Interaction Methods and Use Cases for a Full-Touch Sensing Smartphone

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Abstract

Touchscreens are successful in recent smartphones due to a combination of input and output in a single interface. Despite their advantages, touch input still suffers from common limitations such as the fat-finger problem. To address these limitations, prior work proposed a variety of interaction techniques based on input sensors beyond the touchscreen. These were evaluated from a technical perspective. In contrast, we envision a smartphone that senses touch input on the whole device. Through interviews with experienced interaction designers, we elicited interaction methods to address touch input limitations from a different perspective. In this work, we focus on the interview results and present a smartphone prototype which senses touch input on the whole device. It has dimensions similar to regular phones and can be used to evaluate presented findings under realistic conditions in future work.

Author Keywords

Smartphone; fat-finger; reachability; back touch; edge touch.

ACM Classification Keywords

H.5.2 [User Interfaces]: Prototyping

Introduction & Related Work

Smartphones provide a sheer amount of functionality in the form of a small device. Through touchscreens, they com-

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bine input and output in a single interface. Despite the flexibility of this combination, smartphones are equipped with additional input sources beyond the touchscreen. For example, this includes volume and home buttons to provide shortcuts to common functionality, or fingerprint scanners for authentication and touch input from the device's rear.

Direct touch interaction yields further limitations which are currently not solved by additional input sources. Most common limitations include the fat-finger [16] and occlusion problem [19], as well as reachability issues on larger smartphones [3]. Software-based solutions can circumvent these limitations by introducing additional interaction elements on the touchscreen [11, 15, 18, 20]. However, they overload the interface with additional information and induce additional overhead as users need to trigger them manually.


Figure 1: Mockup of a *full-touch smartphone*. The actual prototype is described on page 6.

Prior research used additional input sources beyond the touchscreen to address these limitations. Baudisch *et al.* [2] showed that Back-of-Device (BoD) interaction enables users to accurately select targets across different screen sizes and that it performs better than software-based methods like *Shift* [18]. Wigdor *et al.* [19] developed a pseudo-transparent touchscreen and found that users prefer BoD interaction due to reduced occlusion and higher precision. Löchtefeld *et al.* [13] found that users feel more comfortable with BoD input when selecting targets that are further away from the thumb.

To increase the reachability of such targets during one-handed interaction, Le *et al.* [12] used a BoD touch panel to enable users to freely move the screen content. Similarly, Cheng *et al.* [6] equipped the rear of a tablet with touch sensors to dynamically arrange the position of the keyboard based on the users hand grip location for better reachability. Prior work also used grip pressure and patterns to infer users' intention [17] or trigger actions [5] as their performance are shown to not being affected by encumbrance [8].

Previous work investigated interaction methods to address touch input limitations from a technical perspective. Prototypes mostly focus on the evaluation only (e.g. using external touchpads [13], building devices from scratch [17]) rather than on everyday use. We can expect that smartphones with touch sensing capability around the whole device can soon be produced for the mass-market. With the vision of such a *full-touch smartphone*, we assume that experienced interaction designers solve touch input limitations from a different perspective. Thus, we conducted semi-structured interviews with eight experienced interaction designers about interaction methods on a *full-touch smartphone* to deal with touch input limitations. Based on these findings, we present our *full-touch smartphone* prototype with which we plan to evaluate the suggestions in future work. Thus, the contribution of this work is two-fold: (1) interview with interaction designers on interaction methods and use cases for a *full-touch smartphone*, and (2) a *full-touch smartphone* prototype which we built to be as realistic as possible in terms of device dimensions.

Interviews

We conducted semi-structured interviews to explore interaction methods and use cases for a *full-touch smartphone*. Particularly, we focus on following research questions:

1. How can we use a *full-touch smartphone* to address common touch input limitations such as the fat-finger problem or reachability issues?
2. What are novel use cases for a *full-touch smartphone*?

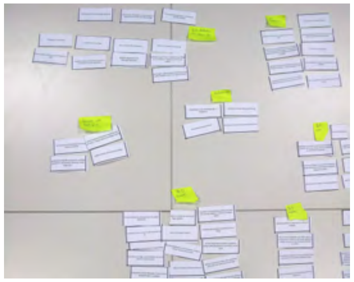

Figure 2: Coding and clustering participants' answers into respective clusters.

Figure 3: Participant demonstrating reachability issues on smartphones.

