Touch Accessibility on the Front and the Back of held Tablet Devices

Katrin Wolf[1], Robert Schleicher[2], Michael Rohs[3]

[1]Stuttgart University, [2]Technical University Berlin, [3]Leibnitz University Hannover
Katrin.wolf@acm.org, robert.schleicher@tu-berlin.de, michael.rohs@hci.uni-hannover.de

Abstract. Digits cannot reach the entire interaction areas of hand-held tablet through direct touch. This paper explores which areas are accessible for direct touch on the front as well as on the back of tablets. The insights gained can serve as base for interactions designers to place GUI widgets, highlight areas that are hardly touchable, and thus, motivate further research on indirect pointing techniques for touch interactions.

Keywords: Touch; tablet; accessibility; back-of-device; biomechanics.

1 Introduction

Direct touch is the dominant paradigm for touch interaction. With the rise of tablet devices, a new form factor of mobile devices is challenging interaction designers as the different size and weight fundamentally change the requirements on ergonomic interaction design compared to intensively investigated mobile phone interaction. A symmetric bimanual grip while holding a tablet in landscape orientation was recommended to be most appropriate (Oulasvirta et al., 2013) for enabling the ergonomic usage of tablet devices. Beyond common touchscreen interaction, that grip enables also back-of-device interaction with tablet-sized devices, as e.g. proposed by Wigdor et al. (2007) and Hincapié-Ramos et al. (2014).

The accessibility of interaction areas on the touchscreen and on the back of the device is limited through the length of the digits while tablets are held with two hands. Odell and Chandrasekaran (2012) found that the center of tablets cannot be reached through direct touch while tablets are held with two hands. Insights into the accessibility of tablets' surfaces are fundamental for designing touch interfaces and in particular for placing widgets. Thus, locations that are touchable while a tablet is held with two hands, considering the front and comparing it's accessibility with the back of the device, are explored in the presented paper.

adfa, p. 1, 2011.

2 Related Work

The act of grasping (i.e., prehension) has been widely studied (Jones and Lederman, 2006; MacKenzie and Iberall, 1994), but research that aims to understand ergonomics of touch interaction while people grasp objects has just begun. Touch accessibility for mobile phones was investigated in order most ergonomic thump poses (Trudeau et al., 2012); and for areas out of reach, alternative pointing techniques were developed (Karlson and Bederson, 2007; Roudaut et al., 2008; Kim et al., 2012). Different form factors result in different ergonomic interface requirements; and research on accessibility of the interaction areas of tablet devices is rare. Odell and Chandrasekaran (2012) investigated interaction areas of the symmetric two-handed grip for tablets' touchscreens. Participants were asked to draw with their finger paint on paper attached to a tablet's touchscreen while holding it with two hands. No paint was drawn in the center of the tablet. Thus, Odell and Chandrasekaran concluded that the center of the tablet is not reachable. They provided no precise dimensions for the accessible touch areas; and the interaction areas are just roughly defined. For back-of-device interaction to our best knowledge no research on touch accessibility has been done.

3 Method

To find out to which extent users are able to touch both, the front and the back of a tablet with each single digit while holding a tablet, a user study has been conducted to record the areas of a tablet's surface that can be touched.

3.1 Design

17 participants, 9 female and 8 male, aged between 13 and 57 years (mean=30, SD=11) that volunteered in the experiment were asked to solve tasks with an interactive prototype. A 5x2 within design with repeated measurements was used. The dependent variables were digit and hand. The independent variables were amount of touched pixels, x-positions and y-positions of touch events, handedness, and digit length to analyze if the length of a digit influences the position of the area that can be reached.

3.2 Task

The participants were instructed to hold the device in landscape format using both hands in a symmetrical grip (Figure 1). During that time participants were standing. The task was to draw a large as possible black shape on a blue background through touch. Each digit should be used, starting from the touch position where the digits were resting while holding the tablet with two hands. The participants were solving that task with the thumbs on the front and with all remaining fingers separately on the back of the device. This was repeated five times for each finger of both hands. During the task, the grasp should not be re-adjusted, while rotations of the hand root were allowed.

