How to Communicate New Input Techniques

Sven Mayer[1], **Lars Lischke**[1], **Adrian Lankseweirt**[1], **Huy Viet Le**[1], **Niels Henze**[1,2]
[1]University of Stuttgart, Stuttgart, Germany
{sven.mayer, lars.lischke, adrian.lanksweirt, huy.le}@vis.uni-stuttgart.de
[2]University of Regensburg, Regensburg, Germany, niels.henze@ur.de

ABSTRACT
Touchscreens are among the most ubiquitous input technologies. Commercial devices typically limit the input to 2D touch points. While a body of work enhances the interaction through finger recognition and diverse gestures, advanced input techniques have had a limited commercial impact. A major challenge is explaining new input techniques to users. In this paper, we investigate how to communicate novel input techniques for smartphones. Through interviews with 12 UX experts, we identified three potential approaches: *Depiction* uses an icon to visualize the input technique, *Pop-up* shows a modal dialog when the input technique is available, and *Tutorial* explains all available input techniques in a centralized way. To understand which approach is most preferred by users we conducted a study with 36 participants that introduced novel techniques using one of the communication methods. While *Depiction* was preferred, we found that the approach should be selected based on the complexity of the interaction, novelty to the user, and the device size.

ACM Classification Keywords
H.5.2 User Interfaces: User-centered design

Author Keywords
Finger orientation; finger-aware interaction; finger roll interaction; nail/knuckle interaction; interaction methods; user interface.

INTRODUCTION
In 2017, 5 billion mobile phones were in use and 66% of the world's population used one[1]. Over the last decade, smartphones have not only become the primary device for mobile interaction but also serve as the primary computing device for many users. Consequently, diverse and increasingly complex mobile applications have become available. Today, virtually all applications that are available for desktop computers are also available for smartphones. While the number of smartphone users and the diversity of applications increases every year, the basic input techniques essentially remain the same. Despite all efforts to promote other input techniques such as speech, advanced gestures, and air touch, a variation of a single touch, the main input remains the single touch on touchscreens. This is in clear contrast to desktop computers which enable expressive input techniques through combinations of mice and keyboards.

A number of input techniques beyond a single touch including force touch and gesture shortcuts are possible on touchscreen devices. However, they are not widely used, often unknown to users, and not well communicated. Recent research proposed further input techniques to enlarge the input space of today's touch devices, including finger-aware input [6], finger orientation input [30], phone squeeze input [20], and Back-of-Device (BoD) interaction [8]. While some of these techniques are already available for commercial devices, none have become widely used.

As system's functions have to be learned they are not always obvious. As shown by Müller et al. [33], a visual cue that highlights input possibilities significantly increases how often people interact with a system. Moreover, both Shneiderman et al. [41] and Norman [34] argue for the *discoverability* of interaction and indeed we see many ways to help users to understand new input techniques. Hover effects are, for example, a common way to communicate the possibility to click a button. More complex interactions are harder to communicate. With Word 1997, Microsoft introduced Clippy, a virtual assistant that provided in-situ help for text processing by highlighting possible actions. Clippy was removed six years later and is considered a classic example of how not to foster discoverability [36].

As the affordance of input techniques for touchscreens that go beyond simple touch interaction is limited, novel input techniques for touchscreens must be communicated. The most common approach to introduce novel input techniques is through the graphical user interface (GUI). Today, Apple use the "Tips" app to explain how all features of the iOS eco-system work. In cases of an update, Apple triggers notifications to advise users that they can learn about new features in the "Tips" app. On their U11 smartphones, HTC informs users about "Edge Sense" during the device setup and additionally shows a pop-up whenever edge sense can be used within an app. While Apple's "Tips" app and HTC's device setup enable users to understand how to use new input techniques, true discoverability in the sense of Shneiderman et al. [41] and

[1]www.gsma.com/mobileeconomy/

NordiCHI'18, September 29-October 3, 2018, Oslo, Norway

ISBN 978-1-4503-6437-9/18/09…$15.00
DOI: https://doi.org/10.1145/3240167.3240176

Norman [34] is not achieved. They both argue that a function should be self-explanatory and new input techniques should seamlessly be learned while using the device.

In this paper, we seek to understand how user experience (UX) experts envision to communicate input techniques beyond a single touch. Moreover, we aim to understand which communication method is preferred by users. Therefore, we conducted design sessions with UX experts. We asked them how they envision enabling discoverability. We found that designers were split between three different approaches to communicate new input techniques: a) *Depiction*, an approach similar to Shneiderman et al. [41] that highlights available input technique through icons; b) a *Pop-up* which informs users about available input techniques whenever a new one is available; and c) the *Tutorial* which explains all input techniques in a centralized way. We evaluated the three approaches using five different tasks. In each task, the user needed to use a different novel input technique, namely: *Finger Orientation Interaction*, *Finger Roll Interaction*, *Nail/Knuckle Interaction*, and *Finger-Aware Interaction*. We found that participants preferred *Depiction* over both *Pop-ups* and the *Tutorial*.

RELATED WORK

First, we present state-of-the-art approaches to communicating input techniques. We then highlight four novel input techniques which potentially will make it into consumer devices. In our studies, the four techniques form the foundation to study ways for communicating novel input techniques. All four have been studied in detail in previous work but are not widely available for consumer devices: *Finger Orientation Interaction*, *Finger Roll Interaction*, *Nail/Knuckle Interaction*, and *Finger-Aware Interaction*.

Communication of new Input Techniques

While Shneiderman et al. [41] and Norman [34] both argue for interaction *discoverability*, today's mobile devices look different from their vision of usable interaction. Apple, as one of the main players in the mobile market with over one billion active devices[2], uses the "Tips" app[3] on all their iOS devices to introduce new features by triggering a notification and guiding the user through a tutorial. HTC's "Edge Sense" is communicated to users during device setup and additionally a pop-up is shown whenever Edge Sense can be used.

The pinch-to-zoom gesture is available on all major smartphones, Microsoft Windows' touch interface, digital cameras (e.g. Sony Alpha a7 iii), and computer trackpads. However, an on-device communication concept was never developed. The two-finger gesture dates back to 1985 when Krueger et al. [24] used the index finger and the thumb to indicate the size of an ellipsis. One of the first occurrences where pinch-to-zoom is described is by Rubine [38] in 1992. In 2005, it was used by Han [14] in a tabletop scenario. However, until 2007 it was not used for consumer devices nor was a strategy developed to communicate the pinch-to-zoom gesture to users. With the first iPhone, the gesture became available in a consumer product but a way to communicate the gesture on the device was not implemented. Instead, Apple used the presentation of the iPhone[4] to communicate the gesture live on stage by showcasing it twice; once for photos and later for maps. The presentation of the iPhone and subsequent ads by Apple explained the gesture to potential users, which emerged as a cross-platform gesture in the following years.

Samsung's latest launcher, which is for instance pre-installed on the Galaxy S9, shows a line on the side to indicate that a swipe to the center of the screen allows users to open a shortcut menu and the iPhone X presents a swipeable line at the bottom of the screen as a replacement for the home button. A wide range of opportunities to use swipe interactions, for example in the Gmail app which allows swiping left or right to archive an email, are not visually communicated. The iPhone's force touch allows a user to preview and open content and is also not visually communicated. Instead, it was presented in an Apple keynote and subsequent ads. The long press in the Android eco-system is never communicated; users must discover the input technique. Lastly, another gesture which became a cross-platform standard is the "pull-to-refresh" gesture, which is implemented by all major apps, such as Gmail, Facebook, and Instagram, but never communicated to the user.

