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IndexAccess : A GUI Movement System by Back-of-Device Interaction for One-Handed Operation on a Large Screen Smartphone

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Abstract

The use of large screen smartphones has been increasing yearly. Large screens have many advantages in that they can display a lot of information at once. However, when people operate smartphones with one hand, several usability problems can occur due to the posture of the user's hand when holding the device. Among those problems, a significant one we have noticed was that it is difficult to reach the top of the screen with the thumb. In this paper, we propose "IndexAccess": a system to assist the one-handed operation of comparatively large smartphones by pulling down the GUI on the screen by back-of-device operation using one's finger (excluding the thumb). In this study, we implemented the IndexAccess system with an application for iOS and a sensor module. After this, we conducted an experiment to investigate the performance and effectiveness of this system on usability by comparing it with Apple's Reachability in an experiment. Consequently, IndexAccess enables the participants to point more rapidly in the upper half area of screen than Reachability. On the other hand, the participants touched slower in the lower half of the screen than Reachability. It is thought that one of the reasons for this is the prototype was detecting the position of the index finger and moving the display at all times. Consequently, we will improve the usability of IndexAccess by using a pressure-sensitive touch panel instead of a photo-reflective sensor. We will also attempt to move the display not only vertically but horizontally.

Keywords: user-interface, smartphone, back-of-device

1 Introduction

The size of smartphone screens has been increasing since smartphones were first introduced. Specifically, while screen sizes were previously less than 3.5 inches (71.1mm × 53.3mm) as of 2010, they are often now more than 5 inches (101.6mm×76.2mm) as of 2015. Large screens have some advantages – on legibility for instance, by displaying characters and images larger; and by allowing users who have comparatively large fingers to point and tap the GUI easily. Whereas in terms of usability for users having relatively small hands (hereafter referred to as small-hand users), a large screen has the disadvantage that when they hold and operate smartphone with one hand, the area their thumb can reach is limited (Figure 1). It is possible that to touch the upper part or the edge of the left and right of a large screen with the thumb, though it requires the user to stretch their hand or to shift the position in which they are holding the device. Because of the risk of dropping a device like this, users change between one-handed operation and two-handed operation frequently depending on the purpose. For instance, we usually scroll on the screen in one hand and use the other hand to touch the search window or the back button in the top of screen. A two-handed operation referred to here is considered in on of the following two ways: (1) holding a device in one hand, and operate with the other hand, and; (2) holding a device in two hands from both sides, and operating with both thumbs.

There is ample research and several examples that assist one-handed operation of a large screen smartphone using the front touchscreen [1][7]. In these ways, a thumb is the only digit used in almost all operation. Based on this, we assume that using the fingers other than the thumb in the area except the front touchscreen is an effective way to improve one-handed operation. This is, as it were, role-sharing of the fingers.

In this paper, we introduce IndexAccess, a back-of-device (BoD) interaction system that enables users to reach and tap the whole of the screen easily, enhancing usability of a large

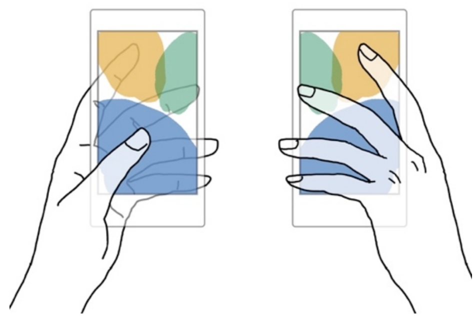


Figure 1: The possible area for each finger (thumb: blue; index finger: yellow, middle finger: green) to touch on the 5 inch smartphone.

smartphone during one-handed operation.

2 Related works

There is a lot of previous research on BoD interaction and they discuss a wide range of purposes.

Firstly, before smartphones first appeared, there are some studies that focused on the characteristic of feature phones and PDAs (Personal digital assistant) having keys and buttons on the front side of the device. Hiraoka et al. (2003) [4] put 12 keys on the back of a device to reduce the buttons on the front side and to make the screen larger. Okada et al. (2009) [5] allowed users to do pointing operations on a feature phone.

