Measuring Touch Bias of One Thumb Posture on Direct Touch-based Mobile Devices

Kangwook Lee
Department of Computer Science, KAIST
291 Daehak-ro
Yuseong-gu, Daejeon, Korea
chaximeer@kaist.ac.kr

Sangtae Kim
KAIST Institute for IT Convergence, KAIST
291 Daehak-ro
Yuseong-gu, Daejeon, Korea
expanne@gmail.com

Sung-Hyon Myaeng
Department of Computer Science, KAIST
291 Daehak-ro
Yuseong-gu, Daejeon, Korea
myaeng@kaist.ac.kr

CHI 2013 Extended Abstracts, April 27–May 2, 2013, Paris, France.
ACM 978-1-4503-1952-2/13/04.

Abstract
Direct-touch interactive surfaces become pervasive in our daily lives due to personal mobile devices such as smartphones. However, inaccurate target pointing on direct touch-based mobile devices, which occurs due to the ambiguity of the user-aimed point estimation from the finger contact region, often causes trouble for users. To understand this problem of direct-touch interactions, we conducted an experimental study where we explored the touch bias of one thumb posture on direct touch-based mobile devices. Moreover, we proposed a novel method of splitting a touch surface into several regions; this method enables an analysis of the touch bias according to angular and longitudinal criteria.

Author Keywords
Touch bias; Direct-touch interaction; One thumb posture

ACM Classification Keywords
H.1.2 [User/Machine Systems]: Human factors; H.5.2 [User Interfaces]: Input devices and strategies

General Terms
Human Factors, Experimentation, Measurement

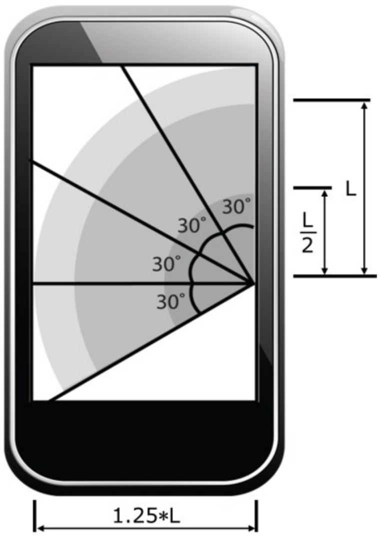

Figure 1. A touch surface can be divided by the angle conditions and the distance conditions.

	Mean	Standard deviation
Familiarity on touch	3.83	0.71
Thumb tip width	2.0	0.27
Thumb tip length	2.73	0.54
Thumb length	6.27	0.61

Table 1. The detailed statistics for the 12 subjects. The self-evaluated familiarity with touch interactions is measured on a 5 point scale and the unit of the other parameters is cm.

Introduction

In direct-touch interactive surfaces, a touch input is fed as an area form of the user's finger contact region, not as a point form. Thus, a process is necessary to estimate the user-aimed point from the area input of the contact region. However, due to the unsatisfactory performance of current user-aimed point estimation, it is still difficult to implement precise touch pointing regardless of user familiarity with direct-touch interaction.

To solve this practical problem of direct-touch interactions, we conducted an empirical study where we explored characteristics of touch bias on a direct touch-based mobile device, which is one of the most popular direct touch-based devices. Since one thumb posture is used most often for interactions with mobile devices [6], we investigate the touch bias of the one thumb posture as a first step. To put this into more detail, we studied the direct-touch bias of the one thumb posture on mobile devices by measuring gaps between the center points of the direct-touch contact regions and the target points. In the pursuit of the research goal, we designed an experiment to investigate on the touch bias of the one thumb posture on regions split by a novel method that considers both the user's ergonomic factor and the device's form factor. Moreover, we analyzed our experimental results from two perspectives, the direction and the size of the touch bias, in order to address the touch bias of each split region more clearly.

Related work

The traditional way to estimate a user-aimed point in direct-touch interactions is to extract the center point from the finger contact region. However, the contact region is often too large to estimate a user-aimed point from its center point. Thus, many user-aimed point estimation techniques that use finger or hand properties have been proposed.

Forlines et al. [1] indicated that two different types of finger contact regions, vertical contact and oblique contact regions, generate different contact area shapes. These differences cause different selection error rates. Their study only reports on differences between the two contact region types, however, there has been no follow up study to discuss target pointing precision or usability of the two contact region types. Moscovich et al. [2] proposed that hand gestures, finger layout, finger joint angle, and so on, could be considered as available interaction properties. Malik et al. [3] adopt finger orientation first. The system uses a pair of overhead cameras to track the entire hand of the user; the system then infers finger orientations accordingly. Wang et al. [4] proposed an algorithm that detects finger orientation from contact information by considering the dynamics of the finger landing process.

