Tactile Presentation to a Back Side Finger While Operating with a Front Side Finger for Smartphone*

Khurelbaatar Sugarragchaa, Yuriko Nakai, and Hiroyuki Kajimoto, *The University of Electro-Communications, Japan*

Abstract— **In most common methods of tactile presentation on touch screen, the tactile display was directly attached or contacted onto the screen. Therefore, the tactile display must be transparent so that it does not obstruct the view of the screen. On the other hand, if the tactile sensation is presented at back side of the device, the tactile display does not need to be transparent. However, the cost of covering the whole back side with high-density tactile display is high. To overcome these limitations, we proposed to use a small and dense tactile display placed at the back side and touched with one finger. The tactile display is able to present the information around the operating finger touching the screen to the finger on back side of device. This paper reports the ability of shape discrimination, by comparing two cases where the device is operated by one hand and both two hand.**

I. Introduction

With the spread of the mobile touch-screen devices, the improving comfort and accuracy of the operation has become an important issue. The touch panel can be intuitively operated by directly touching the icon or button on the screen. However, it is known that the lack of clear tactile feedback such as click feeling causes degradation of performance such as operating errors [1][2]. To overcome this limitation, a lot of tactile presentation methods for touch panel have been proposed, and for most of them the tactile feedback is presented to finger that touches the screen (in this paper, referred to as "operating finger"). ActiveClick [3] and New Feelings touch panel [4] realized click feeling by vibrating the whole touch panel. Teslatouch [5] realized a representation of texture feeling by controlling electrostatic friction on the touch panel. Takasaki et al.[6], and Winfield et al. [7] modified surface texture by the presence or absence of ultrasonic vibration. 2.5D Display [8] presented friction and texture feeling by adding horizontal force to the finger. However, most of these methods have a limitation of spatial resolution; i.e., the sensation is presented to the whole fingertip and the resolution is limited to the finger size when the finger stands still.

There are some studies aiming to realize higher resolution tactile presentation. Skeletouch [9] enabled electrical stimulation on the screen by using a transparent electrode. Tactus Technology's Tactile Layer [10] enabled tactile cue of the button position by physically deforming touch panel surface. Fundamental limitation of all these works is that, the tactile sensation is presented to the operating finger, so that the necessity of transparent tactile display that doesn't visually obstruct the screen dramatically limits the ways to present tactile sensation on touch panel, and high density tactile feedback becomes difficult.

One way to cope with this problem is presenting tactile sensation on the back side of the screen. The tactile display is placed on the back side, so it does not require to be transparent. In the field of mobile devices, there are many studies that placed a touch sensor on the back side to avoid the problem of a finger hiding a screen (referred to as fat finger problem) [11][12], but development of a tactile display on the back side is relatively rare. ActiveClick [3] proposed the tactile presentation on the back side, SemFeel [13] and Alexander et al. [14] used vibration motors and ultrasonic generated air field respectively, to present tactile sensation at the back area of mobile device. Fukushima et al. [15] developed a method to present tactile feedback to the whole hand palm by laying electro-tactile display on the back of the touch panel. However, the cost of the tactile presentation to the entire back side is high and it requires a large amount of power supply.

Considering all these issues, we proposed a method using a small and dense tactile display placed on the back side and touched by one finger (in this paper, referred to as "presentation finger") (Fig.1). The information around the operating finger on the screen is presented by the tactile display. The electro-tactile display is employed to reduce size and thickness.

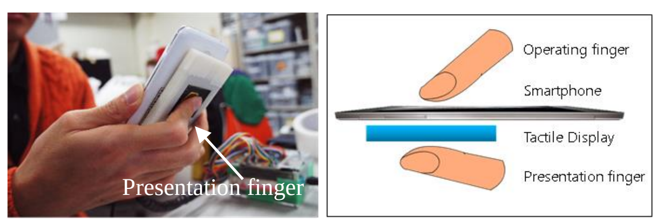

Figure 1. Appearance of the Device: Tactile sensation is presented to a back side finger while a front side finger operates smartphone.

In this case, the tactile pattern presented to the presentation finger dynamically moves with the motion of the operating finger. The key question of this method is that, whether the tactile perception of the presentation finger and the movement of the operating finger can be integrated and interpreted. We considered this integration is possible, since Optacon [16], which is widely used as a visual-tactile conversion device for the visually impaired, is in the similar situation (i.e., one hand

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K. Sugarragchaa is with the University of Electro-Communications, 1-5-1, Chofugaoka, Chofu, 182-8585 Japan (e-mail: sura@kaji-lab.jp).