Secondly, some studies focused on the problem of occlusion when users touch the screen. Wigdor et al. (2007) [2] suggested LucidTouch, which provides feedback as if a finger on the back of the device can be seen through the device. Baudisch et al. (2009) [3] focused on the devices have a small screen device that is keenly influenced by the occlusion of the finger like a wearable device.

Thirdly, some studies focused on problems due to large screen devices. MagStick, by Roudaut et al. (2008) [6], is a cursor which moves in a direction that is opposite to the direction the thumb moved and is attached to a target. This allowed users to point at a target but not to select it. Conversely, TouchOver asserted by Onishi et al. (2014) [1], sends operations done in the lower area of the screen to the upper area to operate the lower area indirectly. This allowed not only pointing in the GUI but also tapping or selecting. In addition, there are studies that describe allowing easy one-handed operation by way of operating on screen directly. Karlson et al. (2008) [7] presented ThumbSpace, which reduced the size of GUI and display in the lower area of the screen. Tosa et al. (2013) [8] proposed LoopTouch, a device that has a touch sensor on the front and back of the device to operate GUI components that a user's thumb cannot reach. Hakoda et al. (2015) [9] presented a tactile interface system using a hole on the back of device. Finally, as an important advanced example, there is Apple's Reachability which is provided in iPhones from model 6 running iOS8 or above. When users tap the home button twice, the GUI moves downward a certain fixed length.

These studies address the problem of the unreachable area by moving the GUI and operating in the area that is reachable by the thumb. However, some of the moving GUI operations are done with the thumb. It increases the operation route of the thumb, which can lead to fatigue. Additionally, some of them fix the distance that users can move. There is a possibility that the fixed distance can not accommodate various hand sizes. However, in this present study, we suggest a more intuitive operation of movement.

3 IndexAccess

IndexAccess is an interactive system that assists to manipulate the GUI in the area where the thumb can not reach easily. There are two main features of this system.

Move GUIs downwards flexibly

As a solution to the unreachable area problem, we used a method that moves the GUI in the thumb's unreachable area downward and enables the user to touch them within the reachable area. In this way, users can tap the GUI as they see it. Moreover, in order to manage various hand sizes, we aimed that the users can move the GUI as far as they need flexibly.

Back-of Device interaction with index finger

As a way of implementing flexible moving, we adopted a BoD interaction with the index finger. In a related work [9], the index finger was used for simple detection of whether a hole in the back of device is covered or not. In this system, we detect the vertical distance that the index finger has moved with some sensors and link it with the distance that the GUI is moving. This way allows users to operate intuitively as if they touch the screen from the back of device and pull down the screen directly.

In other related works, the thumb does all operation of moving the GUI as well as regular input (e.g., tapping a button), the thumb's tasks are increasing. Therefore, such a role-sharing of operation between all of the fingers can reduce reliance on thumb movement, therefore reducing fatigue.

4 Prototype system

Figure 3 shows the system flow of IndexAccess. We implemented this prototype, which consists of a sensor module and a smartphone running our application. We used an iPhone 6 (dimension of device: 138.14mm x 66.97mm x 6.85mm, dimension of screen: 4.7inch (104.05mm x 58.5mm), resolution: 750 x 1334) as an example regarded as a large smartphone which can be difficult to use in one hand for the small-handed user.

