Back-of-Device Interaction based on the Range of Motion of the Index Finger

Hiroyuki Hakoda, Yoshitomo Fukatsu, Buntarou Shizuki, Jiro Tanaka
University of Tsukuba, Japan
{hakoda,fukatsu,shizuki,jiro}@iplab.cs.tsukuba.ac.jp

ABSTRACT

We show a back-of-device (BoD) interaction based on the range of motion of the index finger to improve the usability of a touchscreen mobile device held in one hand. To design this interaction, we conducted two experiments to investigate the range of motion of the index finger on the back of mobile devices. On the basis of those results, we designed a prototype system that has a hole in the back, where users perform our BoD interaction by covering the hole with their index finger. This design provides them with the tactile feedback provided by a hole, and allows users to naturally control the front and back simultaneously.

Author Keywords

One-handed interaction; pointing; motor skill.

ACM Classification Keywords

H5.2. Information interfaces and presentation : User Interfaces — Input devices & strategies; Interaction styles.

INTRODUCTION

Since users of a touchscreen mobile device expect to use it with one-handed thumb input (Karlson and Bederson, 2006), although the interaction space on a touchscreen for one-handed thumb is limited, expanding the space would significantly improve a mobile device's usability. One promising approach to expand the space is elaborating touch gestures (e.g. MicroRolls (Roudaut et al., 2009), The Fat Thumb (Boring et al. 2012), and Bezel Swipe (Roth and Turner, 2009)). This approach has a great advantage where these touch gestures can be added without any additional hardware (i.e., the gestures can be detected with just the touchscreen).

Moreover, using additional modalities and channels is another approach to expand the space and has also been explored extensively. For example, ForceTap and ForceDrag (Heo and Lee, 2011, 2012) use pressure in addition to touch. Clip-on Gadgets (Yu et al., 2011) and ExtenstionSticker (Kato and Miyashita, 2015) are physical controllers that extend the interaction area of a multi touchscreen with conductive materials to map the user's input on the controllers to touch points on the edges of touchscreens, each of which also can be used to extend the interaction space with one-handed thumb use.

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Back-of-device (BoD) interaction, which uses the back of a mobile device as an interaction space, follows the above approaches. This approach is attractive because the interaction itself is inherently occlusion-free since the fingers used for the interaction do not cover the touchscreen. Moreover, the interaction can be used solely and in combination with conventional front-of-device interactions, and thus has potential to expand the space further.

The characteristics of one-handed thumb and interfaces designed on the basis of these characteristics have been extensively researched (Wang et al. 2013; Henze et al. 2011; Park and Han, 2010), as have the ones designed on the basis of the range of motions of the thumb (Takahama and Go, 2010; Kimioka et al., 2011). However, after reading the above literature, we found that BoD interaction still has much room to be explored. For example, if the range of motion of the index finger (hereinafter, the index finger's range) on the back can be revealed, BoD interaction based on this range will become designable.

Our goal is to investigate the index finger's range on the back of a touchscreen mobile device held in one hand, while the device is operated on its front. To achieve this goal, we conducted two experiments. The primary contributions of this work are: 1) the data of the index finger's range on the back of a device from the user studies, which help us better understand the characteristics of BoD interaction and serve as stems to design such interaction, and 2) a design of BoD interaction and its prototype system as an example to show how to use the data.

RELATED WORK

Previous research on BoD interactions showed their usefulness and applications. For example, Wigdor et al. (2007) and Baudisch et al. (2009) showed that BoD interaction resolves occlusion when users touch the screen. Kim et al. (2012) and Schoenleben et al. (2013) presented a text entry method on the back of the device. Löchtefeld et al. (2013) evaluated a hybrid front- and back-of-device interaction for target selection. Tosa et al. (2013) proposed LoopTouch, a device that has a touch sensor on the front and back of the device to manipulate GUI components that a user's thumb cannot reach. Xiao et al. (2013) presented a BoD interaction where a user covers a back-facing camera with her index finger. Seipp et al. (2014) utilized a user's pats of her fingers on the side and back of a mobile device, which are detected by using built-in sensors. BoD authentication is effective against shoulder surfing (De Luca et al., 2013; Leiva and Català, 2014). In our research, we focus on the index finger's range on the back and propose a BoD interaction depending on the range.