Finger Orientation Interaction

Since the beginning of the touchscreen era multiple use cases emerged for how to utilize a finger's orientation for input. Wang et al. [44] proposed the use of the finger orientation for interaction with tabletops. Wang and Ren [45] proposed use cases of the new input dimension, such as selecting items in a pie menu by rotating the finger. Later, Xiao et al. [48] enlarged the set of use cases to the smartwatch domain. *Z-touch* by Takeoaka et al. [42] used finger pitch angle as an input source, for controlling Bezier curves in a drawing application. Rogers et al. [35] as well as Xiao et al. [48] proposed new user interface (UI) controls such as rolling context menus and circular slider where the yaw angle is mapped to a "twist" sensitive control. Moreover, Mayer et al. [29, 31] showed ergonomic constraints when using *Finger Orientation Interaction*. Furthermore, Goguey et al. [11] highlighted the range of pitch and roll movements which occur during tabletop interaction. These constraints need to be take into consideration when designers and researchers implementing new UI controls.

As finger orientation is that common we see a number of approaches to acquiring the orientation to enrich the interaction. While Kratz et al. [23] and later also Mayer et al. [32] used depth cameras above the touchscreen to identify the orientation, Rogers et al. [35] used a dedicated sensor array for identification. However, recent approaches use the capacitive image provided by commercial touchscreens. Both Xiao et al. [48] and Mayer et al. [30] used a machine learning approach to achieve higher accuracy.

Finger Roll Interaction

Roudaut et al. [37] proposed using the roll of the finger for input. They envision a circular clockwise / counterclockwise

[2] https://apple.com/newsroom/2018/02/apple-reports-first-quarter-results/
[3] https://tips.apple.com/en-us/ios/iphone
[4] Macworld San Francisco 2007 Keynote 2007-01-09: youtube.com/watch?v=t4OEsI0Sc_s

input by rolling the finger to the side. They argue that the circular gesture can be used to access hidden menus. Huang et al. [22] used the finger roll to implement a keyboard on smartwatches.

Roudaut et al. [37] distinguish between taps, strokes and roll inputs by analyzing the trajectory of the touch input. Hernandez-Rebollar et al. [18, 19] used six dual-axis accelerometers attached to the fingers to track the position and the roll of the fingers. Huang et al. [22] also used inertial measurement sensors to implement a keyboard that assigns different characters to different areas of users' finger pads contacting the touchscreen.

Nail/Knuckle Interaction

The most prominent work regarding nail/knuckle interaction is by Harrison et al. [16]. They envision using a normal tap as one input and further distinguish between knuckle, nail and fingertip. Lopes et al. [26] use different hand gestures for actions such as copying, pasting and deleting objects. Lastly, Hsiu et al. [21] used nail deformation as an indirect measurement to estimate the "force" on the touchscreen.

Harrison et al. [16] identify the different inputs based on changes in the acoustical spectrogram retrieved from conventional medical stethoscope with an electret microphone. In contrast, Lopes et al. [26] use the sound of the gesture for input identification. They used the characteristics of the amplitude and the frequency to detect different interactions.

Finger-Aware Interaction

Finger-aware interaction is mostly used with a specific finger as a modifier of a touch event, allowing different fingers to be responsible for different actions. Colley and Häkkilä [6] used finger-aware interaction to map different functions onto the fingers themselves. For instance, they envisioned navigating the contact app with different fingers, e.g., opening a contact using the index finger and making a call by tapping the contact with the thumb. Gupta and Balakrishnan [13] implemented a smartwatch keyboard which makes uses of finger-aware interaction by mapping two characters to one key and, depending on the finger used, one of the two characters is send to the application layer. Gupta et al. [12] proposed "Porous Interfaces". Two applications are stacked on top of each other with a semi-transparent front layer. They envisioned an interaction where one finger can interact with the front application and another with the application in the background.

Finger identification approaches that attach sensors to the user generally yield the best recognition rate. A large body of work applied infrared sensing from beneath a tabletop for finger-aware interaction [1, 9, 10]. Gupta et al. [12, 13] used infrared sensors mounted on different fingers to identify touches made by the index and middle finger. Similarly, Masson et al. [28] based their recognition on touchpads using vibration sensors attached to the user's finger. Further approaches include using electromyography [2], gloves [27], RFID tags [43] and recently capacitive images [25]. Another approach uses cameras to identify touches from different fingers. Researchers predominantly used a combination of RGB cameras and computer vision [46, 49].

Summary

While touchscreens have become one of the most important input devices for mobile computers, most commonly used input techniques are essentially a variation of a simple touch on the screen. Commercial devices assume that users are already aware of the available input techniques or explain them through tutorials. Research that investigates how to communicate novel input techniques is, however, sparse. In contrast, a large body of work proposed novel input techniques for touchscreens which all have the potential to enrich mobile interaction but are not used in practice. Thus, in this paper, we investigate how to communicate new input techniques to users. We use *Nail/Knuckle Interaction*, *Finger Orientation Interaction*, *Finger Roll Interaction*, and *Finger-Aware Interaction* to study possible approaches for communicating novel input techniques.

DESIGN SESSIONS

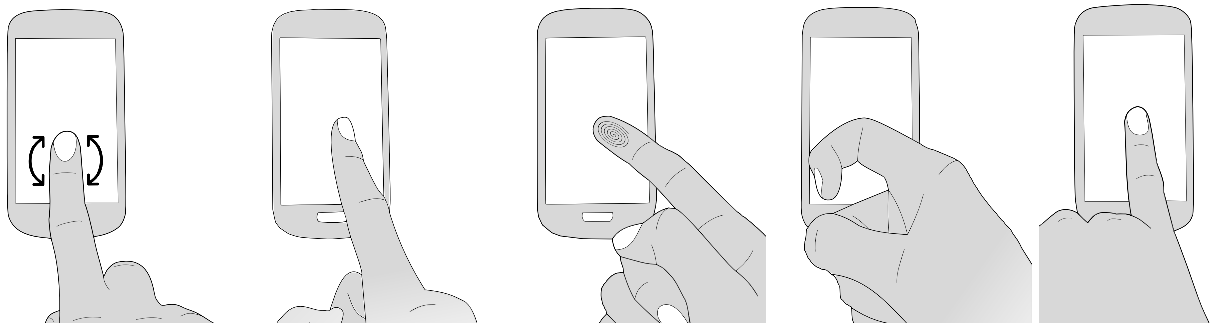
To explore ways to communicate new input techniques, we conducted an interview series with 12 UX experts. We recruited the experts (9 male and 3 female) from two leading design universities and one institute focusing on human-computer interaction (HCI). All interviews were audio recorded for later analysis. For the assessment of the four input techniques, we used a Latin square design to balance the order.

Procedure

After the experts were welcomed, they were asked to sign a consent form and fill in a questionnaire about demographics. Then we introduced them to the interview and explained its overall intent: "How should a touchscreen system introduce new input techniques?" Participants had the chance to ask questions throughout the study. After the general introduction, we informed the participants about the four input techniques using a slideshow, namely: *Nail/Knuckle Interaction*, *Finger Orientation Interaction*, *Finger Roll Interaction*, and *Finger-Aware Interaction*, see Figure 1. For each input technique we had an idea creation phase where we asked the experts to imagine how the input techniques could be used in the mobile devices' most popular types of applications [4], such as instant messaging, browsing, and email apps.