Participants & Prototype

Since we are interested in answers based on interaction design experiences, we recruited 8 participants who have worked with smartphones from an interaction design perspective. Participants were between 23 and 50 years old ($M = 31.6$, $SD = 9.2$) with two of them being female. The participants comprised two professors for mobile communication and mobile application development from a local university, one project lead for strategy and interaction design at a design company, and graduate and PhD students in the field of interaction or communication design.

To give participants a better vision of a *full-touch smartphone*, we presented a video of the concept and handed them a mockup during the interview (see Fig. 1). The mockup consists of a 3d-printed frame with two 5$''$ touchscreens mounted on the back and the front side. We attached weights within the frame to create a more realistic haptic feeling. Participants used the mockup to demonstrate actions of which we took photos.

Procedure

The semi-structured interviews took place in a quiet room within the company or institution of the participant and were audio-recorded. Interviews lasted about 40 minutes and comprised four parts: Firstly, we asked ice-breaker questions about participants' smartphones and situations in which they are using it. Secondly, we asked participants about limitations and difficulties that they encounter while dealing with touch input on usual smartphones. Prior to the third part, we introduced the prototype as described above. We then explored interaction techniques on a *full-touch smartphone* which addresses the limitations mentioned by the participant in the previous part. We ensured that all participants proposed solutions for at least the fat-finger and occlusion problem, as well as the reachability issue. In the last part, we explored novel use cases for a full-touch smartphone. Participants were asked to suggest scenarios in which the additional surfaces of such a smartphone can be used to implement functionality which is not feasible on recent smartphones.

Results

All audio recordings were transcribed. Based on the transcript, we extracted all comments and printed them on paper to code and cluster answers into respective categories (see Fig. 2).

Limitations of Smartphone Input

When asked about limitations and difficulties in interacting with recent smartphones, the majority of participants were unanimous about the fat-finger problem [2]. They described this through "*too big fingers*" (P1, P3, P6) and "*undersized user interface elements*" (P1, P3, P5, P6, P8). Consequence of this are occlusion issues ("*When drawing, I cannot see the result.*" - P6) which also leads to users "*[not knowing] what a touch is triggering*" (P8). The latter phenomenon is caused by a misconception of the registered touch point between user and touchscreen [9] and the lack of haptical feedback which renders blind input nearly impossible (P3, P6). Thus, participants argue that users are required to frequently look at the touchscreen to adjust their input which leads to a high cognitive demand when doing something else simultaneously ("*[..] is difficult as I need to see where I am walking and where I want to touch simultaneously.*" - P3). This becomes even more detrimental when external disturbances, such as jerks while running (P2) or bumps in public transport (P3), affects the user.

Despite software-based solutions like iPhone's *Reachability* [7] or Samsung's one-handed mode [1], participants (P2, P5, P7) still regard the limited thumb range during one-handed use as a input limitation (see Fig. 3). As these methods require a manual activation, participants "*do not see any additional value compared to just [adapting] the hand grip.*" (P2). However, adapting the hand grip and therefore tilting the device while stretching the thumb leads to unintentional input ("*[..] when trying to reach targets on the upper left corner, my palm unintentionally touches the touchscreen which is not filtered out by the operating system.*" - P7). Especially when holding objects in the other hand (i.e. being encumbered [14]), this can become a critical issue for the users according to P1, P3 and P5.

Figure 4: Participant showing how to change camera settings on the edges.

Improving Smartphone Interaction

With experienced interaction designers, we explored different interaction methods to overcome the described limitations of touch input on smartphones. We describe the interaction methods clustered into categories and explain how they help to overcome the limitations.

Figure 5: Participant demonstrating scrolling on the device's right edge by swiping down the thumb.

Back-of-Device Input and Feedback. As occlusion issues and lack of feedback on the registered touch position can be detrimental, participants suggested two methods based on BoD input to tackle these limitations. P2-P8 envisioned to use the back side to control a cursor on the front screen to avoid occlusion through the finger. As the lower area of the back side is already covered by the hand holding the device, P2 suggested to only use the upper half either by mapping the front screen to this area, or to control the cursor in a relative manner similar to laptop's touch pads. Moreover, participants all agreed that a confirmation is required to avoid unintentional input, e.g. by squeezing the device or applying pressure onto the desired touch position (P2). Similar to prior work [2, 19], P2 and P3 envisioned a pseudo-transparent touchscreen by showing the registered touch point and finger shape of the back side as an overlay on the front screen. Thus, users would receive feedback on their finger and touch position while occlusion can be avoided.

