

Tactile Presentation to the Back of a Smartphone with Simultaneous Screen Operation

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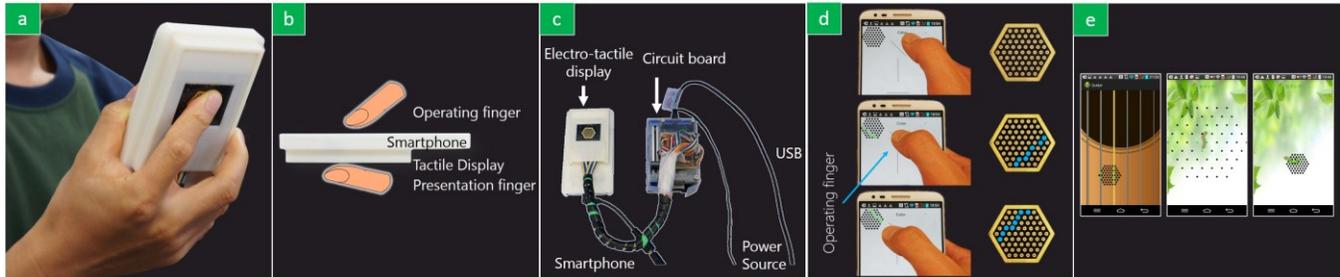


Figure 1. System device and applications. (a) Appearance of the device with a user. (b) The smartphone and the electro-tactile display. (c) Overall view of the prototype. (d) Sample shape on the screen and electro-tactile presentation. The mirror image of the shape under the operating finger is presented to the finger on the back of the smartphone (e) Sample applications of guitar and worm-touch sensations presented to the tactile display.

ABSTRACT

The most common method of presenting tactile stimuli to touch screens has been to directly attach a tactile display to the screens. This requires a transparent tactile display so that the view is not obstructed. In contrast, transparency is not required if the tactile stimuli are presented on the back of the device. However, stimulating the entire palm is not appropriate because touch screens are typically used by only one finger. To overcome these limitations, we propose a new method in which tactile feedback is delivered to a single finger on the back of a touch screen. We used an electro-tactile display because it is small and dense. The tactile display presents touch stimuli as mirror images of the shapes on the touch screen. By comparing cases in which the device was operated by one or two hands, we found that shape discrimination is possible using this method.

Author Keywords

Electro-tactile display; Smartphone; Tactile feedback.

ACM Classification Keywords

H.5.2. [Information interfaces and presentation]: User Interfaces-Haptic I/O.

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INTRODUCTION

With the spread of mobile touch-screen devices, improving comfort and accuracy of operation has become an important issue. Even though the devices can be intuitively operated by directly touching icons or buttons on the screen, the lack of clear tactile feedback such as a click feeling causes degradation of performance (operating errors) [4, 10]. To overcome this limitation, several tactile presentation methods have been proposed, with most of them presenting tactile feedback to a finger that is touching the screen (in this paper, referred to as “operating finger”). ActiveClick [2] realized a click feeling by vibrating the entire touch panel. Teslatouch [1] created a texture feeling by controlling electrostatic friction on the touch panel. Winfield et al. [12] modified surface texture by modulating the presence or absence of ultrasonic vibration. 2.5D Display [9] achieved the feelings of friction and texture by adding horizontal force to the finger. While these devices had some success, they are limited in spatial resolution, presenting only rough shapes or vibrations. Some studies have tried to generate higher resolution tactile presentations. Skeletouch [7] enabled electrical stimulation of the screen using a transparent electrode. Tactus Technology’s Tactile Layer [11] created tactile cues for button position by physically deforming the touch panel surface. The main issue with these methods is that the tactile stimulation is presented to the operating finger, and the tactile display needs to be transparent to avoid obscuring the touch screen. This dramatically limits the ways that tactile stimulation can be presented, and makes the device high in density and cost.

To cope with this issue, ActiveClick [2] proposed that tactile stimulation be presented to the back of the screen. Because

the tactile display is placed on the back of the device, it does not need to be transparent. SemFeel [14] used vibration motors to present tactile stimulation to the back area of a mobile device. Fukushima et al. [3] presented tactile feedback to the hand by placing an electro-tactile display on the back of the touch panel. However, these methods present tactile feedback to the entire palm of the hand holding the device, and are thus inappropriate because the shape is being touched by a single fingertip.