Furthermore, there has been a study to investigate the user's touch behavior on certain applications, including the one by Henze et al. [5]. Their investigation was based on an analysis of more than 100 million touch inputs which were collected by a game application. Azenkot et al. [6] explored touch behavior on soft keyboards when they were used with two thumbs, an index finger, and one thumb; they found that distinct patterns exist for input among those three hand postures.

Method of Study

Assumptions & Hypotheses

As we mentioned in the introduction, we focus only on investigating touch bias in a certain environment, the one thumb posture in direct touch-based mobile devices,

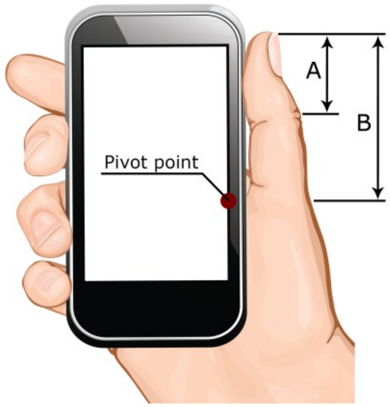

Figure 2. The thumb properties. A is the thumb tip length and B is the thumb length.

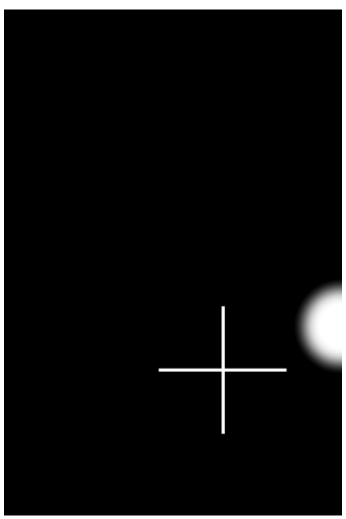

Figure 3. A running example of the experiment app. The white cross indicates the target point and the white circle on the right side is the pivot point.

which is the most often used position. Moreover, we assume that the user-aimed point is estimated according to the center point of the contact region, and that the touch bias is the bias between the center point and its target point. In addition, we defined the position of the user's carpometacarpal joint, which is a reference point for the sweeping movement of the user's thumb, as a pivot point. With these assumptions, we make the following hypotheses in order to determine the touch bias.

H_{A1}: Center point is biased by DPT(Distance between Pivot point and Target point).

H_{A2}: Center point is biased by APT(Angle between Pivot point and Target point).

Experiment Design
To examine the hypotheses, we design an experiment to consider the effects of DPT and APT on touch biases. As a first step, we propose a method to carve up a touch surface into distinct regions.

First, to consider effect of the distance factor, i.e. DPT, on touch biases, we split the distance made by the target points and the user's pivot point into 3 levels: [0, L/2), [L/2, L) and [L, 1.25*L], where L indicates the width of the touch surface. Since most direct touch-based mobile devices are designed to enable the one thumb posture, we mainly consider the device's form factor as a longitudinal parameter. In addition, we use iPod touch 4G as the test device where the value of L is 4.5 cm.

Second, to consider the effect of the angular factors, i.e. APT, on touch biases, we split the angle made by the target points and the user's pivot point into 4 levels: [-30°, 0°), [0°, 30°), [30°, 60°) and [60°, 90°]. We do not consider the angle between -90° and -30°, i.e. [-90°, -30°), for our empirical study because target points located in that angle range are almost impossible to touch directly without changing the pivot point. With these two criteria, a mobile device's touch surface can be split into 12 regions as shown in Figure 1.

For the experiment, we recruit 12 subjects, 8 men and 4 women. All the subjects are right-handers and direct touch-based mobile device users. The detailed statistics for the 12 subjects are shown in Table 1. Figure 2 shows the thumb properties used for subject statistics. The thumb tip length is the distance from the thumb's meta-carpophalangeal joint to the end of the thumb; the thumb length is the distance from the thumb's carpometacarpal joint to the end of the thumb; the thumb width is the longest horizontal distance of the thumb tip.

For the smooth progress of the experiment, we make an app that generates target points corresponding to 12 split regions; we store experimental records, including the coordinates of the target points and the pivot points, in a database. Figure 3 shows a running example of the app. In addition, the pivot point can be modified easily by dragging it to record the subject's actual grip.

