

Effects of Holding Ring Attached to Mobile Devices on Pointing Accuracy

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Abstract. It is difficult for a user to operate a touch screen device accurately under the eyes-free condition. The difficulties arise from the absence of visual or tactile feedback under this condition. This research focuses on the effectiveness of a holding ring attached to the back of mobile devices to improve pointing accuracy under the eyes-free condition. We explored the extent to which the holding ring improves the pointing accuracy by preparing three mobile devices with holding rings attached in different positions and a mobile device without a holding ring. The pointing accuracy was then evaluated by performing user studies. The result suggested that the pointing accuracy could be improved under the target condition, which is $15.4 \text{ mm} \times 10.4 \text{ mm}$, by attaching the holding ring.

Keywords: Eyes-free input · Back-of-device interaction · Tactile feedback · One-handed operation · Touch screen · Smartphone · Thumb-based input

1 Introduction

Using a mobile device with a touch screen (hereafter a mobile device) while walking has emerged as a social problem, because it consumes the user's visual attention and thus, causes of traffic accidents [1, 2]. One of the solutions to this problem is an eyes-free touch input which enables the user to operate the mobile device without watching the display of the device. However, it is difficult to operate a mobile device without being able to look at the display [3] because there is neither visual nor tactile feedback.

Our idea to address the above issue was prompted by a previous solution and research. The user of a one-handed keyboard (e.g., Twiddler Tek Gear Inc.) uses a belt to hold the keyboard stably. Fukatsu et al. [4] and Corsten et al. [5] showed that the pointing accuracy in eyes-free touch input is improved by tactile landmarks on the back of the device. These solutions and research results suggest that the back of a device presents potential design space for improving the performance of the input via the touch screen located on the front of a mobile device.



Fig. 1. A holding ring.

Our idea in this research is to use a ring-shaped part, e.g., VENICEN Ring Holder2, on the back of a device to prevent the device from falling(hereafter, a holding ring). Our assumption was that attaching a holding ring would be able to improve the eyes-free pointing accuracy during one-handed operation (Fig. 1), because the user's gripping attitude is stabilized. In this research, we conducted user studies to measure the eyes-free pointing accuracy, using mobile devices to which a holding ring is attached in different positions to examine the above idea.

2 Related Work

2.1 Back of Device

Previous research showed that touch-enabling the back of a touch screen device improves the usability of the device. For example, Baudisch et al. [6] showed that touch-enabling the back of an ultra-small device improved the pointing accuracy on the front side. Wigdor et al. [7] proposed a tabletop system of which the back is touch-enabled, and which extended input vocabulary by detecting touch on the back of the table. LucidTouch [8] is a see-through mobile device which has touch sensors on its back. It improves the pointing accuracy and the usability of text entry on the front side because the see-through device allows the user to see the user's fingers and hand on the back of the device; it also showed bimanual input techniques which coordinately use the front and back.

Pointing accuracy in eyes-free touch input was shown to improve by tactile landmarks on the back of the device. For example, HaptiCase [5] provides back-of-device tactile landmarks that the user senses with their fingers to estimate the location of touch at the front, and thus allows the user to touch with high precision under the eyes-free condition. Fukatsu et al. [4] showed that tactile textures attached on the back of the device can improve pointing accuracy.

In contrast to the above research, we explore the effect of attaching a holding ring to the back of the device for eyes-free touch input.