After the idea creation session we interviewed the experts in depth on each of the four input techniques. Following this they each then chose one of their use-cases for a more in-depth interview comprising 13 questions to ensure good designs as laid out in the "Eight Golden Rules" by Shneiderman et al. [41] and the "Seven Fundamental Design Principles" by Don Norman [34]. For each input technique, we gave the experts a sheet of paper with five designated sections for drawings, labeled (1) pre interaction, (2) interaction possibilities, (3) during the interaction, (4) after the interaction, and (5) possible error stats. We asked the experts to use the sections they needed to sketch their ideas.

We wrapped up the interview with final remarks and answered remaining questions. Lastly, we thanked the experts for their participation in our expert interviews and reimbursed them with €10.



(a) Finger Orientation (b) Finger Roll (c) Nail (d) Knuckle (e) Finger-Aware

Figure 1. The input techniques which were used to study possible communication patters for novel input techniques: *Finger Orientation Interaction*, *Finger Roll Interaction*, *Nail/Knuckle Interaction*, and *Finger-Aware Interaction*.

Results

We conducted 12 expert interviews with a total length of $1,005\,min$ ($M = 83.3\,minutes$, $SD = 7.2$, $Min = 60$, $Max = 120$). We transcribed all interviews and coded them using Atlas.ti[5]. We transcribed the interview literally while not summarizing or transcribing phonetically. However, we transcribed pauses longer than one second to understand the conversation. This technique is known to offer a subjective experience [3]. Next, three researchers coded one interview of the material to establish an initial coding tree. A single researcher coded the rest of the data. Finally, we employed a simplified version of qualitative coding with affinity diagramming [15] for interview analysis as this offers a rapid way to analyze and understand the feedback provided by interviews. In the following, we first present insightful comments from the idea creation session and then about the four discussed input techniques. To relate opinions, we name the experts E1 to E12. A set of sketches drawn by the experts is shown in Figure 2.

Summarizing how the experts rated the intuitiveness of the input techniques, only 3 experts considered *Nail/Knuckle Interaction* as the most intuitive input technique, followed by the *Finger Roll Interaction* where 6 experts found them to be generally intuitive. Lastly, both *Finger Orientation* and *Finger-Aware Interaction* was found to be generally intuitive by 7 experts.

Finger Orientation Interaction

As discussed earlier, finger orientation input has, unlike the other input techniques, two dimensions, which can be changed at the same time. Further, in previous research, finger orientation has often been studied as a single input technique. This is reflected in the interviews. Experts either used it as a combined input techniques where two parameters can be changed at the same time or as two independent operations.

The experts envisioned using *Finger Orientation Interaction* for several use cases. They generally considered the input technique to be mainly useful for manipulating views. Manipulations such as zooming, which today is typically realized using two fingers, can be substituted using the orientation of the finger. Here, zooming (E1, E3, E6, E11) and scrolling (E4, E5, E6, E9) were named as examples for fundamental input techniques. Further, manipulating a 3D view as a more complex use case was envisioned (E2, E5, E7, E8). It could be, for example, used to manipulate an object or to zoom and rotate a map at the same time. Furthermore, E10 imagined changing values by changing the orientation of a finger. Thereby, the user could select dates in a calendar using the pitch of the finger. Similarly, E1-E4 envisioned setting the time or a timer using the yaw of the finger. The experts also imagined accessing different shortcuts with each angle of the finger (E3, E6, E9, E12) or mapping it to a brush type or a brush size (E5, E8) in a drawing application. E1 and E10 proposed using uncomfortable finger orientations for safety-critical actions, e.g., factory reset.

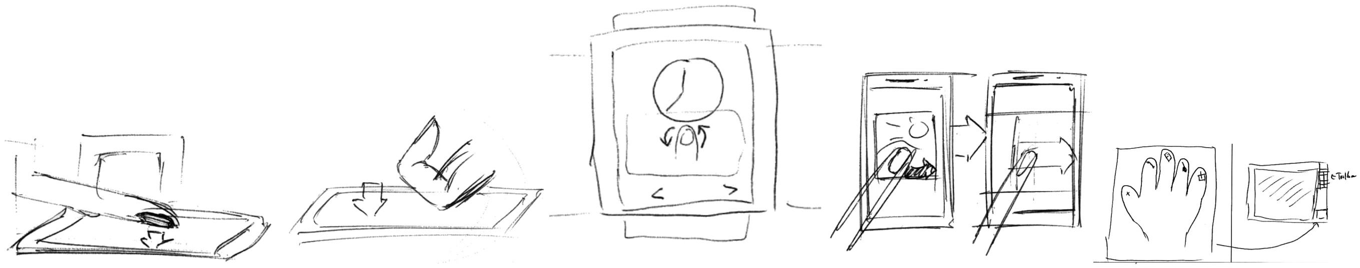
Eight experts considered pop-ups to be an appropriate way for communicating the input technique to users (E1, E2, E4-E6, E8, E11, E12). Moreover, E10 suggested a more intuitive way to communicate the input technique, where the user is guided by an interactive animation to learn how the new input technique works. Furthermore, E5 and E11 suggested using a tutorial to explain the input techniques. Using icons to visualize the new input technique, thus following the depiction method, was mentioned by E3.

The experts generally agreed that smartphones are well-suited for implementing finger orientation input. Five highlighted that finger orientation is also well suited for input on smartwatches; on the other hand, finger orientation on tablets was only highlighted three times. Additionally, E9 stated that finger orientation input should always be implemented as a relative input, as performing absolute angles is difficult for users.

Finger Roll Interaction

Experts considered *Finger Roll Interaction* to be useful for switching between views (E1, E4-E9); either to switch between apps or in an app switch between views. As in-app use cases, the experts proposed moving between one messenger conversation and another or to flip pages in an ebook. Switching between views using roll input could also be used to manipulate UI elements such as a “Switch” or toggle button (E1, E4-E9). This switching function could also be imple-

[5] http://atlasti.com/de/produkt/v7-windows/



(a) Nail Icon (b) Knuckle Icon (c) Finger Orientation Alarm (d) Finger Roll Gallery (e) Finger-Aware Drawing

Figure 2. Sketches drawn by the experts during the interview to underline their strategies for their use cases. (a) and (b) present possible *depiction* icons to guide the user to use their nail or knuckle as input. (c) - (e) present three different use cases each for one input technique.

mented as a scrolling function according to 3 experts (E2, E9, E12). On the other hand, again experts made use of rolling as a continuous input for UI elements such as adjusting a thermostat (E10) or to set a position on a slider as used for music and video player manipulation (E2). Further, two experts (E3 and E8) envisioned the *Finger Roll Interaction* to control games. Lastly, a shortcut menu similar to Roudaut et al. [37] was mentioned by E6.

The experts proposed two basic approaches for communicating finger roll input to users: (1) using a pop-up and (2) using an icon that depicts the interaction. Here, E1, E4-E9, E11, and E12 suggested using pop-ups. E2, E3, E8, E10 suggested depiction to communication the interaction. The experts envisioned using an icon combined with a specific way of guiding the user to the interaction. For the guidance, the experts envisioned a transformation of the touched object whenever a *Finger Roll Interaction* is possible. For instance, E2 suggested transforming the "play" button in a music app into a slider when skimming through the song is possible using *Finger Roll Interaction*.

The experts generally envisioned *Finger Roll Interaction* to be used on all screen sizes. However, E5 and E8 had concerns in regards to using *Finger Roll Interaction* on smartwatches.