Motor skills of fingers in manipulating mobile devices and their applications have been researched. Specifically, the characteristics of one-handed thumb and input methods depending on its characteristics have been extensively researched (Wang et al. 2013; Henze et al. 2011; Park and Han, 2010). In addition, Colley et al. (2014) measured input performance of fingers and revealed that the comfort and perceived speed differed for each finger. Takahama et al. (2010) proposed a one-handed text entry method that provides a stable hold, where users can input text by rubbing the screen with a thumb on a touchscreen. Kimioka et al. (2011) proposed a text entry method adopting two arc-shaped keyboards for two-handed multi-touch gestures by using both thumbs on a tablet. Wolf et al. (2014) revealed that touch gestures on the front and back of a tablet have different characteristics. In contrast, we focus on the index finger's range on the back of the device.

Various manipulations for mobile devices have been devised by adding simple hardware. Sato et al. (2012) attached a translucent elastic hemisphere with embedded markers on a built-in camera and used an optical measurement method to measure three-axis force on the hemisphere. Spelmezan et al. (2013) added a physical button composed of a pressure sensor and a proximity sensor to recognize six kinds of gestures with a thumb for one-handed interaction. Corsten et al. (2015) and Fukatsu et al. (2013, 2014) added BoD tactile landmarks for eyes-free touch. Laput et al.'s Acoustruments (2015) are passive elements to expand input vocabulary of handheld devices by utilizing existing audio functionality. Xiao et al. (2014) enriched interactions on a smartwatch by using the watch face as a multi-degree-of-freedom mechanical interface. zSense (Withana et al. 2015) uses IR sensors and emitters to detect depth gestures. We attached IR sensors to detect gestures to a hole on a mobile device as a BoD interaction.

EXPERIMENT 1

We conducted an experiment to investigate the index finger's range under the assumption that the BoD interaction is solely used.

Participants and Apparatus

Six participants (five males and one female; age: 22–27) took part in this experiment. Five were right-handed, and the other was left-handed.

We used the following three different-sized mobile devices to investigate the relationship between the range and the size of devices, Small: iPhone 4S (115.2 x 8.6 x 9.3 mm), Medium: iPhone 5s (123.8 x 58.6 x 7.6 mm), and Large: iPhone 6 (138.1 x 67.0 x 6.9 mm).

Procedure

At first, we explained the purpose and the tasks. We also asked participants to use the index finger of the hand usually used to hold their own devices to perform the tasks (Figure 1). Then, we asked them to wear a thumb-

Figure 1: The participants were asked to hold the mobile device after turning it over in Exp1.

Figure 2: The thumb- and index finger-less glove that the participants wore in both experiments.

and index-fingerless glove (Figure 2) in order to avoid the device detecting touches by fingers other than the index finger (and the thumb in Exp2). After this, we handed out the device, and they turned it over to record touches on the back. Before the tasks, we instructed them to launch a memo application, and then input their names to explore the hand posture with which they could perform the tasks most easily. We also instructed them to maintain the hand posture as much as possible during the tasks.

After this, we asked them to touch the following three types of point/areas only once as the tasks. **Optimum point.** We asked them to place their index finger on the easiest point to touch (optimum point) on the back of the device while naturally touching the front. **Easy area**. We asked them to touch the area they could easily touch with their index finger (easy area), without struggling to stretch or bend their index finger, while touching the front of the device with their thumb naturally. **Possible area.** We asked them to touch the largest area where they could with their index finger (possible area) while maintaining the hand posture that was determined before the tasks. They performed the above tasks with the three types of devices. After all the tasks were finished, we asked them to complete a questionnaire. Each participant took about 15 minutes to complete Exp1.

Results and Analysis

Among the five participants, the left-handed participant used his left hand to perform the tasks. Therefore, we flipped the data collected from him horizontally.

Figure 3a shows the distribution of the optimum points. In this figure, the points of a color represent touch points by a participant. Each gray point represents the centroid of all the participants' optimum points under each condition. Because an optimum point is the easiest point to place a user's index finger when the user controls a device as usual, designing a BoD interaction using the area around the gray point in Figure 3a would make the interaction easy to use.

Figure 3b shows the distribution of the easy areas. Each colored convex hull represents the convex hull of the touch points by a participant. A color represents the same participant as in Figure 3a. We show the centroid of all the participants' optimum points as a gray point as a reference. Because an easy area is the area where a user can easily touch with the user's index finger while touching the front of the device with her thumb naturally, designing a BoD interaction using the easy area would make the combination of front- and back-of-device interaction easy.