To record the user's actual contact regions, we place a plastic film on our test device's touch surface and apply red ink to the subject's right thumb. After each experimental trial, the plastic film that contains the user's thumb print, which represents the contact region, is collected and replaced for the next trial. These steps are repeated 12 times to cover all of the 12 regions; we finally collect 144 plastic films for 12 regional conditions from 12 subjects.

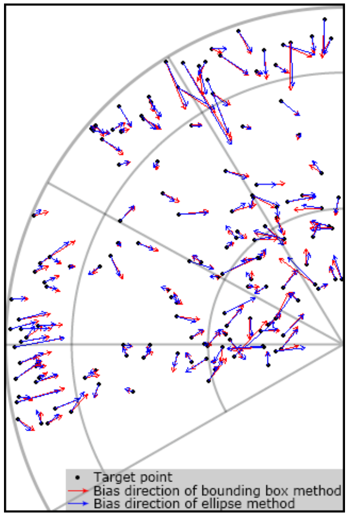

Figure 6. The directions of the touch biases, i.e. the directions from the target points to the extracted center points, for 144 experimental records.

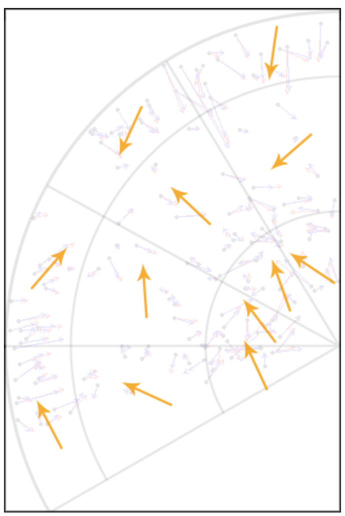

Figure 7. The general directions of the touch biases of the 12 regions.

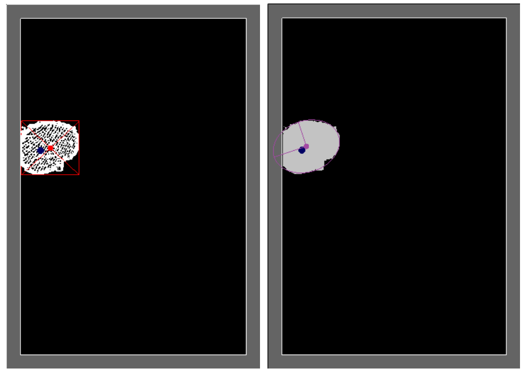

Figure 4. An example to demonstrate the image processing steps for an experimental record. The left shows the extracted center point by the bounding box method and the right shows the extracted center by the ellipse method.

To analyze the biases, we scan all 144 plastic films and extract contours of thumbprints from each film by image processing. Then we calculate the center points of the extracted contours using two different methods: One is a basic method that calculates the center point from the contour's out-bounding rectangle parallel to the x-axis and the y-axis. The other is an advanced method proposed in Pilu et al.'s work [7]; this method calculates the center point from the contour's least fitted ellipse. Figure 4 shows an example of these image processing steps.

In short, the whole procedure for the experiment can be summarized as shown in Figure 5.

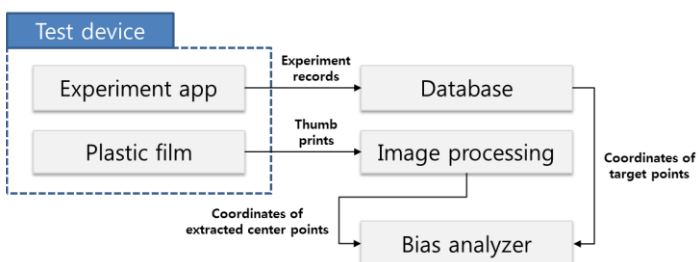

Figure 5. The experiment overview.

Results and Discussion

Results

To express the touch bias of the one thumb posture on a direct-touch interactive surface, we establish two perspectives to analyze the results: the direction of touch biases and the size of touch biases.