Nail/Knuckle Interaction

In contrast to *Finger Orientation* and *Finger Roll*, this interaction uses categorical input rather than continuous input dimensions. This led to two different types of actions in the interviews. However, the actual use of nail or knuckle can easily be applied to the other input techniques. Most of the experts stated that input technique could be implemented for system-wide actions.

All experts saw nail and knuckle input as a perfect solution for shortcuts, such as taking a screenshot (E1, E4-E8, E11, E12), undo (E2, E3, E8), marking mail as spam (E9), snoozing of the alarm (E7), and within music applications (E10). Furthermore, the input technique could be used to select multiple objects and for scrolling, similar to finger-aware interaction (E2). Nail and knuckle input was further envisioned for unlocking or turning on the screen using a knock (E8, E9) and opening the context menu (E1, E4). E3 would use the input for safety-critical input like a factory reset. E4 had the idea to replace already existing functions like long-press replacement.

Experts generally agreed on two ways to communicate the new interaction; first, by showing a pop-up, when the interaction is available for the first time. However, as most of the proposed use cases are system-wide operations, the experts also proposed explaining the input technique during the setup of the device in a tutorial.

Four experts stated that whenever a special action is triggered visual feedback to the user would be beneficial. Four experts proposed a growing wave similar to the pattern a drop produces on a water surface. Furthermore, experts see the usefulness of nail and knuckle interaction as rather limited. Four experts considered the input technique to be useful for all touchscreen devices, two only for smartphones, and one for tablets. Lastly, two experts (E2, E9) argued that there might be problems in using the nail input with long nails and that this should be studied independently.

Finger-Aware Interaction

Experts proposed finger-specific shortcuts (E2-E4, E8, E10, E12) for certain apps such as calendars (E2, E4, E10) or to stop an alarm (E2). They also proposed different tones for each finger in a piano application (E10). Three experts (E3, E10, E12) saw a benefit for drawing apps. They envisioned two different approaches, either to map a different color to each finger or to map different brushes to each finger. Another area was the text editing domain. E1 and E6 envisioned copy and paste using two dedicated fingers, and E7 proposed enhancing caret positioning using finger-aware input. A specific finger could be used to select whole words, unlike today's implementation of caret manipulation. E8 and E9 envisioned using a specific finger open a system-wide context menu. On the other hand, multi-finger shortcuts have been proposed for app switching similar to the iOS implementation (E4). E4 and E5 see a benefit for finger-aware interaction on keyboards, where for example italic text could be realized using one finger, or one finger used to enter the second layer of characters on each key to substitute the long-press. Both E2 and E11 proposed a UI element with a maximum of five options, one per finger. They envision this to be similar to a slider, without taking up the space on the screen to fit a long slider widget.

The majority of the experts drew a hand like a symbol to communicate the different option per finger to the user. However, they again used the representations in different ways to explain the finger-aware interaction to the user. Six experts (E1, E4, E6, E9, E11, E12) stated they would use icons with text to communicate the interaction, with the two options of when the device is getting set up or when the interaction is available for the first time pop-ups. E2, E3, E5, E7, E8, and E10 preferred a depiction as the form of communication. Moreover, three of the experts stated that they would see the benefit of finger-aware interaction for larger screens (E5, E7, E9).

Interview Discussion

To understand how UX experts would design ways to communicate new input techniques, we asked them which use cases they envisioned and how they would communicate the input techniques to users. We asked them to envision use cases for the following four input techniques: *Nail/Knuckle Interaction*, *Finger Orientation Interaction*, *Finger Roll Interaction*, and *Finger-Aware Interaction*. They did so, then each elaborated on their favorite use case in-depth. They envisioned how this use case would work with the new input technique and how they would communicate this to users.

We found that experts are split between three methods to introduce a new input technique. The most common method was to use *Pop-up*s whenever a new input technique is available. Second, we found that for interaction techniques which they found to be intuitive they suggested using less obtrusive *Depiction* (e.g. icons) to communicate a new technique. Last, the experts suggested using an introduction during device setup using a *Tutorial* where the user is guided through a process and the option to revisit the tutorial as in the iPhone's "Tips" app. The results of the design session showed that the experts envisioned a wide variety of use cases but focused on three different methods to communicate new input techniques to users. They would choose a given method on the basis of how intuitive they considered the input technique to be. In the following, we compare the three communication patterns: *Depiction*, *Pop-up*, and *Tutorial* using a study where users are asked to learn and to perform the new input techniques.

Depiction: a small icon next to the element of interest in the UI depicting the available input techniques. The depiction is intended to work without additional textual explanations.

Pop-up: a modal dialog which appears the first time an input technique is available in the next view. The pop-up contains a textual description and visual depiction.

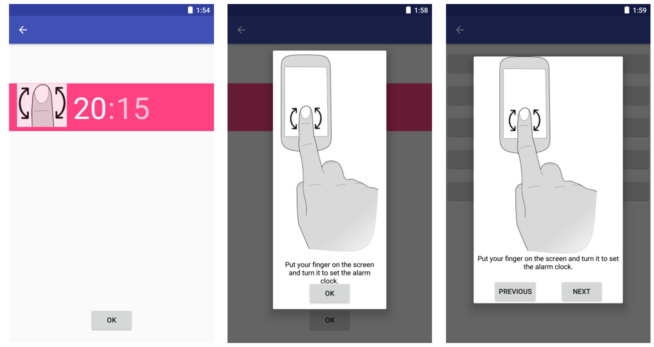
Tutorial: an introduction into all new input techniques at once, either when the input technique becomes available through an update or when setting up the device, again, using a combination of textual description and depiction.

EVALUATION

Based on the findings from the interview series, we designed a lab study in which we compared the three communication methods *Depiction*, *Pop-up*, and *Tutorial* with regards to their UX.

Study Design

We conducted a lab study to compare the three methods for communicating new input techniques proposed by the UX experts. Namely we compare the CommunicationPatterns:



(a) *Depiction* (b) *Pop-up* (c) *Tutorial*

Figure 3. The three different CommunicationPatterns which were proposed by the experts in the design session.

Depiction, *Pop-up*, and *Tutorial*, see Figure 3. We prototyped five different Tasks: *Alarm*, *Chat*, *Drawing*, *Gallery*, and *Map*, see Figure 4. To minimize the influence of unreliable novel implementations of the discussed touchscreen-based input techniques we used a Wizard-of-Oz study design [7]. We conducted the study with CommunicationPatterns as a between-subjects variable while Tasks was a within-subjects variable. This ensures that participants had no experience with an input techniques when it is explained through one of the CommunicationPatterns. We used the system usability scale (SUS) [5], the AttrakDiff [17] questionnaire, and three open questions to evaluate the UX of the mixed design study with CommunicationPatterns $\times$ Tasks.