Gestures & UI on Adjacent Sides. Participants (P1, P3-P5, P8) argued that not only fingers do occlude desired content but also input controls such as buttons, menus or sliders. This is especially the case for games (P1, P3, P8), camera applications (P4, P8), image editors (P1) or maps (P8) as their main focus lies on the graphical content. Thus, participants suggested to move input controls to the device's edge (P1, P3-P7) or back (P2, P3, P6).

When asked for examples, P5 and P8 envisioned a camera application with input controls on the edges (see Fig. 4). Similar to usual cameras, adjustments (e.g. focus, brightness, etc.) can be made on the device edges without occluding the front screen. Other examples include movements such as pinching or dragging a slider: P8 suggested to use the back side to perform scrolling or zooming operations while P3 envisioned the edges for scrolling or for manipulation of values similar to sliders (see Fig. 5). Interestingly, when demonstrating the slider on the edge, participants reportedly stated that "*it feels more comfortable and natural than on the front screen, especially when using the device one-handed*" (P1, P3, P8). Similarly, games also profit from a move of input controls to the edge or back of the device (P1, P3, P8).

As touch buttons and sliders do not provide any haptical feedback which makes it difficult to locate them, participants suggested to visualize buttons and sliders with ambient lights on the edges while augmenting them with vibration feedback similar to the home button of an iPhone 7 (P5).

Simultaneous Use of Multiple Sides. Conforming to prior work [21], participants (P1, P3, P6, P7) suggested to

Figure 6: Participant demonstrating a metaphorical grip pattern.

Figure 7: The full-touch smartphone prototype with touch sensing capabilities on the front, back, left, right and bottom side.

use the edge and back side as a proxy space for areas that are not reachable by the thumb due to its limited length. For example, input controls on the top half can be accessed by the index finger from the back side while input controls on the lower half can be accessed by the thumb on the front. Moreover, due to thumb and index finger moving independently, three participants envisioned simple gestures on the back side to e.g. trigger system actions (e.g. "*switching or closing apps*" - P6) or to move the screen content to a more reachable position (P2, P5) (cf. [12]).

Similarly, P7 suggested a function to zoom into parts of the screen depending on the position chosen on the device's edges. P1 suggested double-sided buttons that trigger different actions depending on the touching side. For example, "*clicking the button from the front side opens a window to write a message while clicking from the back side opens a window to write a direct message to a pre-defined contact*" (P1).

Squeeze Interaction. Participants envisioned actions to be triggered when the phone is squeezed. This includes accepting calls or hanging up (P5), taking photos (P1), zooming in and out (P5), or spawning a quick-launch bar (P1). This is beneficial as prior work found that squeeze interaction is not affected by encumbrance or walking jerks [8].

Hand Grip Pattern Recognition. Participants envisioned to train specific hand grips to accept or decline calls (P2), change the song or volume (P4) or to launch applications (P2). Metaphorical grip patterns (e.g. a finger pinching the corner) could be interpreted as modifiers by e.g. keeping the screen as it is when rotating the device (P7, see Fig. 6).

Moreover, users' natural hand grip can be recognized to adapt the user interface. For example, the user interface adapts to the user's handedness (P3, P6), or arrange controls based on the finger's position (P3, P4). Grip patterns can also be used to suggest subsequent actions, or facilitate actions by e.g. enlarging the keyboard when needed (P2).

Use Cases and Opinions

With more information available about the hand grip and finger placement, participants envisioned the system to use this information to recognize different features, such as handedness, grip stability, range of the thumb for a dynamic placement of buttons, or the users frustration (P6). Moreover, patterns can be used to authenticate the user similar to what *Bodyprint* [10] does for the front screen (P1, P2, P7). In general, these ideas require research to be done which is why P3 also envisioned a *full-touch smartphone* as a research tool. We imagine to use such a device to seek understanding on how the hand interacts with the device without the need of cameras or motion trackers. This enables studies also to be conducted in mobile situations.

In general, participants liked the idea of a *full-touch smartphone* (e.g. "*super exciting*" - P2; "*attracts attention*" - P5; "*exciting possibilities*" - P8) and thus came up with 17.8 ($SD = 3.0$) ideas on average per participant. Despite the excitement, some participants were concerned about unintentional input (P1, P4, P5, P7), lack of compatibility with recent user interfaces (P3, P8), and increased battery consumption (P6).