3.3 Apparatus

The interactive prototype consisted of an application that was implemented on an ASUS Eee Pad Transformer TF101 with a screen size of 1280x742 pixels (without bottom menu bar). The entire device has the dimensions of 27.1cm x 17.1cm. The bezels are 20mm (horizontal top) and 26mm (vertical). During the tasks, the touch events were recorded in logfiles. Moreover, a screenshot was saved after finishing each task. When drawing with the thumb, the device was held in the common way with the screen facing the user for allowing the participants to see what regions they have been touched (Figure 1, left). For recording the touch events of the fingers that naturally were placed at the back of the device, the device was flipped so that back-side was facing the users (Figure 1, right). To give the visual feedback about the areas that were touched, the drawing application was presented on an external screen from a laptop that was connected via Bluetooth with the tablet.

Fig. 1. Apparatus for recording the accessible areas for each thumb and finger.

3.4 Measurements

The position of a touched pixel is assumed to influence its reachability. The positions of touch events on the tablet were recorded in logfiles as well as the number of deleted pixels per digit. With 17 participants, two hands, five trials per hand and per digit, this amounts to a total of 850 data units. Handedness and demographic data were recorded in a questionnaire. Moreover, the length of each finger and thumb of the right and the left hand of each participant were measured. The thumb was measured from its second joint counted from the tip and the fingers were measured from the joint at the palm like it has been done the ergonomic data collection of Lange and Windel (2006). After each trial the image that showed the deleted pixel area (black area on the blue screen shown in Figure 1) was saved.

3.5 Procedure

After an introduction, the participants solved the drawing task five times with each digit per hand. Nine of the participants started with their dominant, eight with the other hand. All participants interacted with the device in standing position. After completing the tasks, the participants filled in a demographic questionnaire.

4 Results

The accessible area was described through: size, position, and through the minimal and maximal distances from the edges (minX, minY, maxX, maxY) measured in pixels to be the distance from the top and the left screen border as well as through the range of the shape along the x- and y-axis. The ranges between the minimal and maximal distances from the edges were calculated through subtracting both distances (rangeX=maxX-minX, rangeY=maxY-mixY).

The means and standard deviations of the dependent variables per digit are presented in Table 1 (without distinguishing between hands as hand was not significantly influencing the variables, as described below).

	pixel	minX	maxX	rangeX	minY	maxY	rangeY
	thumb						
mean	61539	12	240	229	168	612	444
SD	3509	9	11	9	10	8	14
	index finger						
mean	58650	40	257	217	140	547	408
SD	3545	9	11	9	10	8	14
	pixel	minX	maxX	rangeX	minY	maxY	rangeY
	middle finger						
mean	60262	71	302	231	188	594	406
SD	3545	9	11	9	10	8	14
	ring finger						
mean	50354	71	288	217	291	648	357
SD	3544	9	11	9	10	8	14
	little finger						
little	39455	61	245	184	362	683	323
	3507	9	11	9	10	8	14

Tab. 1. Means and standard deviations for the dependent variables pixel, rangeX/Y, minX/Y and maxX/Y for the independent variable digit (in pixels).

ANOVAs were used to show whether hand or digit type had a significant influence on the touch positions that could be reached per digit. Repeated measure ANOVAs with *hand* and *digit* as within-subject factors using a 5% significance level showed a significant difference for the dependent variable pixel ($F_{4,240}$=7.355, p<0.001), rangeX ($F_{4,269}$=5.751, p<0.001), minX ($F_{4,325}$=7.818, p<0.001), maxX ($F_{4,229}$=8.476, p<0.001), rangeY ($F_{4,262}$=12.786, p<0.001), minY ($F_{4,243}$=74.592, p<0.001) and maxY ($F_{4,243}$=35.093, p<0.001) only for the factor *digit*. Thus, while the type of *digit* (index, middle, ring, little finger or thumb) had a significant influence on deleted pixels and deleted area parameters (see Figure 2); the *hand* the area was deleted with did not.