2.2 Eyes-free Input

Some research proposed eyes-free input methods. For example, Slide Rule [9] is a method that allows blind users to access touch screen applications in eyes-free by using voice guidance along with multi-touch interaction techniques. A user study with 10 blind people showed that Slide Rule was faster than a system based on a screen reader and participants preferred Slide Rule. BrailleTouch [10] is a method that allows users to input text in an eyes-free manner. It shows a Braille cell, which consists of a 3 by 2 binary matrix on the touch screen of a mobile touch screen device; where the user places their fingers in a one-to-one correspondence to a standard Braillewriter to input a character. Bragdon et al. [11] investigated the effect of various situations on touch screen interaction. One of the investigated situations was an eyes-free environment. As a result, these authors suggested that, in terms of performance, the most notable effect for touch screen interaction came from not looking at all times. Gustafson et al. [12] proposed palm-based imaginary interfaces that use a human palm as input surface mapped to an invisible GUI based upon the user's spatial memory such as the home screen GUI of a smartphone. They investigated pointing time under sighted and blindfolded conditions. Their results indicated the potential of imaginary interfaces for blind and eyes-free use.

In contrast to the above research, we focus on improving the accuracy of eyes-free input by attaching a holding ring.

2.3 Tactile Feedback

It is possible to improve pointing accuracy using tactile feedback. FingerFlux [13] is an output technique to generate near-surface haptic feedback by magnets. The technique can reduce drifting when operating on-screen targets in eyes-free condition. Kincaid [14] proposed tactile guide overlays for touch screens. An overlay is a transparent Lexan sheet cut and hollowed out to fit the buttons, sliders, and other components on touch screens. An evaluation shows that a tactile guide overlay can decrease task time compared to a bare touch screen. Touchplates [15] is an overlay for touch screens designed for accessibility. El-Glaly et al. [16] proposed augmenting a touch screen with a tactile overlay that consists of a border, a vertical ruler, horizontal lines, vertical lines, or landmarks. MudPad [17] is a system that can provide localized active haptic feedback on multitouch screens. This allows users to explore the interface haptically.

Various kinds of tactile feedback other than the above ones have been explored in the HCI field. For example, TeslaTouch [18] produces various kinds of tactile sensations by controlling electrostatic friction between a touch surface and the user's fingers by exploiting the principle of electrovibration. UltraHaptics [19] is multi-point midair haptic feedback for touch surfaces radiated using a phased array of ultrasonic transducers. BaduumTouch [20] is an attractive force feedback interface using air suction.

In contrast to the above research, we use tactile feedback in the form of a holding ring attached to the back of a mobile device and to explore how the feedback affects the eyes-free pointing accuracy on the touch screen.

3 Evaluation

We conducted a user study to measure pointing accuracy using mobile devices with a holding ring attached in different positions.

3.1 Design

Participants

Six male participants including three of the authors ranging in age from 22 to 24 took part in the evaluation as volunteers. They were using mobile devices with touch screens on a daily basis. All participants were right-handed.

Apparatus

We used four mobile devices all of which were Apple iPhone 4S devices with a 3.5-inch screen (ring conditions). We attached a holding ring to three of them in three different positions as shown in Fig. 2 and used one of them as is. In summary, we tested the following four different ring conditions:

Top

We attached the holding ring to the back of the device 2.0 cm above the center of the touch screen.

Middle

We attached the holding ring at the back of the devices in the center of the touch screen.

Bottom

We attached the holding ring to the back of the device 2.0 cm below the center of the touch screen.

NoRing

Nothing was attached.



Fig. 2. Ring conditions (from left to right): Top, Middle, Bottom, and NoRing.

Procedure

We located a 17-inch display on a desk, to mirror the screen of the mobile device (Fig. 3). We asked the participants to sit down on a chair and hold the mobile device with their right hand. We also asked them to position their right elbow on the desk, and their middle finger through the holding ring at their proximal interphalangeal joint. Furthermore, we covered the participants' hand holding the mobile device to prevent the participant from observing the display of the mobile device.

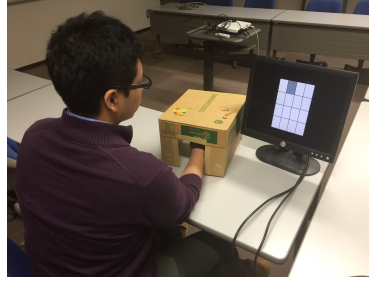


Fig. 3. Setup of the evaluation.