First, we analyze the direction of the touch biases. Figure 6 shows the directions of the touch biases, which indicate the directions from the target points to the extracted center points, for all 144 experimental records. Since we extract center points in two ways, the bounding box method and the ellipse method, there are two differently-colored touch bias directions for each target point. To investigate the directional characteristics of the touch biases in more detail, we estimate the general directions of the touch biases for each of the 12 regions with 2-dimensional vector space models, as shown in Figure 7. With the estimated general directions and the subjects' information, we can determine two facts. One is that the general directions of touch biases are built in a direction opposite to the pivot point when DPT is under the subject's thumb length; on the other hand, general touch bias directions move toward the pivot point when DPT exceeds the subject's thumb length.

Second, we analyze the size of the touch biases. To measure the size of the touch biases, we adopt DCT(Distance between Center point and Target point) as measurement. Table 2 and Figure 8 show the average size of the touch biases for the 12 regions. The regions are represented by their angle conditions and distance conditions, for which 0=[-30°, 0°], 1=(0°, 30°], 2=(30°, 60°], 3=(60°, 90°] in terms of angle and 0=[0, L/2), 1=[L/2, L), 2=[L, 1.25*L] in terms of distance.

(Unit: pixel)

Region	Bounding Box	Ellipse
00	18.22407	18.9263
01	9.170539	5.309184
02	13.76258	14.42784
10	15.19257	13.94537
11	11.39987	8.998738
12	9.424793	9.425902
20	9.528719	10.59959
21	8.425021	8.213978
22	14.40942	14.38743
30	10.54535	8.955751
31	13.60835	14.29194
32	20.94156	16.00483

Table 2. The average size of the touch biases for the 12 regions.

Under the DPT based view, the average size of the touch biases can be sorted as follows: distance condition 1 < distance condition 0 < distance condition 2, i.e. (L/2, L] < [0, L/2] < (L, 1.25*L]. On the other hand, under the APT based view, the average size of the touch biases can be sorted as follows: angle condition 1 < angle condition 2 < angle condition 0 < angle condition 3, i.e. (0°, 30°], (30°, 60°], [-30°, 0°], (60°, 90°].

In addition, based on Holz et al.'s idea [8], we make an aimed point estimation model, Ellipse_Mod, which translates the center point extracted by the ellipse method to a +20% position on the major axis of the extracted ellipse. The average size of the touch biases caused by the two center point extraction methods and by the proposed estimation method are shown in Table 3.

Notice that we do not attach results of two-way repeated measures ANOVA because the quantity of experimental data is insufficient to derive a statistical analysis.

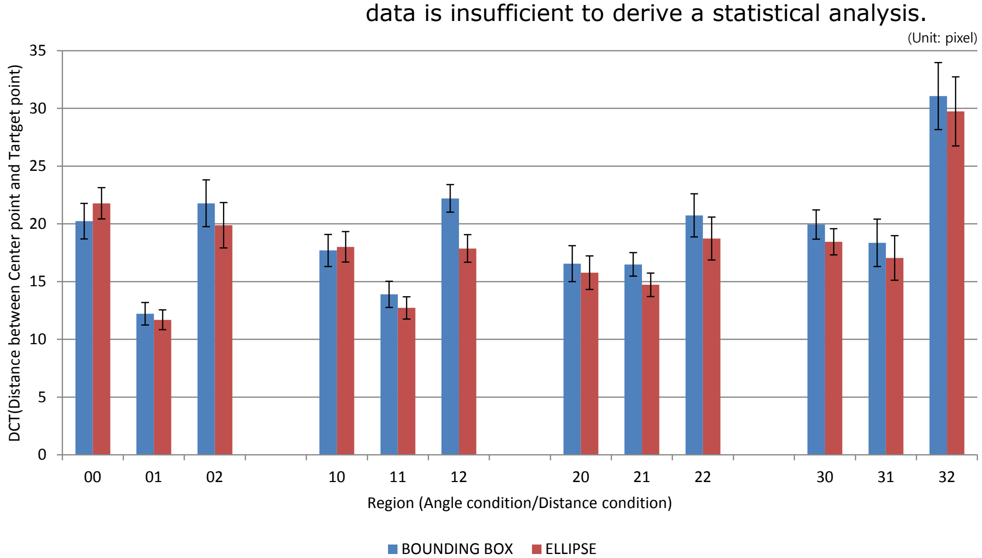

Figure 8. The average size of the touch biases for the 12 regions. The error bars show standard errors.

Discussion

For convenience in explanation, we define a new term, "relax point", to indicate the position of the thumb's tip when a user holds a device without any tension on his or her thumb.

From the analysis of the biased directions, we can obtain the insight that the general direction of the touch bias is formed in the way of relaxing the thumb tension. In other words, the general directions seem to be moving forward to the relax point.