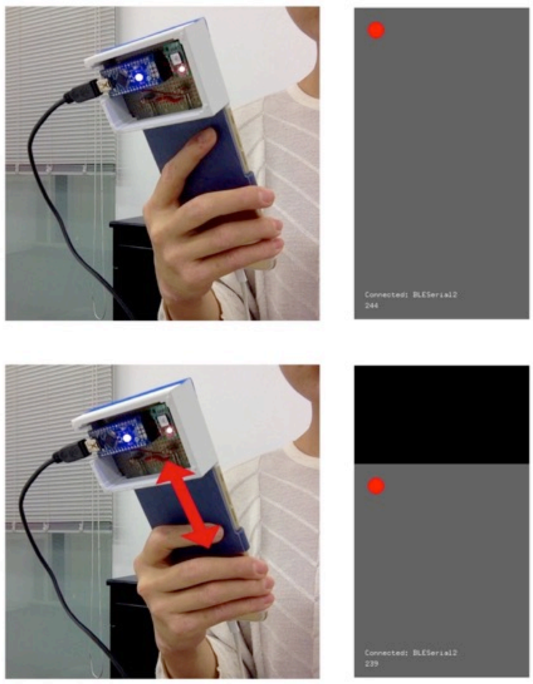


Figure 2: Moving of index finger on back of the device (left) and the GUI on the front screen (right).

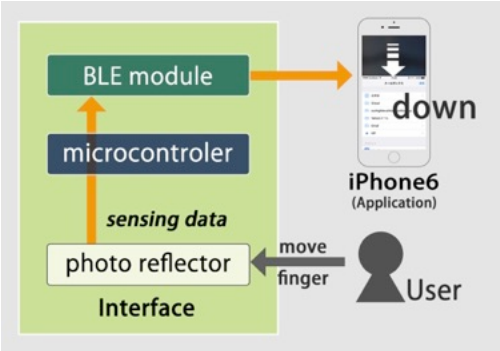


Figure 3: The system flow of IndexAccess.

4.1 Sensor module and Mounting tool

Figure 4 shows the circuit diagram of the sensor module. This module is consisted of a photo-reflective sensor (ROHM Corp.'s RPR-220) and a Bluetooth Low Energy (BLE) module (ASAKUSAGIKEN Corp.'s BLESerial2) and built on a universal circuit board (72mm x 47mm). We used the photo-reflective sensor to detect the position of the index finger on the back of the device because it was easy to implement. The data from the sensor was sent via the microcomputer to the iPhone 6 using BLE.

As shown in Figure 2, we attached this module to the back of the iPhone 6 with an original mounting tool that we modeled with 3D CAD software (Rhinoceros for Mac) and printed with a 3D Printer (Figure 6). Due to the characteristics of a photo-reflective sensor, the data we captured is not from measuring the distance of index finger movements but an absolute distance from the sensor to the index finger. Therefore, we designed this tool so as to make it possible to slide vertically and adjust the position of the sensor for each user. Additionally, we prepared two modules varying the position of the photo-reflective sensor. One (shown in Figure 5) has two photo-reflective sensors in a position closer to left and right, another has one sensor in the center of the width of the smartphone.

4.2 Application

We aimed to create an intuitive interaction where users feel as if they are touching the GUI directly and dragging it physically from the back of device. In this study, we demonstrated this BoD interaction with simple graphical feedback on the front screen as shown in the right side of Figure 7. We drew a rectangle the same size as the screen as a hypothetical GUI. We set coordinates (0,0) at the left upper corner and coordinates (320, 568) at the right lower corner on the iPhone 6's screen. This rectangle's Y-coordinate changes within the range of $0 \leq y \leq 370$ according to the data received from microcomputer. Thus, this interface moves downward from the start position but does not move upward. Additionally, this prototype system does not have the function of switching between ON and OFF, therefore the interface follows movement of the index finger on the back of device at all times.

5 Performance evaluation experiment

We conducted an experiment to investigate the operational performance of IndexAccess. This experiment consisted of performance check tests and a questionnaire about using a smartphone on a daily basis. In the tests, we asked participants to do a simple pointing task and recorded the time taken and accuracy rate. In addition, to compare the performance of IndexAccess and Apple's Reachability, we asked participants to do the same content and the same amount of tasks using both of the two systems.

5.1 Participants

Nine participants (five males and four females, aged 22-35) took part in this experiment. All participants use a smartphone everyday. Seven of the nine users were right-handed, the others were left-handed. The period they had used a smartphone varied from 21 to 84 months and the average was 46.4 months.