Regarding the *hand*, no significant results were observed for any of the parameters pixel, rangeX, minX, maxX, y-range, minY, and maxY, as the *p*-value was always equal or higher than 0.673. Moreover, no significant interaction effect of *hand***digit* was found for the dependent variable pixel, which would otherwise indicate that a certain *digit* performed better with a certain *hand*, for instance the dominant one which may have been expected.

Sidak-corrected pairwise comparisons indicated significant differences for deleted pixels per *digit* only between little finger vs. thumb, index finger, and middle finger (see Figure 2). The widths of the deleted areas (rangeX) differed significantly for the little vs. thumb, middle, and ring finger. The deleted areas showed significant different heights for thumb vs. ring and thumb vs. little finger, and also for little vs. index finger and little vs. middle finger.

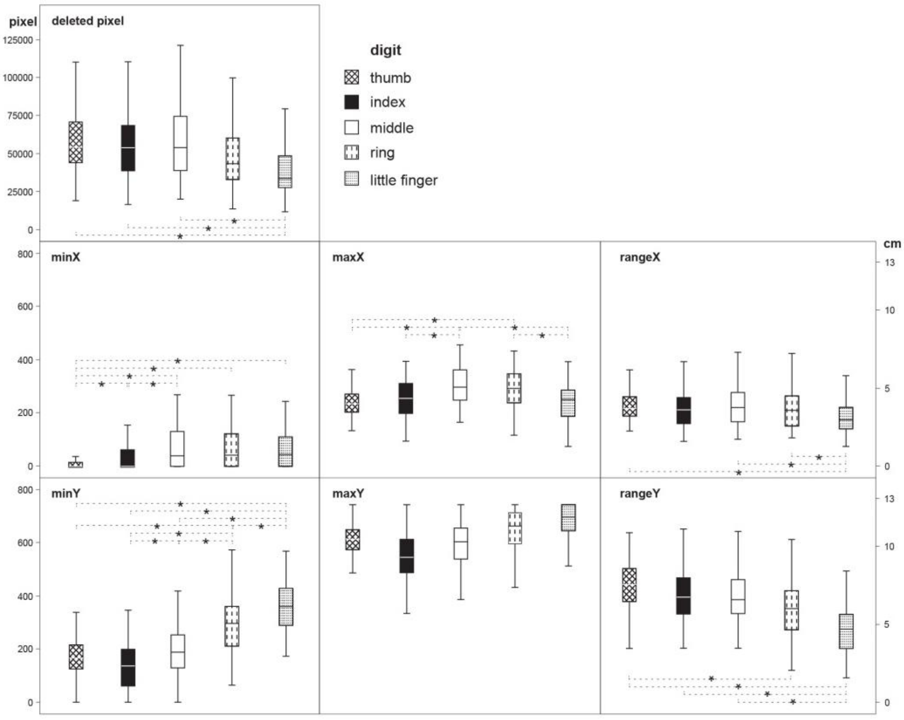

Fig. 2. Boxplots for the dependent variables: sum of deleted pixels, distance of access areas front the edges (minX, maxX, minY, maxY) and range between min & max. Significant differences are marked with *.

The post-hoc tests showed that the averages of the minimal distance of the deleted areas from the vertical edges (minX) differed significantly between the thumb and all fingers. Moreover, the areas that were deleted with the index and middle finger differed significantly in their average closeness to the vertical edge. The furthest points from the vertical edges that were touched with each digit were measured with the variable maxX, which was significantly different between the thumb vs. middle and ring finger.

The average distances of the deleted areas from the horizontal top edge showed significantly different results between ring finger and all others, also between little finger and the rest as well as vs. index and middle finger. No significant difference was found for the closeness of the deleted areas to the bottom edge (maxY). Thus, touch accessibility for all digits seems not to vary horizontally.