The screen of the mobile device, which is split into a 4×4 or 5×5 grid (split conditions) as shown in Fig. 4, was mirrored on the display. As a trial, a gray rectangle (hereafter target) was shown in one of the grids. We asked the participants to point (i.e., tap) the corresponding position on the screen of the mobile device as accurately as possible. Specifically, we also asked the participants to touch down on the touch screen with their finger, move their fingers on the touch screen to find the target, and then raise their fingers from the touch screen. We used the point where the fingers were raised (i.e., the coordinate of the touch up event) for analysis in pointing accuracy.

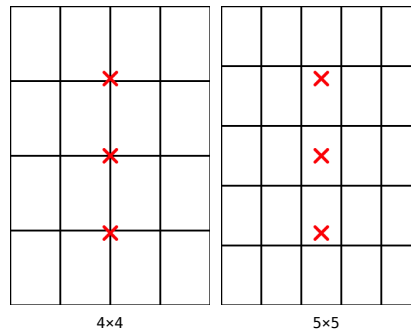


Fig. 4. Display of the mobile device on each split condition. The three X marks illustrate the positions of the holding rings under the Top, Middle, and Bottom conditions. Note that the X marks were not presented to the participants in this evaluation.

The following is the procedure according to which a participant carried out the task:

1. When the participant taps the target that is positioned on the upper left of the screen of the mobile device, the first trial starts: a target is shown on the display.
2. The participant points to the corresponding position on the touch screen of the mobile device.
3. Regardless of the success or failure of the pointing, a tap sound is played to promote the participant to move on to the next trial. The next target is shown on the display randomly.

Split conditions were changed in a randomized order between the participants to counterbalance the order effect. A task consists of 15 training trials (the participants watch the display of the mobile device), 15 training trials (the participants do not watch the display of the mobile device), and 50 trials (80 trials in total). Each participant carried out this task once in each ring condition in each split condition (i.e., 8 tasks = 640 trials in total) and completed all 8 tasks in approximately 40 minutes.

3.2 Result and Discussion

Fig. 5 shows the pointing accuracy of each split condition. Table 1 lists the standard deviation of the distances between the target and the touch point (hereafter variance) in each split condition. Fig. 6 shows the pointing accuracy of each target in each ring condition in each split condition. In Fig. 6, the darker the area is, the higher the accuracy of the area is. Fig. 7 shows the center of gravity of the touch points in each target in each condition. In Fig. 7, the circles show the standard deviation of the variances in each split condition in each target; the points show the center of gravity of touch points in each split condition in each target .

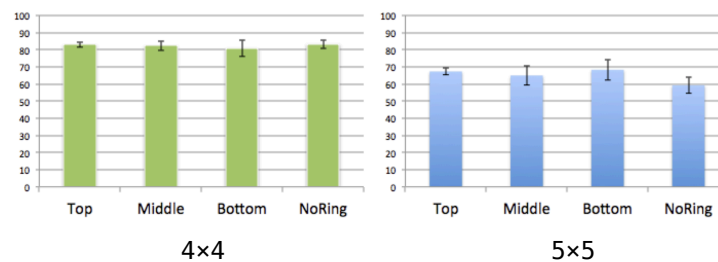
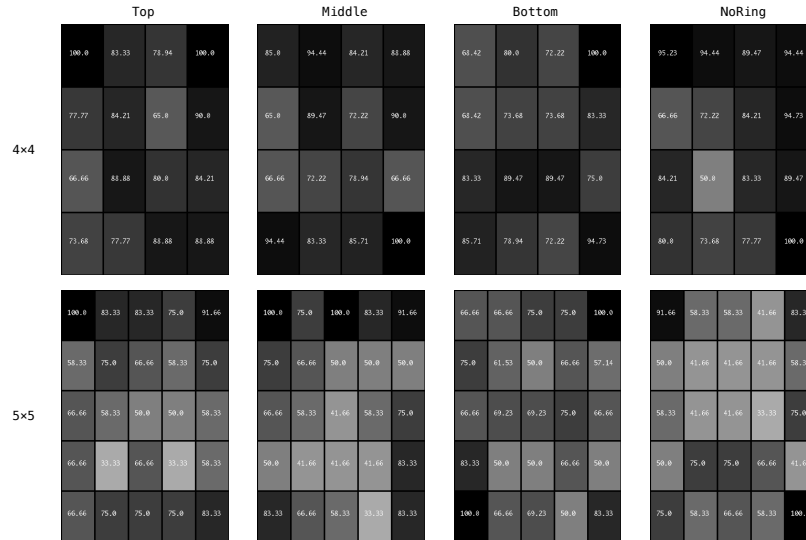