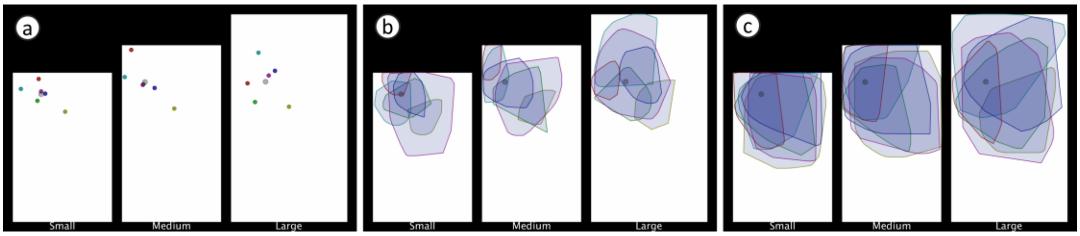

Figure 3: Distribution of (a) optimum points, (b) easy areas, and (c) possible areas. Gray points show centroids.

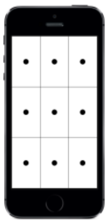

Figure 4: Positions of protrusions (black points).

Figure 5: A mobile device with nine protrusions.

Figure 6: Front condition: The user touches protrusions with his/her index finger, and the touchscreen with his/her thumb.

Figure 7: Back condition: The user touches protrusions with his/her thumb, and the touchscreen with his/her index finger.

Figure 3c shows the distribution of the possible areas. Each colored convex hull represents the convex hull of the touch participants' optimum points as a gray point as a reference.

These results suggest that, while the size does not affect the optimum point (their distances from the bottom-right corner were 73.3 mm, 79.9 mm, and 81.5 mm in Small, Medium, and Large condition, respectively), neither does the range (e.g., the easy areas were 403.1 mm^2, 439.0 mm^2, and 614.5 mm^2).

EXPERIMENT 2

Although Exp1 was designed to investigate the index finger's range when only BoD interactions are used, users should preferably be able to control the front and back of a mobile device simultaneously. Therefore, we designed Exp2 to investigate the index finger's range of the back of device while the thumb touches various places on the front, and the thumb's range of the front while the index finger touches various places on the back.

Participants and Apparatus

Six participants (five males and one female; age: 21–24) took part in this experiment. As before, five were right-handed and one was left-handed. The left-handed participant used his right hand in this experiment, because he answered that he operated his own mobile device with his right hand. None had ever used BoD interactions.

We used the same apparatus as in Exp1.

Procedure

The task was to touch the possible area in Exp1 while touching a protrusion on the back. We used a seal for decorating smartphones (5 x 5 x 0.6 mm) as a protrusion. We divided the screen into 3 x 3 grids (Figure 4) and attached a protrusion to the center of each grid (Figure 5). Participants wore the same glove as in Exp1.

We asked the participants to touch a protrusion, and then touch the possible area while touching the protrusion. Specifically, we instructed them to perform the task just by moving the index finger, not by changing the hand posture. They performed the above task for each of nine protrusions, two surface conditions (i.e., front and back shown in Figure 6 and Figure 7), and three types of mobile devices. After the tasks, we asked them to evaluate the usability of each condition by using a nine-point Likert scale (1 = strongly disagree, 9 = strongly agree) and to complete a questionnaire. We also measured the lengths of their hands and fingers. The participants took about 15 minutes to complete this experiment.

Results and Analysis

Figure 8 compares the results under the front condition with the results of Exp1. In all the device conditions, the protrusions which show the three highest usabilities are located near the optimum points. This means that the result of Exp2 are consistent with those of Exp1. Therefore, it is suggested that a BoD interaction would make the device easy to control by designing the interaction using the position of the optimum point obtained from Exp1 or the high usability position in Exp2.

Under the back condition, the protrusions showing usability above 5 (neutral) are located near the bottom (Figure 9). This result suggests that, in the case of manipulating a device on the back while manipulating it on the front, the interaction would be made easy by designing a BoD interaction using the bottom area.

PROTOTYPE SYSTEM

We implemented a prototype system for the Small condition as an example on the basis of our experimental results. This system consists of a smartphone case and a sensor module (Figure 10b). The case (61.7 x 118.2 x 13.8 mm), which we 3D-printed, has a hole (7 mm diameter, 2 mm depth) on the optimum point as shown in Figure 10a. To detect gestures to the hole, we placed a photoreflector (GENIXTEK Corp.'s TPR-105) because of its simple and easy implementation. The readings from the sensor are sent by a microcomputer (we used konashi (Matsumura et al., 2013) in our current implementation) via Bluetooth LE to an iPhone 4S.