Y. Nakai is with the University of Electro-Communications, 1-5-1, Chofugaoka, Chofu, 182-8585 Japan (e-mail: yuriko@kaji-lab.jp).

H. Kajimoto is with the University of Electro-Communications 1-5-1, Chofugaoka Chofu, 182-8585 Japan / Japan Science and Technology Agency, (e-mail: kajimoto@kaji-lab.jp).

finger touches the tactile display while the other hand holds the camera). The main difference between the Optacon and our system is that the tactile display is on the back side of the screen.

In this paper, after composing the system using electro-tactile display and smartphone, we conducted experiments to confirm the integration ability of the user during using the device.

II. Prototype

We attached electro-tactile display [17] at the back side of a smartphone (LG G2, 138.5 × 70.9 × 8.9 mm, Android 4.2.2). The electro-tactile display comprises 61 electrodes with 1.2 mm diameter (Fig.2). The distance between centers of the two adjacent electrodes is 2 mm. The size of entire display becomes a regular hexagon with side length of 10mm.

The tactile display is connected directly to the smartphone by USB serial communication. The smartphone transmits the tactile presentation pattern to the tactile display corresponding to the position of the operating finger.

Figure 2. Prototype. The tactile display is attached on the back side of the smartphone.

III. System Algorithm

The tactile display presents the information around the operating finger on the screen to the presentation finger. As previously mentioned, the presentation finger is stationary. The user perceives the tactile feedback on the presentation finger and integrates it with the movement of the operating finger.

Fig.3 shows the running prototype and the tactile presentation algorithm. When the operating finger approaches the shapes on the touchscreen, the tactile display on the back side present the tactile mirror image of the shape (left/right inversion). The tactile pattern follows the movement of the operating finger and the user can perceive moving diagonal line with his/her presentation finger.

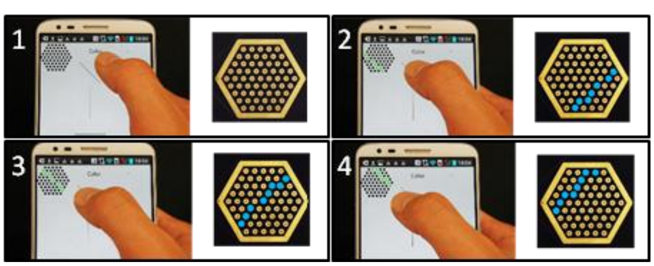


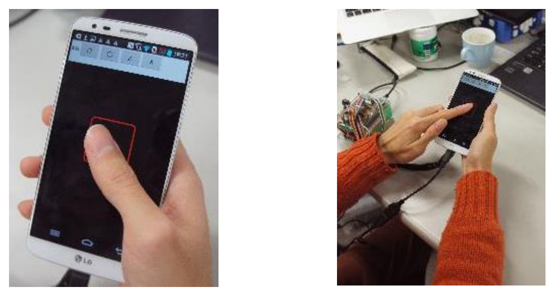
Figure 3. The system design. The mirror image of the shape under the operating finger is presented to the presentation finger at back side. The top left image is shown for explanation and hidden in the evaluation experiment.

IV. Experiment

We conducted two experiments, one is line direction identification, and the other is shape identification. In each experiment we examined two conditions as shown in TABLE I. and Fig.4. The participants were asked to hold the device with their right hands, and put their index fingers of the right hands (dominant hands, because we recruited right-handed participants) on the tactile display. In condition one, participants touched the touch panel with their thumb of the right hand, and in condition two, they touched the touch panel with their index finger of the left hand. In other words, condition one was one-hand experiment, and condition two was two-hand experiment.

TABLE I. Experiment conditions

	Condition 1	**Condition 2**
Presentation finger	Index finger of the right hand	
Operating finger	Thumb of the right hand	Index finger of the left hand



a) One-hand experiment b) Two-hand experiment

Figure 4. Overview of the experiment.