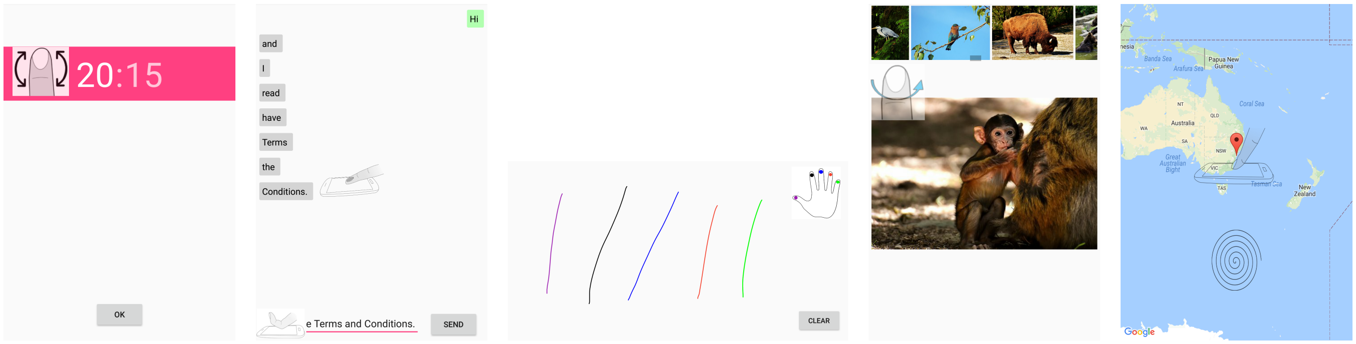
In the *Chat* task, the participant had the option to use *Nail/Knuckle Interaction* to enrich the interaction. To cover the *Finger Orientation Interaction* we added two separate tasks to enable the wizard to recognize the movement accurately. In the *Alarm* task, participants had to rotate the finger around the yaw axis to change the time. In the *Map* task, the pitch of the finger manipulates the map view. In the *Gallery* task, *Finger Roll Interaction* is used to scroll through the images. Finally, *Finger-Aware Interaction* is used for a *Drawing* application, where each finger is mapped to a different color.

Apparatus

We used a Nexus 5X Android smartphone for learning and performing the new input techniques and a Nexus 7 for the wizard. Bluetooth was used to send the commands from the wizard to the smartphone used by the participant. We audio recorded the participants' responses to the open questions. Further, we recorded the whole study using a GoPro Hero3+.

Alarm task: participants were asked to set five different times by changing the yaw orientation of their finger while touching the screen; in which clockwise rotation increased the time. The input technique was realized as a relative input always starting from the last value. For the *Depiction* condition, we displayed an icon with two curved arrows around the finger as proposed by the experts, see Figure 4a.

Chat task: we implemented shortcuts as proposed by the experts. Touching a text using the nail copied the text and touching with the knuckle pasted the text from the clipboard. The



(a) *Alarm* (b) *Chat* (c) *Drawing* (d) *Gallery* (e) *Map*

Figure 4. The five different TASKS used in the evaluation study.

task was to agree to terms and conditions by pasting "I have read the Terms and Conditions" into a textfield word by word. Experts proposed depicting the nail and knuckle, see Figure 4b for the icons used in this task.

Drawing task: participants were asked to draw a scene from their last vacation, a meal, a car, a pet and an island. Participants were further asked to use at least three different colors. Each color was assigned to one finger; the color assignment being shown by a small hand icon, see Figure 4c. By touching the hand participants were able to remap and change colors.

Gallery task: participants were asked to find five specific images in a gallery containing the 100 image[6] using *Finger Roll Interaction*. Scrolling through the images was possible by rolling the finger and visualized with an arrow over an fingertip, see Figure 4d. The position of the *Finger Roll Interaction* was not taken into account. The target images were printed on paper.

Map task: participants were asked to use a map for finding six cities, each on a different continent. Moving the map was possible through panning with the finger, while zooming in and out of the map was realized by changing the pitch of the finger while still touching the screen. This again was visualized by an icon representing the finger and its pitch in relation to the device, see Figure 4e.

Procedure

After welcoming the participants, we explained the purpose and the procedure of the study. Afterward, we asked them to fill out a consent form and a demographics questionnaire. During the whole study, the participants were seated on a chair, the wizard (experimenter) was sitting directly opposite to the participant, with a table in between. The study started by handing the smartphone to the participant. In the *Tutorial* condition, the participant first learned about all input techniques using the tutorial and then started with the TASKS. In the other conditions, the participants directly started with the tasks A pop-up informed them about the input technique in the *Pop-up* condition and an icon representing the input technique was displayed in the *Depiction* condition. The order of the tasks was randomized. No further information was given by the experimenter; however, after each task, participants were asked three questions: (1) Did you feel comfortable performing the input? (2) Did you like the method introducing the input technique? and (3) Do you have suggestions for improving the introduction method?

Participants

We recruited 36 participants (23 male and 13 female). The participants were aged from 20 to 29 years (M = 24.2, SD = .38). The majority (21) of them were Android users, 13 were iOS users, and only 2 were Windows Phone users. In total, the study took between 30 and 40 minutes per participant. We reimbursed them with €5.

RESULTS

In total 36 participants rated 180 interactions, each using an SUS and an AttrakDiff. In detail, each of the three COMMUNICATIONPATTERNS were evaluated with respect to the UX by 12 participants in a between-subjects design. Thus each participant was asked to fill in five SUS and five AttrakDiff one for each TASK. Additionally, they answered a set of three questions regarding the COMMUNICATIONPATTERN. The audio recordings were transcribed by two researchers and we performed a simplified qualitative analysis with affinity diagramming on the interview data [15].

System usability scale (SUS)

To conduct a two-way mixed model analysis of variance (ANOVA), we applied the Aligned Rank Transform (ART) [47] to the SUS scores, using the ARTool toolkit[7] to align and rank our data.

We conducted a two-way mixed model ANOVA to determine whether TASK and COMMUNICATIONPATTERN significantly influenced the usability of the interaction, see Figure 5. For all means and standard deviations see Table 1. Our analysis revealed significant main effects for TASK and COMMUNICATIONPATTERN on SUS score ($F_{4,132} = 5.975$, $p < .001$; $F_{2,33} = 7.783$, $p < .002$, respectively). However, there were no significant two-way interactions between TASK × COMMUNICATIONPATTERN ($F_{8,132} = 1.276$, $p = .261$). Next, pairwise

[6] All images used in the study are under Creative Commons CC0 available at: pixabay.com

[7] depts.washington.edu/madlab/proj/art/index.html

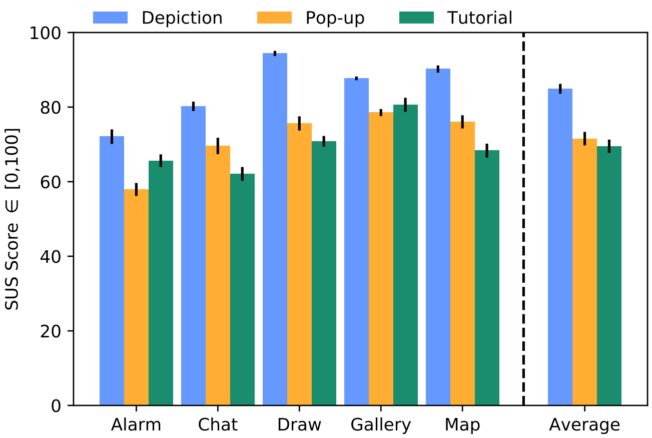


Figure 5. The system usability scale (SUS) results of COMMUNICATIONPATTERN × TASK. Error bars are showing the standard error.