Considering all these issues, we propose a new method that uses an electro-tactile display on the back of a mobile device that stimulates the finger touching the back (in this paper, referred to as “presentation finger”) with a mirror image of the shape being touched by the operating finger. Thus, our device presents tactile stimulation to a finger on the back of the device as if it were touching a shape on the screen (Figure 1a). Because the presentation finger is stationary, we present the tactile pattern dynamically, and move it according to the motion of the operating finger. The key question with this method is whether the tactile perception of the presentation finger and the movement of the operating finger can be integrated and interpreted accurately. We assumed integration is possible because Optacon [8], which is widely used as a visual-tactile conversion device for the visually impaired, works in a similar way (i.e., a finger of one hand touches the tactile display while the other hand holds the camera). The main difference between Optacon and our system is that the tactile display is on the back of the screen.

In this paper, we present our system, which uses an electro-tactile display attached to a smartphone, and report how well the user was able to integrate the two signals while operating the device.

HARDWARE

Figure 2 shows the schematic of our hardware prototype. We attached the electro-tactile display [6] on the backside of a smartphone (LG G2: $138.5 \times 70.9 \times 8.9 \text{ mm}^3$, Android 4.2.2) (Figure 1b). The electro-tactile display comprises 61 1.2-mm diameter electrodes (Figure 1c and d). The distance between the centers of two adjacent electrodes is 2 mm. The entire display becomes a regular hexagon of 10 mm. The electrodes were connected to a shift register IC (HV507) in a controller board through a cable (Figure 1c and Figure 2). The 61 wires making up the cable can be reduced to 8 if IC is directly attached to the smartphone.

The circuit we used is similar to that used by Hamsatouch [5]. The controller board connects to the smartphone via a USB communication cable and consists of a microcontroller (mbed LPC1768), a high-speed D/A and A/D converter, and a voltage/current converter. The controller board generates a high-voltage (300 V) and controls the current density for electro-tactile stimulation. We used a current pulse with a width of 50 μs and refresh rate of 50 Hz. The maximum current density was 5 mA, which can be adjusted by the user for the most comfortable sensation. Though our prototype uses an external power source, we also tested it with an 850-

mAh battery. Because the battery could drive 512 electrodes for over three hours, we consider the recent 2000-mAh smartphone batteries to be acceptable.

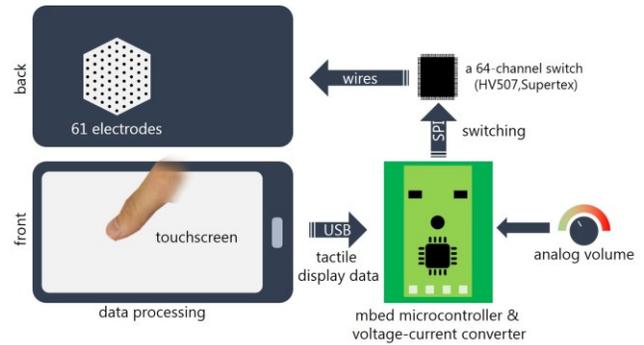


Figure 2. The Hardware.

SYSTEM ALGORITHM

The tactile display presents the information around the operating finger on the screen to the presentation finger. As mentioned above, the presentation finger is stationary and the user is able to sense the information on the smartphone by integrating the tactile feedback sensation from the presentation finger with the movement of the operating finger. The tactile stimulation pattern corresponds to the shape displayed on the screen and the operating finger. As shown in Figure 1d, when the operating finger approaches the shapes on the touchscreen, the tactile display presents tactile stimulation that mirrors them (left/right inversion). The tactile pattern follows the movement of the operating finger and users can perceive diagonal movement on the screen with their presentation fingers.

EXPERIMENT

We conducted two experiments to test how well line direction and shapes can be recognized with our device. Each experiment was conducted with four conditions in a 2 by 2 design: *number of hands* (one-hand, two-hand) \times *device-holding hand* (left, right). “One-hand” refers to holding and operating the device with one hand, and “two-hand” refers to using one hand to hold the device and the other to operate it. The presentation finger was the index finger of the hand holding the device. In the one-hand condition, the operating finger was the thumb of the hand holding the device, while in the two-hand condition it was the index finger of the other hand.

Experiment 1: Line-direction recognition

The first experiment examined whether users could correctly recognize lines with different angles when tactile presentation is to a finger touching the back of the smartphone. Lines were presented horizontally, vertically, 45° to the right, or 45° to the left (depicted here using the symbols “_”, “|”, “/”, and “\”, respectively). The length of each line was 2 cm. We were especially interested in the confusion between the two diagonal lines because the tactile information was the left-right mirror image of the information on the touch panel.

In the experiment, participants were allowed to touch the line pattern multiple times until they recognize it, and we measured the response accuracy and the reaction time. The stimuli were static impressions but the line patterns dynamically moved according to the coordinates of “mirror image”.