A. *Experiment 1: Line Direction Identification*

In this experiment, we examined whether the users can correctly identify the lines with different angles, when the tactile presentation is on the back side of the smartphone. The lines were horizontal "-", vertical "|", 45 degrees right-leaning diagonal line "/" (i.e. slash), and 45 degrees left-leaning diagonal line "\" (i.e. backslash). We were especially interested in the confusion between two diagonal lines, since mirror image of the information of touch panel is presented to the tactile display on the back side of the device.

Participants: We recruited six participants aged between 22 and 27, 23 in average, all males, right-handed. All of them daily used mobile touch-screen devices.

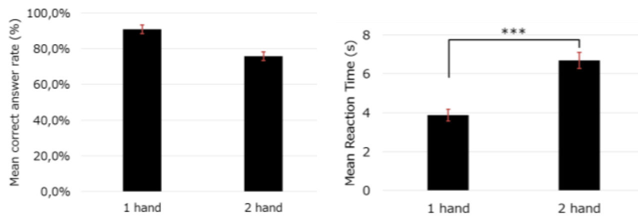
B. *Experiment 1: Results*

Fig.5 shows the results of experiment 1. Fig.5 (a) is the comparison of the mean correct answer rate of "one-hand experiment" and "two-hand experiment". Fig.5 (b) is the comparison of the mean reaction time. The vertical axis of each graph represents the mean correct answer rate and mean reaction time, respectively.

The confusion between two diagonal lines "/" and "\" was low (0.83%). The average correct answer rate of "one-hand experiment" was 90.8% and "two-hand experiment" was

75.8%. The average mean reaction time was 3.9s for one-hand case and 6.7s for two-hand case, and the significant difference between the two mean was found(t-test, $p<0.001$).

The results indicated that when the presentation finger and operating finger were both in the same hand, the correct answer rate became higher and reaction time became faster.



a) Mean correct answer rate b) Mean reaction time

Figure 5. The comparison results of Experiment 1

C. *Experiment 2: Shape Identification Experiment*

We conducted another identification experiment using four different shapes under the same conditions as in experiment 1. The purpose of the experiment was to validate identification ability of more complex shapes. The shapes were square “□”, circle “○”, equilateral triangle “Δ”, and cross-shape “×”.

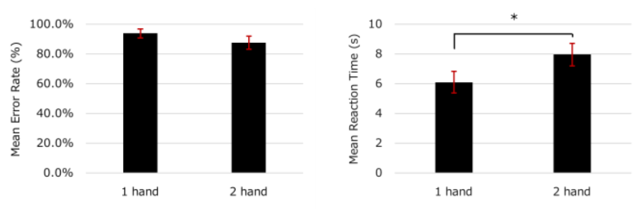
Participants: We recruited four participants aged between 22 and 24, 23 in average, all right-handed males. All of them have participated experiment 1, and this experiment was conducted four days after the experiment 1.

D. *Experiment 2: Results*

Fig.6 shows the results of experiment 1. Fig.6 (a) is the comparison of the mean correct answer rate of “one-hand experiment” and “two hand experiment”. Fig.6 (b) is the comparison of the mean reaction time. The vertical axis of each graph represents the mean correct answer rate and mean reaction time, respectively.

The average correct answer rate of “one-hand experiment” was 93.8% and “two-hand experiment” was 87.6%. The average mean reaction time was 6.1s in one-hand case and 7.96s in two-hand case, and there was a significant difference between these two cases (t-test, $p<0.05$).

Similar to experiment 1, the results of correct answer rate and reaction time indicated that when the presentation finger and operating finger were both in the same hand, the correct answer rate became higher and reaction time became faster.



a) Mean correct answer rate b) Mean reaction time

Figure 6. The comparison results of Experiment 2

V. CONCLUSION

We proposed a tactile presentation method for smartphones, using a small and dense electro-tactile display placed it at the back side of the device. In our method, we presented the information around the operating finger on the screen to the presentation finger through the tactile display on the back side. Two experiments using lines and shapes confirmed that the users can stably identify different line directions and different shape types. Misinterpretation between the mirror images was low.

We also observed that, when the presentation finger and operating finger were both from the same hand the identification performance became higher compared to the case where both of two hands were used. As there is a possibility that dominant and non-dominant hand might affect the results, we conducted supplemental experiment changing the hands. Although the result is partially positive, we cannot conclude the result yet.

For our future works we will develop mobile applications to demonstrate the potential and feasibility of our prototype.

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