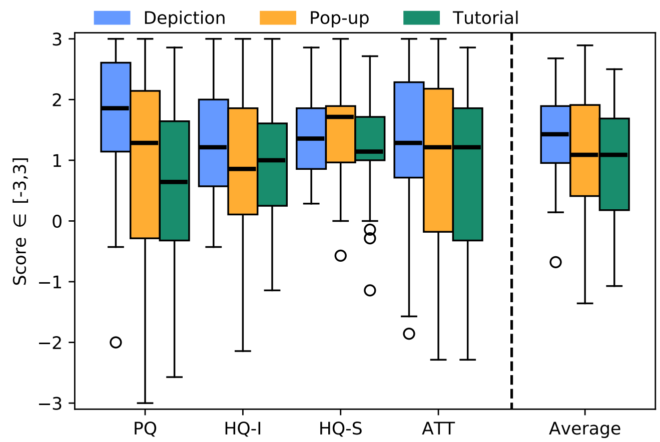


Figure 6. The AttrakDiff results of the four categories Pragmatic Quality (PQ), Hedonic Quality-Identity (HQ-I), Hedonic Quality-Simulation (HQ-S), and Attractiveness (ATT) for the three COMMUNICATIONPATTERNS.

post-hoc comparisons using Tukey's method for p-value adjustment within the levels of the main factor COMMUNICATIONPATTERN revealed significant differences of the SUS score between *Depiction* vs. *Pop-up* ($t_{147.78} = 3.142$, $p < .006$) and *Depiction* vs. *Tutorial* ($t_{147.78} = 3.637$, $p < .002$). However, the pairwise comparisons did not reveal a significant difference for *Pop-up* vs. *Tutorial* ($t_{147.78} = .495$, $p = .874$).

AttrakDiff

To conduct a two-way mixed model ANOVA, we again applied the Aligned Rank Transform (ART) [47] to the three scores of the AttrakDiff, using the ARTool toolkit to align and rank our data. We performed four two-way mixed model ANOVAs one for each scale: Pragmatic Quality (PQ), Hedonic Quality-Identity (HQ-I), Hedonic Quality-Simulation (HQ-S), and Attractiveness (ATT). For all means and standard deviations see Table 2.

We conducted a two-way mixed model ANOVA to determine whether TASK and COMMUNICATIONPATTERN significantly influenced the Pragmatic Quality (PQ), see Table 2 and Figure 7. Our analysis revealed significant main effects for TASK and COMMUNICATIONPATTERN on PQ score ($F_{4,132} = 10.045$, $p < .001$; $F_{2,33} = 5.553$, $p < .01$, respectively). However, there were no significant two-way interactions between TASK × COMMUNICATIONPATTERN ($F_{8,132} = 1.3$, $p = .249$). Next, pairwise post-hoc comparisons using Tukey's method for p-value adjustment within the levels of the main factor COMMUNICATIONPATTERN revealed significant differences of the PQ score between *Depiction* vs. *Tutorial* ($t_{125.79} = 3.256$, $p < .005$). However, the pairwise comparisons did not reveal significant differences for *Depiction* vs. *Pop-up* ($t_{125.79} = 2.244$, $p = .068$) and *Pop-up* vs. *Tutorial* ($t_{125.79} = 1.012$, $p = .571$).

Next, we conducted a second ANOVA to determine whether TASK and COMMUNICATIONPATTERN significantly influenced the Hedonic Quality-Simulation (HQ-S), see Table 2. Our analysis revealed no significant main effects nor a significant two-way interaction ($p > .05$), see Table 2.

Next, we conducted a third ANOVA to determine whether TASK and COMMUNICATIONPATTERN significantly influenced the Hedonic Quality-Identity (HQ-I), see Table 2 and Figures 6 and 7. Our analysis revealed significant main effects for TASK on HQ-I score ($F_{4,132} = 4.071$, $p < .004$). However, there were no significant main effect for COMMUNICATIONPATTERN and no significant two-way interaction between TASK × COMMUNICATIONPATTERN ($F_{2,132} = 1.129$, $p = .336$, $F_{8,132} = .851$, $p = .56$, respectively).

Lastly, we conducted a fourth ANOVA to determine whether TASK and COMMUNICATIONPATTERN significantly influenced the Attractiveness (ATT), see Table 2. Our analysis revealed significant main effects for TASK on ATT score ($F_{4,132} = 9.275$, $p < .001$). However, there were no significant main effect for COMMUNICATIONPATTERN and no significant two-way interaction between TASK × COMMUNICATIONPATTERN ($F_{2,132} = 1.129$, $p = .434$, $F_{8,132} = .885$, $p = .531$, respectively).

Qualitative Results

We asked if they felt comfortable performing the input techniques, here participants provided generally positive feedback. However, the *Alarm* task stood out with 17 out of 36 (47.2 %) participants considering this interaction uncomfortable. All other tasks were considered uncomfortable by fewer than 10

	Depiction		**Pop-up**		**Tutorial**	
	M	**SD**	**M**	**SD**	**M**	**SD**
Alarm	72.1	23.3	57.9	20.8	65.6	20.4
Chat	80.2	15.1	69.6	26.3	62.1	22.3
Drawing	94.4	8.5	75.6	22.7	70.8	17.2
Gallery	87.7	6.2	78.5	11.4	80.6	22.5
Map	90.2	11.6	76.	21.2	68.3	22.4
Mean	84.9	15.9	71.5	21.7	69.5	21.3

Table 1. The system usability scale (SUS) results of COMMUNICATIONPATTERN × TASK, SUS score translate in letter grades as follows: 65.0 - 71.0 = "C", 71.1 72.5 = "C+", and 84.1 - 100.0 = "A+" [40].

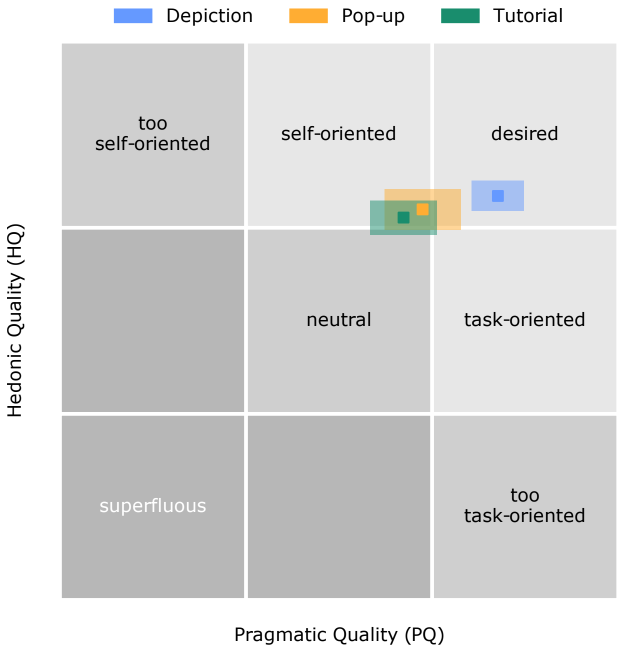


Figure 7. Portfolio presentation graph comparison of the AttrakDiff, with Hedonic Quality (HQ) = Hedonic Quality-Identity (HQ-I) + Hedonic Quality-Simulation (HQ-S).

participants. The *Drawing* tasks seemed to be the most comfortable tasks as they only received negative comments by four participants.

Next, participants were asked to comment on the communication method. Here, we found that the GALLERY task was the most criticized across all COMMUNICATIONPATTERNS (6 × *Depiction*, 3 × *Pop-up*, and 5 × *Tutorial*). On the other hand, in the *Drawing* task, only the *Pop-up*, and *Tutorial* were criticized. All other 164 comments were positive.

Participants provided several comments improving the input techniques. However, in regards to the COMMUNICATIONPATTERNS participants had two major suggestions. First, participants asked for an animation instead of static icons 50 of the 180 (27.8 %) times (16 × *Depiction*, 17 × *Pop-up*, and 17 × *Tutorial*). Second, 16 times participants recommended a video to explain the input techniques (1 × *Depiction*, 7 × *Pop-up*, and 8 × *Tutorial*).

