Fully Hand-and-Finger-Aware Smartphone Interaction

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Abstract

Touchscreens enable intuitive interaction through a combination of input and output. Despite the advantages, touch input on smartphones still poses major challenges that impact the usability. Amongst others, this includes the fat-finger problem, reachability challenges and the lack of shortcuts. To address these challenges, I explore interaction methods for smartphones that extend the input space beyond single taps and swipes on the touchscreen. This includes interacting with different fingers and parts of the hand driven by machine learning and raw capacitive data of the full interacting hand. My contribution is further broadened by the development of smartphone prototypes with full on-device touch sensing capability and an understanding of the physiological limitations of the human hand to inform the design of fully hand-and-finger-aware interaction.

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ACM Classification Keywords

H.5.2 [User Interfaces]: Input devices and strategies

Context and Motivation

Touchscreens combine input and output in a single interface. This enables users to directly touch the user interface which makes the interaction intuitive. However, previous work in HCI showed that touch input on smartphones still poses a number of major challenges that impact the usability. One of the most prominent challenge is the fat-finger problem [1] which renders precise input difficult due to occlusion through the finger (e.g., placing the caret in a text field). Another prominent challenge is the reachability problem. While users prefer to use smartphones one-handed [4], the limited range of the thumb cannot cover the whole touchscreen as shown in Figure 1. As a result, users need to alter the hand grip which can lead to dropping the device. This becomes even more detrimental since large smartphones (over 5.5") are common nowadays.

Touch input is limited to taps and gestures on the front display while further context information about the hand and fingers are omitted. For example, touches from different fingers are treated equally while the fingers on the

Figure 1: Demonstration of the reachability challenge. The limited range of the thumb cannot cover the whole touchscreen.

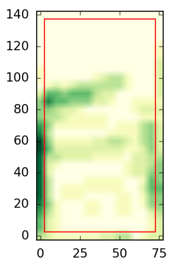

Figure 2: A heatmap showing the finger placement while holding a Samsung Galaxy S4 to read text.

Figure 3: High-precision motion capture system to record finger movements.

Back-of-Device (BoD) are not used for interaction. Recognizing different fingers and involving the fingers on the BoD for interaction can solve the challenges described above. As recent smartphones omit this information, they also limit the input space to provide shortcuts for frequently used functions. This poses a further challenge due to the sheer amount of functions. Instead, shortcuts are provided through hardware controls (e.g., power, volume, and device assistant buttons) and touch gestures. While hardware buttons clutter the device, a large number of touch gestures cannot co-exist due to conflicts with other applications (e.g., gesture keyboards). Conforming to Shneiderman's eight golden rules, the lack of shortcuts caused by touch input limitations impact the pace of interaction.

In my PhD, I explore fully hand-and-finger-aware interaction methods for smartphones. Particularly, I explore the use of different fingers and parts of the hand to solve the reachability challenge. Using the fingers on the BoD compensates the limited range of the thumb without changing the grip. Further, differentiating between inputs of different fingers and parts of the hand extends the input vocabulary which can be leveraged for more shortcuts.

Research Objectives and Status

The main research objectives of my thesis are the design, development, and evaluation of interaction methods for addressing touch input challenges on smartphones. In my thesis, I work towards these objectives in the three following steps: (1) Understanding the physiological limitations of the human hand to derive interaction methods from an ergonomic perspective; (2) developing smartphone prototypes to enable fully hand-and-finger-aware interaction and developing machine learning models to recognize finger and hand parts; and (3) implementing and evaluating fully hand-and-finger-aware interaction methods.

Finger Placement and Ranges

While an understanding of the finger placement and ranges is vital for deriving interaction methods, previous work has only investigated this for the thumb yet. Thus, we conducted a study in which participants performed common tasks on a smartphone while we captured their finger placement. This resulted in an understanding of the finger placements and commonly covered areas on a smartphone (see Figure 5, CHI 16 LBW [11]). In a subsequent paper accepted at CHI 18 [9], we determined the areas on the device surface which are reachable by the fingers without changing the hand grip to understand the ergonomic constraints. We used a high-precision motion capture system (see Figure 3) to capture finger movements of the participants.