On the other hand, from analysis of the size of the touch biases, we can obtain another insight, that the size of the touch biases is affected by the positional relationship between the relax point and the target points. The average size of the touch biases for the 12 regions seems relatively small in the relax point in nearby regions; on the other hand, it is relatively large in distant regions. In other words, it seems that thumb tension affects the size of touch biases.

We think these findings are related to Karlson et al.'s implications [9]. They found that users feel more comfortable in touch interactions on regions close to the center of a touch surface. Moreover, some previous works [5, 6] indicated that the same tendency appeared in their experimental results. With our empirical study results, it is possible to say that a user's physical comfort affects the touch bias in one thumb posture.

Conclusions and Future work

In this paper, we investigate the touch bias of the one thumb posture on direct touch-based mobile devices. We conduct a thorough empirical study to collect the actual touch contact regions for 12 regions on a touch surface;

(Unit: pixel)

	Avg. Touch bias (DCT)
Bounding Box	19.2611
Ellipse	18.0310
Ellipse_Mod	15.8137

Table 3. The average size of the touch biases caused by the two center point extrction methods and by the proposed estimation method.

these regions are divided by their positional relationships to the pivot point. Then, we analyze the touch biases on collected experimental records in consideration of two criteria: the direction and the size of touch bias. Moreover, we produce some ergonomic insights from the analysis, which might lead to a generalization of the touch bias.

We will continue our research in two ways: supplementary research and applications.

As we mentioned in the results and discussion section, the number of experimental records used in this pilot study is insufficient to derive a statistic basis. Thus, we will underpin our findings with reinforcing experimental trials, while augmenting our research for such other postures the index finger posture and two thumbs posture, in order to propose a fully-complete bias model for direct-touch interactions on mobile devices. Moreover, we will also apply our findings to applications. We will study these matters in order to develop a better solution to the estimation of a user-aimed point from a contact region. One of the ideas that have been materialized from this study is the use of the major axis of the ellipse, which is extracted from the fingerprint, to predict the orientations of the touch inputs. By predicting the orientations, the accuracy of aimed point estimation can be improved. Another application idea is to make a typo model for direct touch-based mobile devices with a consideration of the touch biases corresponding to certain hand postures. We expect that the typo model will be able to reduce the error rate for text entries on soft keyboards.

Acknowledgements

This research was supported by the Ministry of Knowledge Economy (MKE, Korea) and National IT Industry Promotion Agency (NIPA, Korea) [NIPA-2012-H0301-12-3005, Information Technology Research Center (ITRC) support program]. We thank members of KAIST Institute for IT Convergence for discussion and experiment participation.

References

[1] Forlines, C., Wigdor, D., Shen, C., and Balakrishnan, R. Direct-touch vs. mouse input for tabletop displays. *Proc. CHI 2007*, ACM Press (2007), 647-656.

[2] Moscovich, T. and Hughes, J.F. Indirect mappings of multi-touch input using one and two hands. *Proc. CHI 2008*, ACM Press (2008), 1275-1284.

[3] Malik, S. and Laszlo, J. Visual touchpad: a two-handed gestural input device. *Proc. ICMI 2004*, ACM Press (2004), 289-296.

[4] Wang, F., Cao, X., Ren, X., and Irani, P. Detecting and leveraging finger orientation for interaction with direct-touch surfaces. *Proc. UIST 2009*, ACM Press (2009), 23-32.

[5] Henze, N., Rukzio, E., and Boll, S. 100,000,000 taps: analysis and improvement of touch performance in the large. *Proc. MobileHCI 2011*, ACM Press (2011), 133-142.

[6] Azenkot, S. and Zhai, S. Touch behavior with different postures on soft smartphone keyboards. *Proc. MobileHCI 2012*, ACM Press (2012), 251-260.

[7] Pilu, M., Fitzgibbon, A.W., and Fisher, R.B. Ellipse-specific direct least-square fitting. *Proc. ICIP 1996*, IEEE Press (1996), 599-602.

[8] Holz, C. and Baudisch, P. Understanding touch. *Proc. CHI 2011*, ACM Press (2011), 2501-2510.

[9] Karlson, A.K., Bederson, B.B., and Contreras-Vidal, J.L. Understanding One Handed Use of Mobile Devices. *In Lumsden, J. (ed.) Handbook of Research on User Interface Design and Evaluation for Mobile Technology*, Idea Group Reference (2007), 86-101.