Participants

We recruited eight participants (six males and two females) aged between 23–26 years (mean 24 years). All participants were right-handed and used mobile touchscreen devices daily.

Procedure

Figure 3 shows the procedure for one set of experiments. The participants were given an explanation of the system and completed a practice session before the experiment (an average of 2 min). In the practice session, the line patterns were visible.

At the beginning of a trial, a red square was shown in the middle of touchscreen, representing the location of the pattern (Figure 3). Choice options for each line type were presented at the bottom of the screen. For each trial, one of the four types of lines was tactily (but not visually) presented when participants touched the touchscreen. Participants chose which one they felt as soon as they recognize it. Each pattern was presented five times in each of the four conditions ((one-hand, two-hand) × (left hand, right hand)), totaling 80 trials (4 lines × 5 repetitions × 4 conditions) for each participant. The order of pattern presentation was random. The order of the four conditions was counterbalanced across participants.

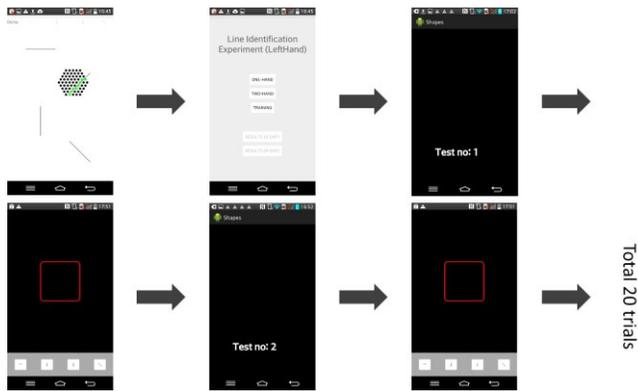


Figure 3. Experimental procedure.

Results and discussion

Figure 4 (left) compares performance accuracy between the one-hand and two-hand conditions for each line pattern. The mean performance rates were 95.6% and 88.1%, respectively. A 4 (*line type*) × 2 (*number of hands*) × 2 (*device-holding hand*) repeated-measures ANOVA indicated main effects of *line type* ($F_{3,105} = 5.851$, $p < 0.01$) and *number of hand* ($F_{1,105} = 11.703$, $p < 0.01$). No significant main effect was observed for *device-holding hand* or for any interaction between the factors.

Table 1 shows the confusion matrix of the Line-direction recognition experiment. The overall performance was 91.9%. Most incorrect answers were for the “-” and “|” patterns, perhaps because of improper orientation or position of the presentation finger. Confusion between the two diagonal lines was low.

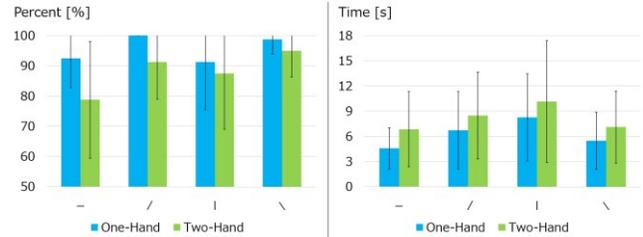


Figure 4. The comparison of results from Experiment 1: (left) mean performance rate, (right) mean reaction time.

		Response			
		-	/		\
Presented lines	-	85.6%	4.4%	1.9%	8.1%
	/	2.5%	95.6%	1.9%	0.0%
		0.0%	5.6%	89.4%	5.0%
	\	1.3%	0.6%	1.3%	96.9%

Table 1. Confusion matrix for the Line-direction recognition experiment.

Figure 4 (right) compares reaction times between the one-hand and two-hand conditions for each line pattern. The mean reaction times were 6.25 s and 8.13 s, respectively. A 4 × 2 × 2 ANOVA (same factors as for performance accuracy) revealed main effects of *line type* ($F_{3,105} = 5.194$, $p < 0.01$) and *number of hand* ($F_{1,105} = 6.675$, $p < 0.01$). No significant main effect was observed for the *device-holding hand* or any interaction between the factors.

The results show that tactile information presented to a finger on the back of a mobile device can be recognized, and that using one hand achieves faster and more accurate recognition than does using two hands. The low error rate for the two diagonal lines indicates that despite only 2 min of practice, users did not have difficulty with the mirror-image tactile stimulation, even though it was presented on the back of the device to a different finger.

Experiment 2: Shape recognition

We conducted the second identification experiment with four different shapes, using almost the same conditions as in Experiment 1. The purpose of the experiment was to validate the ability to identify more complex shapes. The shapes were a square, a circle, an equilateral triangle, and an X (represented here as “□”, “○”, “Δ”, “×”). The shapes fit inside a 2 × 2 cm² box.