The saved images that show the deleted pixels were used for generating heatmaps by putting the black areas with a transparency level of 4% per layer one above the other (Figure 3). The heatmaps for each digit have curved borders towards the vertical middle of the tablet. Moreover, the heatmaps provoke the suggestion that the device bezel was touched as well because the shape of the heatmap appears to be cut on the vertical screen borders. However, that data was not recorded in the logfiles; this trend is also shown in the floor effects of the boxplots of minX for thumb and index finger.

The middle area of the tablet remained untouched. We analyzed if the digit length influences the degree of tablet accessibility per digit. For that comparison, the medians of all participants' digit lengths are used (thumb: median=6.2cm, SD=0.4cm; index finger: median=7.8cm, SD=0.6cm; middle finger: median=8.3mm, SD=0.7cm; ring finger: median=7.9cm, SD=0.7cm; little finger: median=6.4cm, SD=0.5cm). For reaching positions of maximal distance to the device edges, digits of the grasping hand have to be stretched. The maximal reachable distance at the touchscreen was equal 1.10 time the thumb's length. The maximal distances at the back of the device are for the index finger 0.93 time its length, for the middle finger 0.95 times its

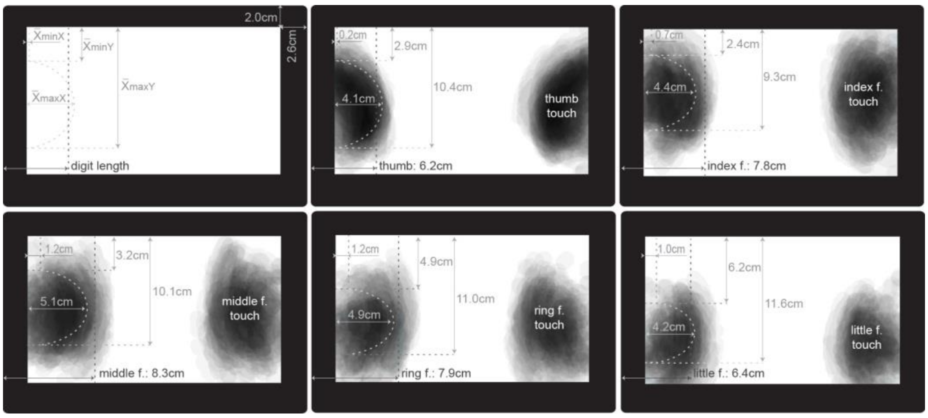

Fig. 3. Touch areas per digit, incl. means ($\bar{x}$) of minx, maxX, minY, manY, and median of digit length. The areas for back-of-device touch are presented in see-through view.

length, for the ring finger 0.95 times its length, and for the little finger 1.06 times its length. Touching very close areas requires users to flex the joints of the digits. The areas that are very closest to the device edge (and to the palm) are less often touched than those a bit further away. In summary, positions, which are located at minimum a bit further away than the vertical bezel as well as at maximum a as far away as the digit's length are accessible for direct touch while grasping a device.

5 Discussion

5.1 Accessing the touchscreen

The results presented here confirm the findings of Odell and Chandrasekaran that the center of tablet touchscreens is not accessible with grasping hands. Moreover, our results show that the limit of reachability is defined by the digits' length. For positions very close to the vertical edges, our findings are different from those of Odell and Chandrasekaran. They present interaction areas that extend the touchscreen of a tablet and state that the bezel is also accessible through direct touch. However, the heatmaps (Figure 2) showed that some participants touched the vertical bezel; statistical analysis indicated that a minimum distance of 2.8cm was in average the closest distance from the device edge that could be touched. Assuming, that the palm was not moved a lot, one could assume the digits were bent a lot for reaching very close positions and stretched for accessing point far away. The hard accessibility of very outer target can be explained through findings of Trudeau et al. (2012). They found for one-handed phone interaction that the thumb performs best when its pose is relaxed, neither strongly bent nor completely stretched. Our results show that areas are accessible that are located between points near the bezel (that require the joints to be much flexed) and points that are a bit less away than a digit's length (to reach these points a digit has to be stretched). However, according to Trudeau et al., the minimum and maximum of the accessible area may lack in usability and an ergonomic optimal distance for touch interaction is located in between both extreme values.