	Depiction		Pop-up		Tutorial	
	M	SD	M	SD	M	SD
PQ	1.71	.14	.9	.21	.69	.18
HQ-I	1.3	.11	.86	.17	.95	.12
HQ-S	1.38	.08	1.53	.1	1.27	.1
ATT	1.35	.15	1.01	.19	.86	.17
Mean	1.44	.18	1.08	.17	.94	.14

Table 2. The AttrakDiff results of the four categories Pragmatic Quality (PQ), Hedonic Quality-Identity (HQ-I), Hedonic Quality-Simulation (HQ-S), and Attractiveness (ATT) of COMMUNICATIONPATTERN × TASK. All scales range between -3 and 3.

DISCUSSION

We conducted a mixed design study with 36 participants. Each participant performed five different TASKS, each with a different input technique. The novel input techniques were communicated in three different ways either through *Depiction*, *Pop-up*, or *Tutorial*. Each participant was only subject to one of the three COMMUNICATIONPATTERNS. In the analysis, we were interested in how the different COMMUNICATIONPATTERNS influenced the participants' ratings rather than how the TASKS performed against each other. Thus, the discussion focuses on comparing the COMMUNICATIONPATTERNS.

Looking at the SUS results, our analysis revealed that the *Depiction* method to communicate new input techniques outperformed both the *Pop-up* and *Tutorial* in terms of overall usability of the techniques. Moreover, the portfolio presentation of the AttrakDiff charted the *Depiction* in the "desired" area while the other COMMUNICATIONPATTERNS were positioned in the less attractive "self-oriented" area. However, only the Pragmatic Quality (PQ) is significantly different for *Depiction* vs. *Tutorial*.

A number of participants commented on the icon for visualizing the available input technique. Across all COMMUNICATIONPATTERNS, they asked for an animation. Moreover, for the *Pop-up* and *Tutorial* they would have liked a video to guide them through the procedure of the new input technique.

Summarizing our results we found that users prefer the *Depiction* approach using icons over both *Pop-up* and *Tutorial* with regards to the SUS, the Pragmatic Quality (PQ) of the AttrakDiff and the qualitative feedback. Therefore, our results are in line with the design recommendation by Shneiderman et al. [41] and Norman [34]. On the other hand, today's consumer devices provide features that lack easy and intuitive discoverability. Thus, they need to use tutorials while setting up a new device or using pop-ups. This is not only true for new devices but also for new in-app features. As a result of our studies, we conclude that *Depiction* is generally preferred by users. However, we also see advantages of the other methods which would suggest that using *Pop-up* or *Tutorial* can in some cases also be beneficial.

Depiction offers an in-situ visualization of the "simple" interactions [39] directly within the UI. While this has the advantage that the user is informed about the input technique right on the spot where the technique is used, the representation is limited to a small visual footprint, similar to the fingerprint icon for unlocking the phone. Therefore, long explanations cannot be embedded within a *Depiction* and the representation always uses display space not only when the interaction is new to the user. Moreover, while animating the *Depiction* is possible, this will guide the users' attention away from the content towards the interaction where the UI should enable to perform a task and not distract the user.

Pop-ups enable developers and designers to a communicate "compound" interactions [39] (multiple gestures as one single input) in different levels of detail. A simple icon combined with text is one option; however, animations or even videos can also be used to communicate input techniques to users. The drawback of *Pop-ups* is that they disrupt the interaction flow and force users to switch the context whenever the *Pop-ups* show up to teach a new input technique.

Tutorials are similar to *Pop-ups* as they can communicate "compound" interactions, but also enable developers and designers to communicate more conditional "compound" interactions and even multiple input techniques at the same time. While the workflow of the user is not interrupted by *Tutorials*, the user is asked to learn multiple input techniques at once which increases the workload and can be confusing.

DESIGN IMPLICATIONS

We derived the following design implications for the three approaches *Depiction*, *Pop-up*, and *Tutorial* to communicate novel input techniques to users.

Interaction complexity dependent communication. "Simple" input techniques should be explained through *Depiction*. "Compound" input techniques should be explained through *Pop-ups* and conditional "compound" input techniques through a *Tutorial*.

Animate if possible. *Pop-ups* and *Tutorials* should be animated and presented in a visually compelling way. However, *Depiction* should be only animated when an input technique is available for the first time; later no animation should be used to avoid distracting the user.

Make use of the screen space. *Pop-ups* are preferable to *Depiction* for small screen sizes to save the space for displaying content. For large screens *Tutorials* are preferable to *Pop-ups* as an extra side view can present all information without cutting down on the user's content.

CONCLUSION

In this paper, we investigated how novel input techniques can be communicated. We first conducted design sessions with 12 UX experts and found that in general there are three approaches for communicating new input techniques, namely: *Depiction*, *Pop-up*, and *Tutorial*. To understand each approach, we conducted a study in which 36 participants were taught new input techniques to perform five different tasks using one of the three approaches. Based on the findings of both studies we derived three design implications for how to communicate new input techniques. In particular, we found that the approach should be selected based on the complexity of the interaction, novelty to the user, and the device size.

While we derived a set of three concrete design implications to introduce users to new input techniques, future research should investigate the long-term effects of each approach as our study was conducted in a lab environment. Here, future research should focus on long term memory effects. Especially when using *Pop-ups* and *Tutorials*, new input techniques might be forgotten over time. As our study was conducted in a lab setting, this possibly influenced the participants' ability to identify the new interaction. Thus, the input techniques should be deployed in real-life tasks which would enable in-the-wild evaluation.

ACKNOWLEDGMENTS

This work is financially supported by the German Research Foundation (DFG) within Cluster of Excellence in Simulation Technology (EXC 310/2) at the University of Stuttgart, the project C04 of SFB/Transregio 161, and the MWK Baden-Württemberg within the Juniorprofessuren-Programm.

REFERENCES

1. Oscar Kin-Chung Au and Chiew-Lan Tai. 2010. Multitouch Finger Registration and Its Applications. In *Proceedings of the 22Nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction (OZCHI '10)*. ACM, New York, NY, USA, 41–48. DOI: http://dx.doi.org/10.1145/1952222.1952233
2. Hrvoje Benko, T. Scott Saponas, Dan Morris, and Desney Tan. 2009. Enhancing Input on and Above the Interactive Surface with Muscle Sensing. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '09)*. ACM, New York, NY, USA, 93–100. DOI:http://dx.doi.org/10.1145/1731903.1731924
3. Ann Blandford, Dominic Furniss, and Stephann Makri. 2016. *Qualitative Hci Research: Going Behind the Scenes*. Morgan & Claypool Publishers. 1–115 pages. DOI: http://dx.doi.org/10.2200/S00706ED1V01Y201602HCI034
4. Matthias Böhmer, Brent Hecht, Johannes Schöning, Antonio Krüger, and Gernot Bauer. 2011. Falling Asleep with Angry Birds, Facebook and Kindle: A Large Scale Study on Mobile Application Usage. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI '11)*. ACM, New York, NY, USA, 47–56. DOI:http://dx.doi.org/10.1145/2037373.2037383
5. John Brooke and others. 1996. SUS-A quick and dirty usability scale. *Usability evaluation in industry* 189, 194 (1996), 4–7.
6. Ashley Colley and Jonna Häkkilä. 2014. Exploring Finger Specific Touch Screen Interaction for Mobile Phone User Interfaces. In *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: The Future of Design (OzCHI '14)*. ACM, New York, NY, USA, 539–548. DOI: http://dx.doi.org/10.1145/2686612.2686699
7. Nils Dahlbäck, Arne Jönsson, and Lars Ahrenberg. 1993. Wizard of Oz studies - why and how. *Knowledge-Based Systems* 6, 4 (1993), 258 – 266. DOI: http://dx.doi.org/10.1016/0950-7051(93)90017-N Special Issue: Intelligent User Interfaces.
8. Alexander De Luca, Emanuel von Zezschwitz, Ngo Dieu Huong Nguyen, Max-Emanuel Maurer, Elisa Rubegni, Marcello Paolo Scipioni, and Marc Langheinrich. 2013. Back-of-device Authentication on Smartphones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 2389–2398. DOI: http://dx.doi.org/10.1145/2470654.2481330