Participants:

We recruited eight participants (seven males and one female), aged 22–26 years (mean, 24 years). All participants were right-handed, and five had participated in Experiment 1.

Results and Discussion

Figure 5 (left) compares performance accuracy between the one-hand and two-hand conditions for each shape. The mean performance rates were 85.6% and 79.4%, respectively. A 4 (*shape*) × 2 (*number of hands*) × 2 (*device-holding hand*) ANOVA indicated a main effect of *shape* ($F_{3, 105} = 6.82$, $p < 0.01$) and a marginally significant effect of *number of hands* ($p = 0.07$). No significant main effect was observed for *device-holding hand* and or any interaction between the factors.

Table 2 shows the confusion matrix for the Shape-recognition experiment. The overall performance was 82.5%. The square was the most difficult to identify, while the cross was the easiest. Most errors occurred by confusing square and circle.

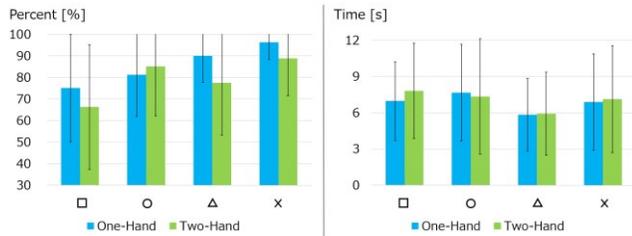


Figure 5. Comparison results from Experiment 2: (left) mean performance rate, (right) mean reaction time.

		Response			
		□	○	△	×
Presented shapes	□	70.6%	21.3%	4.4%	3.8%
	○	5.0%	83.1%	4.4%	7.5%
	△	1.3%	4.4%	83.8%	10.6%
	×	0.6%	0.6%	6.3%	92.5%

Table 2. Confusion matrix for the Shape-recognition experiment.

Figure 5 (right) compares reaction times between the one-hand and two-hand condition for each shape. The mean reaction times were 6.8 s and 7 s, respectively.

Similar to Experiment 1, even when the shapes were complicated, accuracy was better when participants used the same hand for the touchscreen as they did for sensing the tactile stimulation. We also found that the five participants who had already completed Experiment 1 were more accurate and faster than those who had not (old participants: 87.5% and 5.2 s; new participants: 76.2% and 9.8 s). Thus, we think there might be a learning effect.

APPLICATIONS

In addition to the basic shapes in the experiment, we provided two interactive samples shown in Figure 1e.

1) The guitar application can be used for music e-learning or experiencing playing music and 2) the worm application for giving the feel of worms to children as they hear stories about them being read, which is similar to FeelSleeve [13] but has higher shape resolution. The first application presents the

tactile feeling of playing the guitar. The second application presents visual and tactile information of worm movements, which feels like a worm crawling on the skin. We asked participants to try our applications and they mentioned that the system was very realistic. Particularly in the case of the worm application, participants said that the electro-tactile sensation was very similar to what being touched by a worm feels like.

Currently, we have two additional scenarios under development. One is for visually impaired users to touch visual images. The user captures a surrounding scene with a camera, and then touches the image with the operating finger and feels the shapes with the backside finger. The other is a sightless interaction, in which users can read information by just touching the device in their pockets. The system would be that each character is sequentially “written” on the backside finger, while the front side finger modulates speed of the presentation.

CONCLUSION

Here, we have proposed a new method for presenting tactile information to one finger based on the shape touched by another finger. We used a small and dense electro-tactile display, as it is suitable for smartphones. In our method, electro-tactile display is located on the back of a smartphone, produces tactile stimulation that is a mirror image of what an operating finger touches, and delivers it to the presentation finger. Testing with lines and shapes confirmed that users could stably distinguish different line directions and different shapes. Despite the mirror image and being presented on the back to a different finger, misinterpretation of the mirror images was not observed.

We did observe that performance—both accuracy and speed—were better when the presentation finger and operating finger were both on the same hand, even though the operating finger can explore the screen surface more freely when two hands are used. It may be that to understand the relationship between the shape on the screen and tactile mirror image, the relative position of the operating finger and the presentation finger is important. Additionally, our results suggested that performance does not depend on which hand holds the device (dominant or non-dominant).

We also showed that our method can be used to add tactile sensation to entertainment. We envision using the device for people with visual impairments, perhaps as a character presentation system. Although a visual display is not necessary in that case, the coexistence of input (touch panel) and output (tactile display) in a small mobile device will be a practical help for visually impaired people.

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