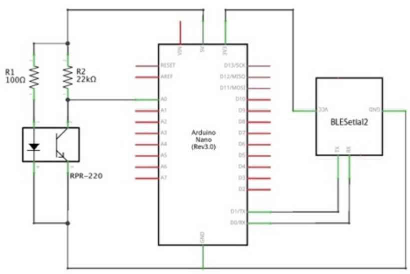


Figure 4: The sensor circuit diagram of the sensor module.

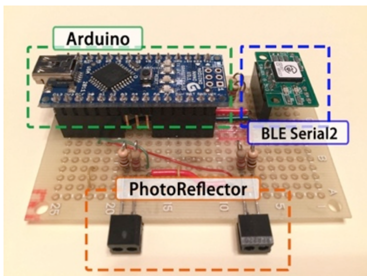


Figure 5: Sensor module built on the universal circuit board.

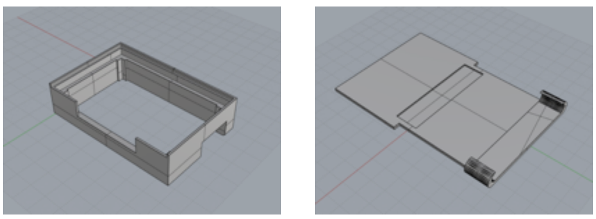
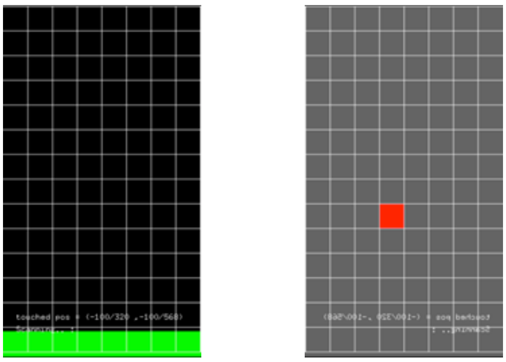


Figure 6: Jig modeled with 3D CAD

5.2 Apparatus

We used an iPhone 6 (dimension of device: 138.14mm x 66.97mm x 6.85mm, dimension of screen: 4.7inch (104.05mm x 58.5mm), resolution: 750 x 1334). We prepared an application for iOS specifically for this experiment and installed it on the iPhone 6. Figure 7 shows the GUI displayed on the front screen while participants did the tasks. The screen is divided into 112 cells consisting of 8 by 14 squares having one side of 7.3mm so that the screen is fully filled. This square is larger than that having one side of 7mm that is the size unaffected on accuracy by the size of tip of their thumb [10]. As shown in Figure 7, a large green rectangle button on the bottom of the screen is a start task button and a small red square is a target button.

In this experiment, we set the following two phases as one task, and 112 (cells) tasks as one session.



Inactive Phase Pointing Phase

Figure 7: GUI of the application for the experiment Inactive phase (left), Pointing phase (right).

Inactive phase (first time): In this phase, a start button appears on the bottom of the screen. When participants tap the button, the interface is switched to the pointing phase.

Pointing phase: In this phase, a target button appears. Participants tap the target button and the interface proceeds to the next task. The time from when the pointing phase GUI appeared to when the target button touched was recorded. We also recorded whether the user tapped the correct area or not. No matter whether they touched the correct area of the target or not, the phase went to the next stage.

Inactive phase (from the second time): After a 0.8 second delay, the start button appears again.

The target button appeared at a random cell for each task. In the experiment using IndexAccess, as mentioned previously, the interface follows the movement of the index finger at all times. Therefore, when participants touch the bottom of the interface, they should use their index finger to display the whole interface on screen. We set the start button on the bottom of the screen because we want participants to put the interface back into its original place so as to show the whole of the interface before the target button appears.

5.3 Procedure

User instructions

At first, we asked participants to sit down and hold the device in one hand as they would hold their own smartphone. In order to investigate realistic performance of the IndexAccess and Reachability, we instructed all of them to use the same holding position and integrate it the way they would normally hold such a device. In addition, we asked them not to shift the position if possible and rely on the function of IndexAccess and Reachability to do the tasks. Under these conditions, in cases where the area in which the target button appears is unreachable for their thumb (in spite of using IndexAccess or Reachability), we asked them to tap the point nearest to the target. We told them that we recorded the time from the start button touched to the target button touched and the correct-error of each pointing action. Accordingly, we told that they should not put an emphasis on performing quickly but with accuracy.

