phi)$ for V_{e2}. The electrostatic force (F_{total}) between the finger and the two-faced electrodes is a simple sum of two electrostatic forces from each electrode F_{e1} and F_{e2}.

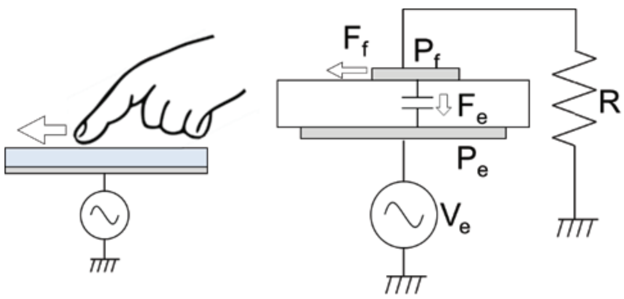
If R is very small, V_f is zero. F_{total} is

$$F_{total} = \frac{\varepsilon S_e}{4d^2} V_0^2 (2 - \cos 4\pi ft - \cos 2\Phi \cos 4\pi ft + \sin 2\Phi \sin 4\pi ft),$$
(4)

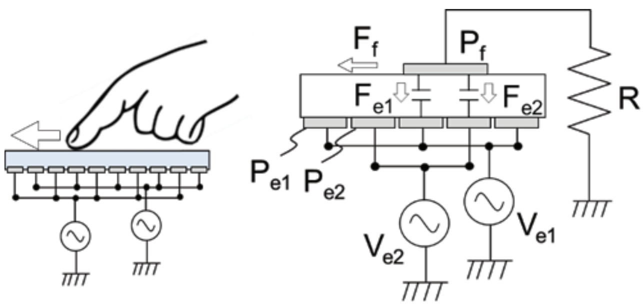
where S_e is the area of one electrode opposing to the finger.

If R is very large, V_f is the average voltage of the two-faced electrodes. F_{total} is

$$F_{total} = \frac{\varepsilon S_e}{4d^2} V_0^2 (\sin 2\pi ft - \cos\Phi \sin 2\pi ft - \sin\Phi \cos 2\pi ft)^2. \quad (5)$$



(a). Single electrode model



(b). Multiple electrode model

Figure 3. Electrostatic force by single/multiple electrodes

These formulas (4) (5) have vibration terms and constant terms. The frequencies are double the driving waveforms' frequency. The coefficients of vibration terms change as Φ changes. Table 1 shows the formula of F_{total} when Φ had some exemplary values: 0°, 90°, and 180°. Two F_{total} formulas were the same at Φ of 180°, but differed at other levels of Φ. We compared the magnitude of coefficients of the vibration terms at each phase. In the case of Φ = 0°, the coefficient of the vibration term was large when R was small. In the case of Φ = 90°, the coefficient of the vibration term was large when R was large. Please note that F_{total}, in the case of Φ = 90° and R was small, was a constant and did not have the vibration term. Thus the coefficient of the vibration term was zero. In the case of Φ = 180°, two coefficients were the same and largest in these comparisons. We found another same coefficient point at degrees between 0°and 90°. On the basis of table 1, we can suggest that the tactile sensation is stable and strong when Φ=180°.

Table 1. Electrostatic force F_{total} at exemplary values of phase difference Φ

(The comparison is based on the magnitude of coefficients of the vibration term.)

Phase differences	Force (R is small)	Comp.	Force (R is large)
Φ = 0°	$\frac{\varepsilon S_e}{2d^2} V_0^2 (1 - \cos 4\pi f t)$	>	0
Φ = 90°	$\frac{\varepsilon S_e}{2d^2} V_0^2$	<	$\frac{\varepsilon S_e}{4d^2} V_0^2 (1 - \sin 4\pi f t)$
Φ = 180°	$\frac{\varepsilon S_e}{2d^2} V_0^2 (1 - \cos 4\pi f t)$	=	$\frac{\varepsilon S_e}{2d^2} V_0^2 (1 - \cos 4\pi f t)$