Discussion

In the context of semi-structured interviews, eight participants suggested different interaction methods for a *full-touch smartphone*. Based on their experiences in interaction design, participants argue that these interaction methods are potential solutions to common touch input limitations. Suggestions to deal with the *fat-finger* and *occlusion*

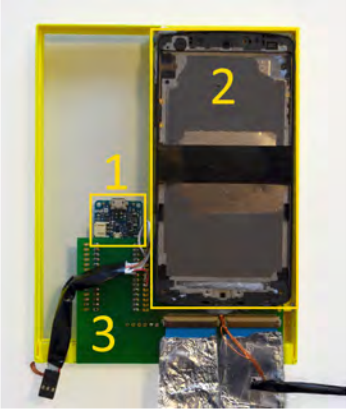

Figure 8: Hardware box containing Arduino (1), two Nexus 5 without touchscreen (2) and PCB (3).

Figure 9: Case of the prototype holding a custom PCB comprising three MPR 121 (1), connectors for touchscreens (2), and flex cables (3) leading to the hardware box.

problem include performing input on the back of the device augmented with positional feedback on the front side, and outsourcing UI components to the edge of the device. As solutions to the *reachability issue*, participants suggested to use adjacent sides as a proxy space to perform input or scroll operations since these are easier to reach. They further suggested interaction by squeezing the device, or to map certain hand grip patterns to functionality. As both interaction methods can be blindly performed, they are suitable for interaction when less focus is available, e.g. while being encumbered or while walking [4, 14].

Some suggestions, such as performing BoD input [2] or arranging the UI according to the grip location [6], were already researched in prior work in HCI and shown to be effective. Besides this, participants also explored novel ideas. Amongst others, these include outsourcing the UI and occluding input (e.g. scrolling gestures) to the edge of the device, or the use of multiple sides simultaneously (i.e. proxy space) to increase reachability. Evaluating these ideas requires a *full-touch smartphone* with dimensions and haptics similar to a mass-market smartphone to avoid influencing the usual hand grip and behavior of the user.

Full-Touch Smartphone Prototype

Prototypes of BoD Smartphones used in prior work comprise two smartphones attached back-to-back. This results in increased thickness which influences the user's usual hand grip. To reduce this thickness, we removed two touchscreens of LG Nexus 5's and mounted them into a 3d-printed frame of a smartphone. We seperated the touchscreens from their counterparts in the hardware box (see. Fig. 8) to save space within the smartphone. Figure 9 shows the components held by the frame while Figure 7 shows the fully assembled smartphone. The smartphone's dimensions are: $136.6\,mm \times 68.4\,mm \times 9.6\,mm$, $115\,g$.

We mounted 16×2 copper plates on the right and left side, and 5 on the bottom side as capacitive sensors for the edges. The frame encloses a printed circuit board (PCB) including 3 capacitive touch controllers (MPR121, see 1 in Fig. 9) for the edge sensors, and a board-to-board connector (see 2 in Fig. 9) on each side for the touchscreens of the Nexus 5's. Using flex cables (see 3 in Fig. 9), we connected this PCB to its counterpart in the hardware box (see 3 in Fig. 8) which is connected to an Arduino (see 1 in Fig. 8) to operate the touch controllers, and the counterparts of two LG Nexus 5 to operate the touchscreens (see 2 in Fig. 8). Both LG Nexus 5 are running Android with a modified kernel to access the capacitive image (cf. [10]). This enables us to recognize touch shapes for use cases such as grip pattern recognition. Separating touchscreens from their counterparts had no negative impact on the performance.

Conclusion & Future Work

We introduced the vision of a smartphone which senses touch input on the whole device. We conducted interviews with experienced interaction designers to explore interaction methods addressing recent limitations of touchscreen input, and use cases that leverage the additional touch surfaces. Our prototype achieves dimensions similar to recent smartphones and thus does not influence the usual hand grip behavior. We use the prototype in future work to evaluate presented ideas under realistic conditions. We plan to implement a selected set of elicited interaction methods and use cases for evaluation. Moreover, we will use the prototype to understand the hand behavior while using the phone in different situations and environments, such as while walking, in public transport vehicles or while being encumbered.

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