Experiment

Before beginning the main experiment, we created a practice session so as to allow the participants to get used to one-handed operation using IndexAccess and Reachability. In IndexAccess, during the practice session, they could move the module sensor vertically and decide the best position. After fixing that firmly, they started the main experiment.

In the main experiment, first they used IndexAccess and did the five sessions, and next they used Reachability and did the same number of sessions. The total number of tasks we required of them was 1120 (112 cells x 5 sessions x 2 systems). The time that this experiment took was 55-75 minutes for each participant.

5.4 Result

Some of the participants used their left hand to do the tasks. Therefore, we flipped the data of the participants horizontally.

Figure 8 shows the average pointing time and error rate with the depth of a color per cell on the screen. In the figure of the pointing time, the average pointing time is longer, the darker the color. We numbered each cells filled on the screen as in the left of Figure 8. In the figure of the error rate, the rate is higher for the darker the color it is. The average pointing time for all cells on the whole screen (cell IDs 1-112) using IndexAccess is 1188.28 milliseconds (SD = 259.83), and that using Reachability is 1114.41 milliseconds (SD = 167.07). Similarly, in the upper half part of the screen (cell IDs 1-56), the average pointing time using IndexAccess is 1408.67 milliseconds (SD = 320.00) and for using Reachability is 1529.13 milliseconds (SD = 235.71). In the lower half part (cell IDs 56-112), using IndexAccess is 975.62 milliseconds (SD = 282.43) and using Reachability is 714.25 milliseconds (SD = 114.60) (Figure 9).

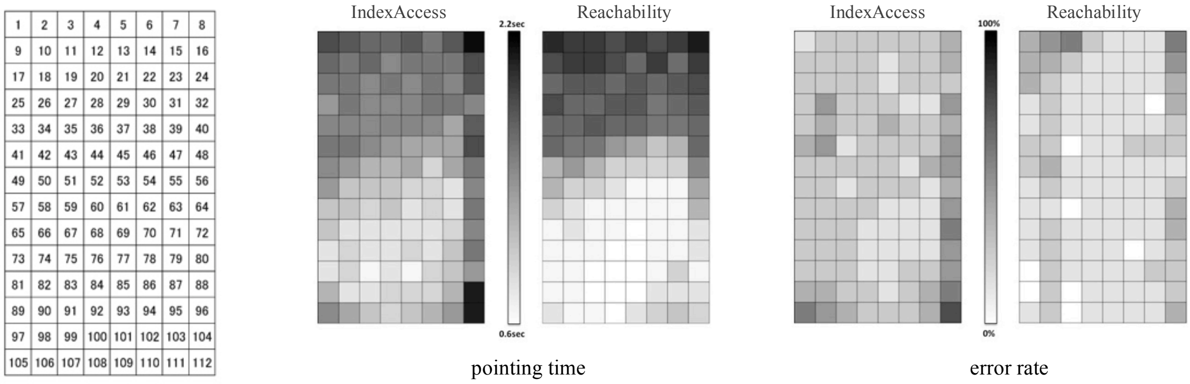


Figure 8: The ID of cells filled on the screen (left) and the result of the experiment: the data of each cells with depth of the color (center and right).

Figures 10 and 11 show the result of nine participants in each session using IndexAccess and Reachability. These graphs show the change of the average pointing time and error rate of each participant over the five sessions. The average pointing time means that the average time taken to tap the target button in each task. Through the five sessions, five participants had come to point at the target faster and more accurately. However, the other four were faster but increased the number of errors or were more accurate but slower. In the first session, the average of all participants was 1.3 seconds (SD = 2.5) and the error rate was 17.9 percent (SD = 12.0), and in the fifth session, the average time was 1.1 (SD = 1.8) second and error rate was 16.7 percent (SD = 12.7). Thus, the decrease of pointing time and error rate was 16 percent and 6.7 percent respectively.