3.3 EVALUATION

We measured the detection threshold voltage instead of measuring F_{total} because measuring F_{total} directly was difficult. The detection threshold voltage can be an indicator of F_{total} because the frequency of F_{total} is affected by neither Φ nor the grounding state of the human body in our model. Thus, we can assume that the Φ presenting small detection threshold voltage presents large F_{total} under the same driving voltage (V_0). We used the tactile panel shown in figure 2. Each of the electrodes of voltage V_{e1} and V_{e2} were arranged diagonally like a checkered pattern in the plane view (see figure 5). We evaluated them by changing two parameters: Phase differences Φ and the grounding state of the human body (W/ or W/O grounding). Figure 4 shows the measured detection threshold voltage for the phase differences. We chose 120 Hz as the frequency of the sine wave (240 Hz as the frequency of the electrostatic force) so that our tactile sensory system became highly sensitive. The detection threshold with grounding decreased when Φ=0° and 180°, and that without grounding decreased when Φ=180°. These results demonstrate that the F_{total} was large and stable when Φ was 180°. We utilized this driving condition in our prototype.

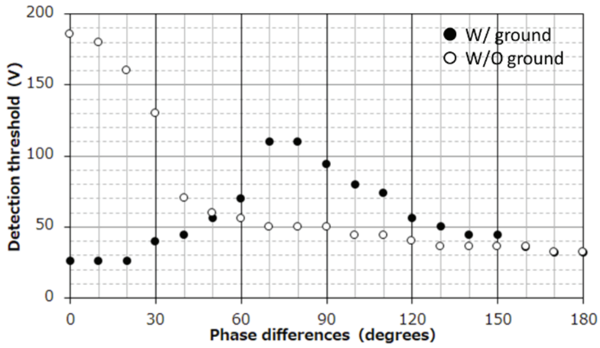


Figure 4. Measured detection threshold voltage vs. phase differences

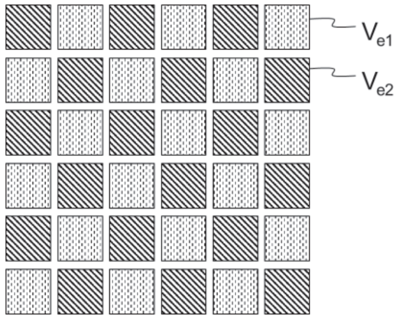


Figure 5. Driving scheme for measuring detection threshold voltage

4 PROTOTYPE DEMONSTRATION

We fabricated a prototype of the visuo-tactile touch display. Table 2 summarizes the specifications. We created two demos using visual and tactile interactions.

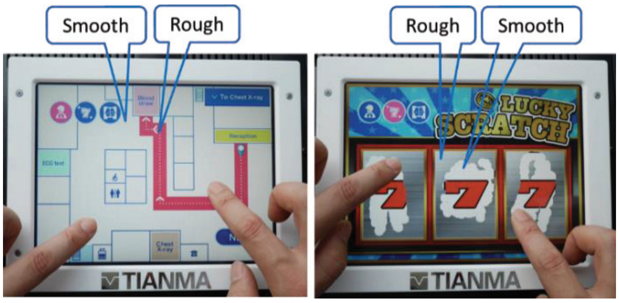
In the first demo, a tactile map in a medical facility shows us the route to the destination visually and tactilely (see figure 6a). The waveforms are supplied only to the electrodes on the route image. We can distinguish complex routes and the other places tactilely.

In the second demo, when a user scratches his/her finger on the touch surface, he/she can feel a rough texture sensation on silver covered parts, then see the hidden image after it is peeled off, and after that feel a smooth texture on the hidden image (see figure 6b). These areas of rough texture sensation can be an arbitrary shape of a figure like a donut shape.

In both of these demos, users can feel stable tactile sensation as intended with the right hand, the left hand, and both hands.

Table 2. Specifications of 8.4” tactile touch display

Visual display	Size (inches)	8.4“
	Active area (mm)	170.4 × 127.8
	Resolution (pixel)	800 × 600
	Luminance (cd/m^2)	800
Tactile touch panel	Number of electrodes	30 × 20
	Electrode unit size (mm)	5.1 × 5.1
	Touch point	10-point touch
	Tactile display type	Friction control
	Tactile signal frequency (Hz)	120



(a). Tactile map (b). Scratch card

Figure 6. Photograph of the prototype

5 CONCLUSIONS

Our visuo-tactile touch display can generate free-shaped tactile sensations at arbitrary positions with a segmented-electrode structure tactile touch panel. We proposed a tactile strength stabilization (TSS) driving scheme in which tactile strength is independent of the grounding state of the human body. This is the world first visuo-tactile touch display that adopt segmented-electrode structure panel. We aim to create interactive displays that bring new user experiences.

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