Smartphone Prototype and Hand Part Recognition

We developed a smartphone prototype with touch sensing capability around the whole device to enable interaction with all fingers and hand parts. Our prototype provides capacitive images (see Figure 4 and 5) of the touches which enables us to reconstruct the hand grip. Further, these images can be used to differentiate between different fingers or hand parts using machine learning. Since we found that a small change in thickness already impacts the usual hand grip [5], we designed our prototype to be nearly identical to a commodity smartphone in dimensions. We published the resulting prototype at MobileHCI 17 [10]. Next, we plan to collect large data sets to develop models to recognize different fingers and to reconstruct the hand grip.

Interaction Methods based on Hand and Finger Awareness

We conducted semi-structured interviews with 10 interaction designers from industry and academia to consider their expertise in design. Particularly, we asked them for common touch challenges that they or their customers experienced and for interaction methods that could solve

Figure 4: Our smartphone prototype with touch sensing on the whole device surface.

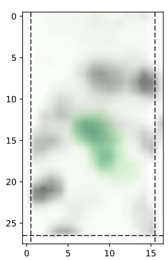

Figure 5: A heatmap provided by our prototype averaged over 8 participants who imitated the grip shown in Figure 6.

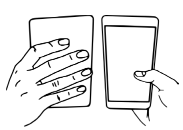

Figure 6: The grip that 8 participants imitated while we recorded the heatmap shown in Figure 5.

these challenges on our smartphone prototype. Amongst others, they proposed using gestures on the rear and edges to improve reachability, and grip pattern recognition and squeeze interaction to provide shortcuts. We presented the results at CHI 17 as late-breaking work [8] and plan to implement and evaluate a number of their suggestions.

So far, we evaluated two of the proposed interaction methods. In a paper published at NordiCHI '16 [5], we evaluated BoD gestures for moving the screen content to improve reachability during one-handed use. The evaluation showed that our method enables to reach the whole screen content in contrast to state-of-the-art methods such as *Reachability* on iPhones. In a paper accepted at CHI 18 [7], we investigate interaction methods based on the detection of different hand parts (e.g., palm and fingers) as a shortcut to frequently used functions. The evaluation revealed that users find our interaction method intuitive and natural.

In our future work, we plan to improve text editing on smartphones by providing shortcuts, e.g., for caret placement and clipboard access. Since input on the device surface avoids both the fat-finger problem and conflicts with gesture keyboards, we hope to find collaborations to apply fully hand-and-finger-aware interaction on different mobile use cases and user interfaces after the doctoral consortium.

Background and Related Work

Previous work investigated the range of the thumb to inform the design of mobile user interfaces [2]. Since BoD and edge input became more relevant in recent years, all other fingers need to be investigated to inform the design of fully hand-and-finger-aware interaction methods. While previous work showed where fingers are typically placed when holding a smartphone [15], no work has been done to study the areas that can be reached by all fingers while holding the device. With our two studies on the finger placements and ranges described above, we contribute to this research.

A prominent approach to implement BoD interaction in HCI is to attach two smartphones back to back. However, this results in a thicker device which impacts the usual hand grip of the user [5]. Closer to our approach, Mohd Noor *et al.* [13] attached a custom flexible PCB with 24 sensors to a commodity smartphone. While hand grips can be detected adequately, the resolution is still too low for precise interaction. Thus, we developed a novel prototype to evaluate interaction methods beyond the touchscreen.

Researchers used capacitive images on smartphones to implement novel interaction methods, including the estimation of finger angles [12], recognizing body parts, and biometric authentication [3]. We plan to extend this to the whole device surface to involve information about the hand grip for interaction. Mohd Noor *et al.* [13] used low-resolution capacitive sensors around a smartphone and the built-in accelerometer to demonstrate that swipe errors can be detected based on grip modulations.

Research Situation and Expected Contributions

I am currently a 2nd year PhD student at the University of Stuttgart. Prior to my PhD program, I collected experiences in HCI primarily in machine learning for mobile interaction [14] and lifelogging [6]. With the vision of future smartphones that incorporate sensors on the whole device surface, the results from this work will inform the design of fully hand-and-finger-aware interaction and further present a number of evaluated interaction methods that can address typical touch input challenges such as the fat-finger problem, reachability challenges and the lack of shortcuts.

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