We compared the 45 sessions (9 participants x 5 sessions) data in these two situations using IndexAccess and Reachability in following three areas: the whole area of screen, the upper half area, the lower half area. We used the paired t-test in the whole area, and Wilcoxon rank sum test in the upper and lower half area. From the calculation comparing the average pointing time on each cell on whole of the screen, there is no significant difference between them ($t(45) = -1.911$, $p = .062 > .05$). Similarly, the calculation of Wilcoxon rank sum test comparing that on the upper half part of screen shows that the average pointing time using IndexAccess is larger than that using Reachability significantly ($W = 689$, $p = 0.008695 < .01$); and on the upper half of the screen, that using IndexAccess is smaller than that using Reachability significantly ($W = 1634$, $p = 1.658e{-07} < .01$).

5.5 Discussion

According to Figure 10, in the first session, the data of a participant who took the longest time to point was approximately twice that of another participant who took the shortest amount of time to point. One reason for such a difference is that the participants had various hand-sizes and some of them did not match with our prototype because of the position of the photo reflective sensor which was fixed

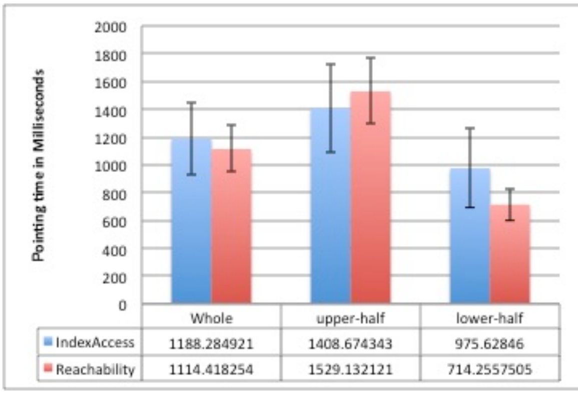


Figure 9: Average of the pointing time over the two systems and the three areas.

position on the sensor module.
From the result comparing IndexAccess and Reachability in the upper area and the lower area, IndexAccess is demonstrated to be more effective in the upper half area of the screen than Reachability. However, in the lower area, Reachability is estimated to be more effective. One reason for this result is that the posture of their hand while they touch the target appearing in lower area was difficult. As mentioned in the experiment category, our prototype did not have the function switching this interaction between ON and OFF. Therefore when they touched the target appearing nearby the lower edge, they should move their index finger up on the back of device to pull up the GUI.
In Figure 8, a rightmost line of both the pointing time and the error rate has particularly dark color on either case using either IndexAccess or Reachability. From this, it can be determined that this was the hardest area for the participants to operate speedily and accurately. We suggest that not only vertical movement of the GUI but also horizontal movement of the GUI is an effective way of addressing this.

6 Conclusion and future work

In this study, we proposed and implemented the IndexAccess system. It is based on the hypothesis that the problem of unreachable areas in one-handed operation of smartphones is