Fig. 5. Pointing accuracy of each split condition.

Table 1. Standard deviation of variances in each split condition.

Grid	Condition	SD (Deviation)	SD (x)	SD (y)
4 × 4	Top	42.45	23.01	35.67
4 × 4	Middle	40.91	20.05	35.67
4 × 4	Bottom	47.55	22.35	41.97
4 × 4	NoRing	42.72	21.24	37.07
5 × 5	Top	44.29	22.93	37.90
5 × 5	Middle	46.43	23.96	39.77
5 × 5	Bottom	45.99	22.91	39.88
5 × 5	NoRing	45.06	24.73	37.66

The pointing accuracy is improved by attaching a holding ring in the 5 × 5 condition as Fig. 5 shows. In the 5 × 5 condition, there are significant differences between the Top and NoRing conditions ($p = .042 < .05$) and the Bottom and NoRing conditions ($p = .048 < .05$). In contrast, in the 4 × 4 condition, there were no significant differences between the four ring conditions. These results suggest that when a target is small (i.e., 5 × 5), attaching the holding ring to the back of a mobile device improves the pointing accuracy. The reason why the effect of the holding ring attached to the mobile device does not appear in the 4 × 4 condition would be because a target in the 4 × 4 condition is so large that the holding ring does not have a room to contribute to lower the pointing accuracy. On the other hand, on smaller targets (i.e., 5 × 5), the ring improves the pointing accuracy because participants need to touch the display more precisely. Fig. 7 supports this observation. In Fig. 7, the circles in the 4 × 4 condition are larger than that in the 5 × 5 condition.

**Fig. 6.** Pointing accuracy of each target in each ring condition in each split condition.

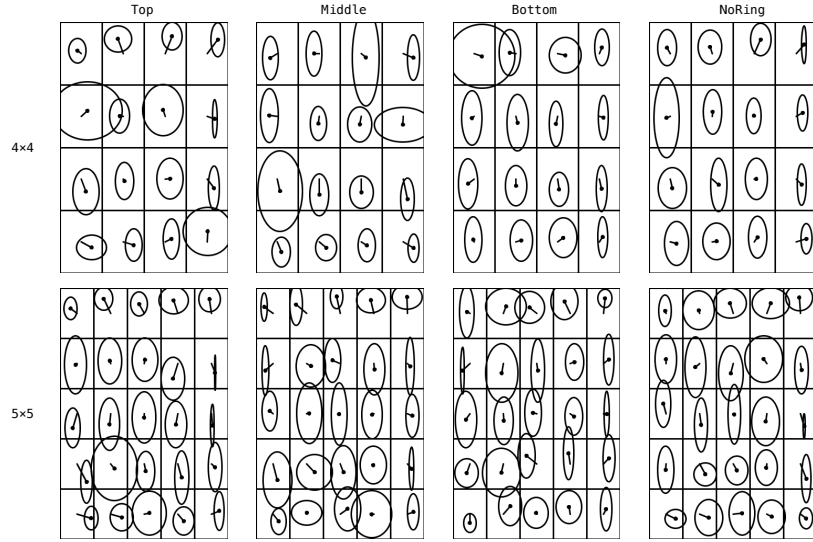


Fig. 7. Center of gravity of each target in each ring condition in each split condition.