5.2 Accessing the back of the device

Similar to the presented results for touchscreen accessibility, the results for back-of-device interaction show that the center of a tablet cannot be touched with grasping hands. No work has been done in investigating back-of-device accessibility so far; but Wolf et al. (2011) explored the manual ability of fingers to perform gestures with grasping hands. It was shown that (beside the thumb) the index and middle fingers are appropriate for gesture execution while grasping. The findings presented here identify also that the index and the middle finger are best flexible and perform best in terms of accessing most areas on the back of a held tablet. Thus, these fingers are most appropriate for back-of-device interaction with grasping hands.

Excluding ring and little fingers from back-of-device interaction allows them to ensure a stable tablet grasp while the index or middle fingers might actively be used for executing gestures.

6 Conclusion

The work presented here investigated the accessibility for direct touch on tablets' touchscreens and backs with grasping hands. Existing work on touchscreen accessibility could be extended by detailed diagrams of touchable areas. Moreover, such diagrams are provided for back-of-device touch. For both the front and the back of tablets, center areas that are further away from the device edge than a digit's length are out of reach for direct touch. However, the outer vertical regions are accessible, the very outer vertical positions are still harder to access as those a bit further away and as known for thumb interaction, also pointing with fingers is most ergonomic if they are neither fully flexed nor completely stretched.

7 References

Hincapié-Ramos, J.D., Roscher, S., Büschel, W., Kister, U., Dachselt, R. and Irani, P. 2014. tPad: Designing Transparent-Display Mobile Interactions. In *Proc. DIS '14*.

Jones, L. A. and Lederman, S. J. 2006. Human Hand Function. Oxford Univ. Press, 2006.

Lange, W., Windel, A. 2006. Kleine Ergonomische Datensammlung. Praxiswissen Arbeitssicherheit, VOL 12, 2006.

Karlson, A.K., Bederson, B.B. 2007. ThumbSpace: generalized one-handed input for touchscreen-based mobile devices. In *Proc. INTERACT 2007*, 324-338.

Kim, S., Yu, J., and Lee, G. 2012. Interaction techniques for unreachable objects on the touchscreen. In *Proc. OzCHI 2012*, 295-298.

MacKenzie, C.L., and Iberall, T. 1994. The Grasping Hand, ISBN-13: 978-0444548573.

Odell, D. and Chandrasekaran, V. 2012. Enabling comfortable thumb interaction in tablet computers: a Windows 8 case study. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 1907-1911.

Oulasvirta, A., Reichel, A., Li, W., Zhang, Y., Bachynskyi, M., Vertanen, K., Kristensson, P.O. 2013. Improving two-thumb text entry on touchscreen devices. In *Proc. CHI '13,* 2765-2774.

Roudaut, A., Huot, S., and Lecolinet, E.. 2008. TapTap and MagStick: improving one-handed target acquisition on small touch-screens. In *Proc. AVI 2008*, 146-153.

Trudeau, M. B., Young, J. G., Jindrich, D. L., and Dennerlein, J. T. 2012. Thumb motor performance varies with thumb and wrist posture during single-handed mobile phone use. *Journal of biomechanics* (2012).

Wigdor, D., Forlines, C., Baudisch, P., Barnwell, J., and Shen, C. 2007. Lucid touch: a see-through mobile device. In *Proc. UIST 2007*, 269-278.

Wolf, K., Naumann, A., Rohs, M., and Müller, J. 2011. Taxonomy of microinteractions: defining microgestures based on ergonomic and scenario-dependent requirements. In *Proc. INTERACT '11*, 559-575.