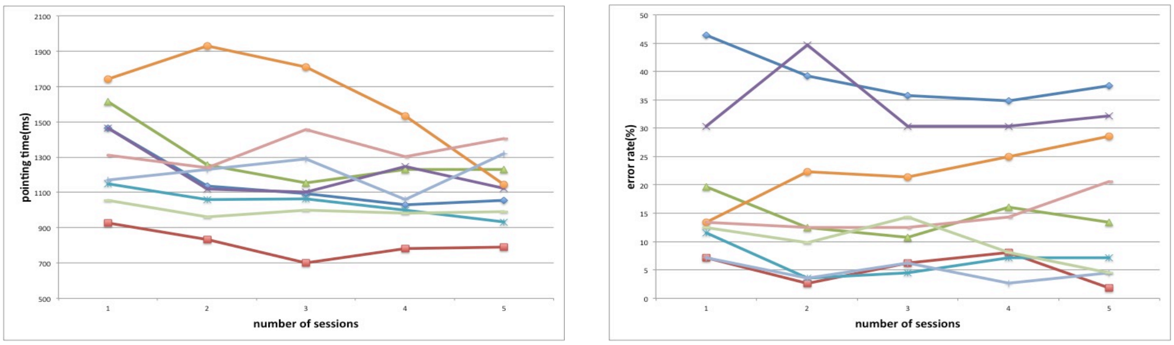


Figure 10: Nine participants' result in whole area of the screen (cell IDs 1-112)
The changes of the pointing time and error rate over the five sessions using IndexAccess.

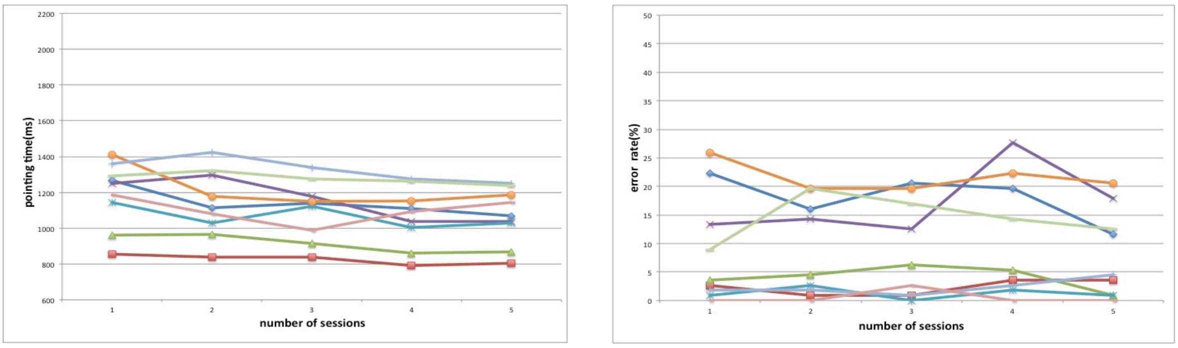


Figure11: Nine participants' result in whole area of the screen (cell IDs 1-112)
The changes of the pointing time and error rate over the five sessions using Apple's Reachability.

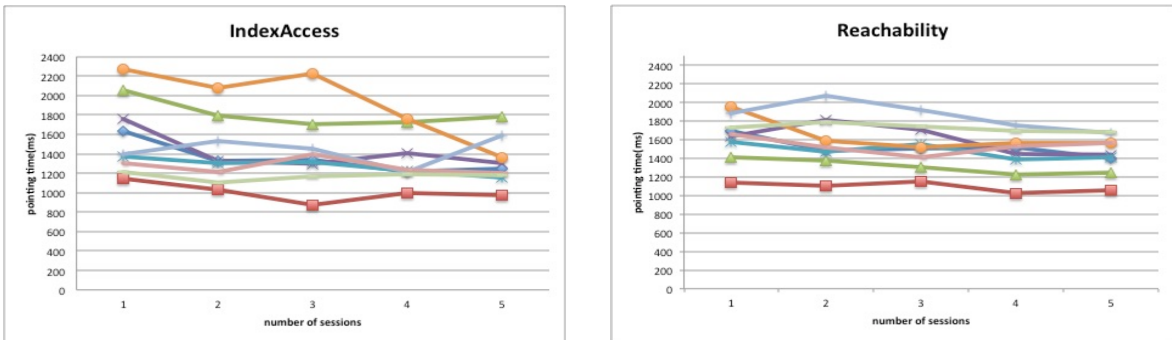


Figure 12: The result in upper half area (cell IDs 1-55)
The changes of the pointing time over the five sessions using IndexAccess and Reachability.