4 Additional Evaluation

Since the result of the first evaluation suggests that the holding ring is effective in improving the pointing accuracy on smaller targets (i.e., 5×5), we conducted an additional evaluation. In this evaluation, we used the same four ring conditions as the first evaluation. However, this time we tested an even smaller split condition: a 6×6 grid. Fig. 8 shows the display of the mobile device in 6×6 condition with the positions of the holding rings. Six participants ranging in age from 21 to 30 took part in the evaluation as volunteers. They differed from the participants who participated in the first evaluation. They were using mobile devices with touch screen on a daily basis. All participants were right-handed. In this additional evaluation, we did not display the grid lines because the target size is too small to touch. Moreover, an X mark illustrating the position of the holding ring *was presented* to the participants.

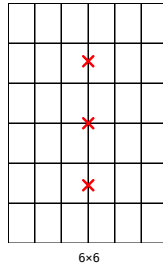


Fig. 8. Display of mobile device on 6×6 condition and positions of holding ring.

Table 2 shows the standard deviation of variances in each ring condition. Fig. 9 shows the center of gravity of touch point of each target in the 6×6 condition. The result of the additional evaluation shows that there are significant difference between the Top and other conditions. The reason might be the fact that participants are forced to touch some of the targets in unusual postures caused by the holding ring. Especially, when participants touch the lowermost targets in the Top condition, the thumb takes an unusual posture. On the other hand, the variance at the Bottom condition is lower than the variance at the Top condition because the thumb can touch the uppermost targets just by reaching out the thumb when participants touch them in the Bottom condition. In summary, since this additional evaluation shows no significant difference between the four ring conditions in 6×6 while the pointing accuracy is improved in the Top and Bottom condition in 5×5 in this first evaluation, it is considered that the holding ring has the potential to improve the pointing accuracy when the target size is approximately $15.4 \text{ mm} \times 10.4 \text{ mm}$ (i.e., 5×5).

Table 2. Standard deviation of variances in 6×6 condition.

Grid	Condition	SD (Deviation)
6×6	Top	34.23
6×6	Middle	24.90
6×6	Bottom	29.29
6×6	NoRing	27.85

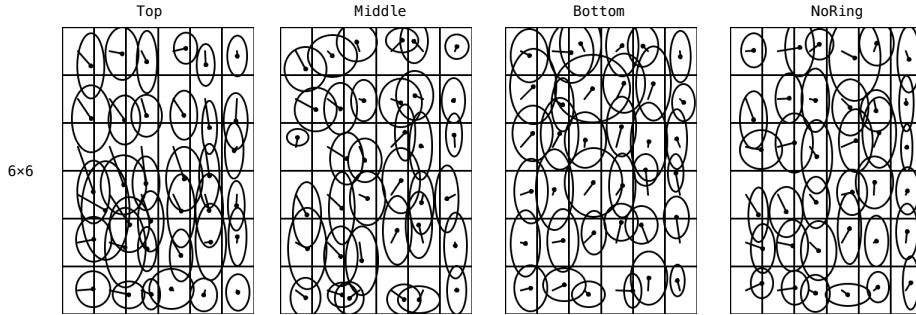


Fig. 9. Center of gravity of each target in each ring condition in 6×6 condition.

5 Conclusion and Future Work

We presented a holding ring attached to the back of a device has the potential to improve the pointing accuracy in one-handed eyes-free input. Specifically, the results of the user studies suggest that the pointing accuracy was improved in the 5×5 condition by attaching a holding ring.

In the future, we plan to conduct user studies to investigate the best attachment point of the holding ring. In addition, because we conducted the two user studies in this research in two separated periods, we plan to combine the two user studies to obtain precise results and analyze the results in detail.

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