We designed gestures to the hole, similar to Thumbs Up (Schmieder et al., 2013) that are touch and in-air gestures

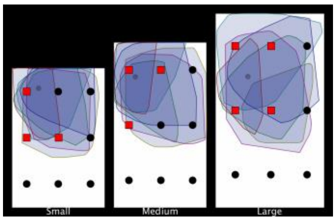

Figure 8: Optimum points (gray points) and possible areas (colored areas) in Exp1, and protrusions with the three highest usabilities (red squares) in Exp2 under the front condition (in the large device condition, four red squares are shown because there are two protrusions with the third highest usability).

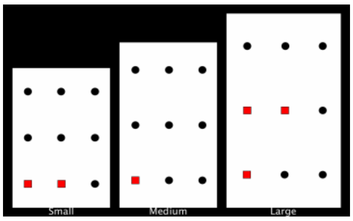

Figure 9: The protrusions with usabilities above 5 in Exp2 under the back condition (red squares).

around a front camera, as our BoD interactions. Specifically, users can COVER and PUSH the hole. With this design, the hole provides users with tactile feedback. We considered that the feedback compensates for the lack of visual feedback, and a hole is easy to cover concurrently with front-of-device interactions. Therefore, COVER is a suitable modifier (similar to the SHIFT key); PUSH is suitable to execute a system-wide command (similar to double-tapping a home button).

APPLICATIONS

Controller for large devices

We implemented Apple's Reachablity. In this application, when a user COVERs the hole, GUIs on the touchscreen move to the bottom Figure 11a); when s/he lifts his or her index finger up from the hole, GUIs go back to the previous positions. A user can control the device easily by moving GUIs to the positions s/he is able to touch during one-handed use.

Launcher for large devices

In this application, when a user PUSHes the hole, an application launcher launches (Figure 11b). This application allows a user to execute an application launcher quickly without manipulating the touchscreen.

Gesture macro

When a user PUSHes the hole twice, a recording mode starts. In this mode, s/he can perform any gestures (e.g., drag and swipe) while COVERing (Figure 11c2). Afterwards, when s/he PUSHes, the recorded gestures are replayed. For instance, a user can record a scroll gesture and activate the gesture multiple times easily by performing multiple PUSHes (Figure 11c3).

DISCUSSION

Although we used the optimum point as a place for the hole, the easy areas can also be used for BoD interactions. Specifically, areas of deep color shown in Figure 3 are candidates for holes. Moreover, Figure 8 also suggests that red squares suit BoD interactions.

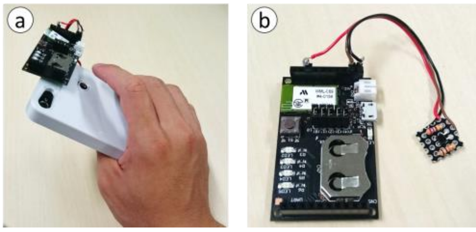

Figure 10: (a) A mobile device with our prototype system that consists of a smartphone case and (b) a sensor module.

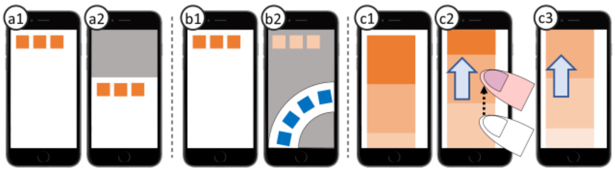

Figure 11: (a) Controller for large devices. (b) Launcher for large devices. (c) Gesture macro.

Naïve implementation will detect COVER when a user puts the device on the desk. To solve this problem, we implemented the prototype software not to detect COVER when readings from the sensor are constant.

In our experiments, we asked the participants to touch three types of point/areas (optimum point, easy area, and possible area) with their thumb or index finger. However, we are interested in examining not only simple touch but also other touch gestures, such as tap and flick. Therefore, we plan to evaluate accuracy and usability for those touch gestures in BoD interactions. Moreover, more participants must be employed to improve the reliability of our experiments. In addition, experiments involving various touch gestures other than touch (e.g., double taps and drags) will lead to further understanding of the characteristics of BoD interaction.

CONCLUSION AND FUTURE WORK

To explore further design space of BoD interactions, we conducted two experiments to investigate the index finger's range on the back. The results indicated that the index finger's range differs for each size of the devices. On the basis of the results, we implemented a prototype system that has a hole on the back. With this design, users can COVER and PUSH the hole, being provided with tactile feedback. We also implemented three applications using the prototype system.

Immediate future work will be to practically evaluate our prototype system. Accordingly, we will confirm whether our experimental results are valid. Moreover, our applications need to be evaluated in a real-world task.

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