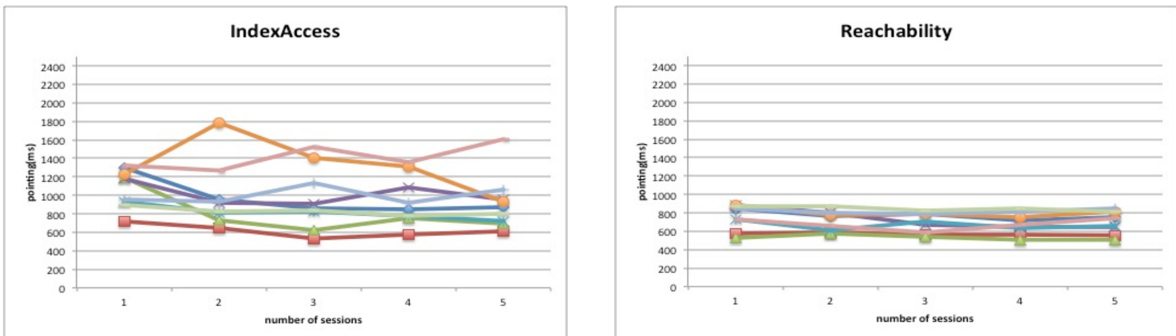


Figure 13: The result in lower half area (cell IDs 56-112)
The changes of the pointing time over the five sessions using IndexAccess and Reachability.

solved by using the fingers (excluding the thumb) on the back of the device and to move the GUI vertically on the screen by the BoD interaction.

We conducted an experiment to investigate the effectiveness of this system by comparing it with Apple's Reachability, which, like our system, moves the GUI vertically. From the results described above, we can assert two main points about this prototype.

The first point is that in the upper half area on the screen, there is a possibility that IndexAccess allows users to reach more rapidly with their thumb than Reachability. However, in the lower half part of screen, we left some problems with this prototype. Secondly, the area unreachable with the thumb is not only the area near by the top of the screen but also the right and left edge of the screen. Additionally, the result in the questionnaire we carried out at the same time as the experiment, all the participants answered the function moving the GUI horizontally may effective.

As immediate future work, we will implement another prototype using a touch panel in order to control the moving and stopping more easily, and will also add a function to move the GUI horizontally.

References

[1] Onishi, K., Shizuki, B., Tanaka, J., *TouchOver: Investigation of Transferring Touch Events for Controlling a Mobile Device with a Large Touchscreen*, In WISS 2014, Japan Society for Software Science and Technology, pp.85-90. (in Japanese)

[2] Wigdor, D., Forlines, C., Baudisch, P., Barnwell, J., Shen, C., *LucidTouch : A see-through mobile device*, Proc. UIST '07 (2007), 269-278.

[3] Baudisch, P., Chu, G., *Back-of-device interaction allows creating very small touch devices*, Proc. CHI'09 (2009), 1923-1932.

[4] Hiraoka, S., Miyamoto, I., Tomimatsu, K., *Behind Touch: Backside key with tactile sense interface for mobile phones*, IPSJ, Vol.44, No11, pp.25202527 (2003) (in Japanese)

[5] Okada, N., Sano, S., Terada, T., Tsukamoto, M., *One hand pointing with touchpad on back side*, IPSJ SIG Technical Report, 2009-HCI-132.

[6] Roudaut, A., Huot, S., Lecolinet, E., *TapTap and MagStick : Improving One-handed Target Acquisition on Small Touch-screens*, Proc. of AVI '08, pp. 146-153, 2008.

[7] Karlson, A. K., Bederson, B. B., *One-handed Touchscreen Input for Legacy Applications*, Proc. CHI'08 (2008), 1399-1408.

[8] Tosa, S., and Tanaka, J., *LoopTouch: One-handed operation technique using the screen looping on mobile devices*, In Interaction 2013, IPSJ (2013), 175-182. (in Japanese)

[9] Hakoda, H., Fukatsu, Y., Shizuki, B., Tanaka, J., *Back-of-Device Interaction based on the Range of Motion of the Index Finger*, Proc. OzCHI'15 (2015), 202-206.

[10] Matsuura, Y., Go, K., *Behavioral Characteristic of One-handed Thumb Operation of Small Touch Screen Device*, IEICE Technical Report ITS2006-86, IE2006-271 (2007-02)