9. Philipp Ewerling, Alexander Kulik, and Bernd Froehlich. 2012. Finger and Hand Detection for Multi-touch Interfaces Based on Maximally Stable Extremal Regions. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces (ITS '12)*. ACM, New York, NY, USA, 173–182. DOI: http://dx.doi.org/10.1145/2396636.2396663

10. Emilien Ghomi, Stéphane Huot, Olivier Bau, Michel Beaudouin-Lafon, and Wendy E. Mackay. 2013. ArpèGe: Learning Multitouch Chord Gestures Vocabularies. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces (ITS '13)*. ACM, New York, NY, USA, 209–218. DOI: http://dx.doi.org/10.1145/2512349.2512795

11. Alix Goguey, Géry Casiez, Daniel Vogel, and Carl Gutwin. 2018. Characterizing Finger Pitch and Roll Orientation During Atomic Touch Actions. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 589, 12 pages. DOI: http://dx.doi.org/10.1145/3173574.3174163

12. Aakar Gupta, Muhammed Anwar, and Ravin Balakrishnan. 2016. Porous Interfaces for Small Screen Multitasking Using Finger Identification. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 145–156. DOI: http://dx.doi.org/10.1145/2984511.2984557

13. Aakar Gupta and Ravin Balakrishnan. 2016. DualKey: Miniature Screen Text Entry via Finger Identification. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 59–70. DOI: http://dx.doi.org/10.1145/2858036.2858052

14. Jefferson Y. Han. 2005. Low-cost Multi-touch Sensing Through Frustrated Total Internal Reflection. In *Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology (UIST '05)*. ACM, New York, NY, USA, 115–118. DOI: http://dx.doi.org/10.1145/1095034.1095054

15. Gunnar Harboe and Elaine M. Huang. 2015. Real-World Affinity Diagramming Practices: Bridging the Paper-Digital Gap. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 95–104. DOI:http://dx.doi.org/10.1145/2702123.2702561

16. Chris Harrison, Julia Schwarz, and Scott E. Hudson. 2011. TapSense: Enhancing Finger Interaction on Touch Surfaces. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology (UIST '11)*. ACM, New York, NY, USA, 627–636. DOI: http://dx.doi.org/10.1145/2047196.2047279

17. Marc Hassenzahl, Michael Burmester, and Franz Koller. 2003. AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In *Mensch & Computer 2003*. Springer, 187–196.

18. Jose L. Hernandez-Rebollar, Nicholas Kyriakopoulos, and Robert W. Lindeman. 2002a. The AcceleGlove: A Whole-hand Input Device for Virtual Reality. In *ACM SIGGRAPH 2002 Conference Abstracts and Applications (SIGGRAPH '02)*. ACM, New York, NY, USA, 259–259. DOI:http://dx.doi.org/10.1145/1242073.1242272

19. Jose L. Hernandez-Rebollar, Robert W. Lindeman, and Nicholas Kyriakopoulos. 2002b. A Multi-Class Pattern Recognition System for Practical Finger Spelling Translation. In *Proceedings of the 4th IEEE International Conference on Multimodal Interfaces (ICMI '02)*. IEEE Computer Society, Washington, DC, USA, 185–. DOI: http://dx.doi.org/10.1109/ICMI.2002.1166990

20. David Holman, Andreas Hollatz, Amartya Banerjee, and Roel Vertegaal. 2013. Unifone: Designing for Auxiliary Finger Input in One-handed Mobile Interactions. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction (TEI '13)*. ACM, New York, NY, USA, 177–184. DOI: http://dx.doi.org/10.1145/2460625.2460653

21. Min-Chieh Hsiu, Chiuan Wang, Da-Yuan Huang, Jhe-Wei Lin, Yu-Chih Lin, De-Nian Yang, Yi-ping Hung, and Mike Chen. 2016. Nail+: Sensing Fingernail Deformation to Detect Finger Force Touch Interactions on Rigid Surfaces. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16)*. ACM, New York, NY, USA, 1–6. DOI: http://dx.doi.org/10.1145/2935334.2935362

22. Da-Yuan Huang, Ming-Chang Tsai, Ying-Chao Tung, Min-Lun Tsai, Yen-Ting Yeh, Liwei Chan, Yi-Ping Hung, and Mike Y. Chen. 2014. TouchSense: Expanding Touchscreen Input Vocabulary Using Different Areas of Users' Finger Pads. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 189–192. DOI: http://dx.doi.org/10.1145/2556288.2557258

23. Sven Kratz, Patrick Chiu, and Maribeth Back. 2013. PointPose: Finger Pose Estimation for Touch Input on Mobile Devices Using a Depth Sensor. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces (ITS '13)*. ACM, New York, NY, USA, 223–230. DOI: http://dx.doi.org/10.1145/2512349.2512824

24. Myron W. Krueger, Thomas Gionfriddo, and Katrin Hinrichsen. 1985. VIDEOPLACE – an Artificial Reality. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '85)*. ACM, New York, NY, USA, 35–40. DOI: http://dx.doi.org/10.1145/317456.317463

25. Huy Viet Le, Sven Mayer, and Niels Henze. 2018. InfiniTouch: Finger-Aware Interaction on Fully Touch Sensitive Smartphones. In *Proceedings of the 31th Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. ACM, New York, NY, USA, 13.

26. Pedro Lopes, Ricardo Jota, and Joaquim A. Jorge. 2011. Augmenting Touch Interaction Through Acoustic Sensing. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '11)*. ACM, New York, NY, USA, 53–56. DOI: http://dx.doi.org/10.1145/2076354.2076364

27. Nicolai Marquardt, Johannes Kiemer, David Ledo, Sebastian Boring, and Saul Greenberg. 2011. Designing User-, Hand-, and Handpart-aware Tabletop Interactions with the TouchID Toolkit. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '11)*. ACM, New York, NY, USA, 21–30. DOI:http://dx.doi.org/10.1145/2076354.2076358

28. Damien Masson, Alix Goguey, Sylvain Malacria, and Géry Casiez. 2017. WhichFingers: Identifying Fingers on Touch Surfaces and Keyboards Using Vibration Sensors. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology (UIST '17)*. ACM, New York, NY, USA, 41–48. DOI: http://dx.doi.org/10.1145/3126594.3126619

29. Sven Mayer, Perihan Gad, Katrin Wolf, Paweł W. Woźniak, and Niels Henze. 2017a. Understanding the Ergonomic Constraints in Designing for Touch Surfaces. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '17)*. ACM, New York, NY, USA, Article 33, 9 pages. DOI: http://dx.doi.org/10.1145/3098279.3098537

30. Sven Mayer, Huy Viet Le, and Niels Henze. 2017b. Estimating the Finger Orientation on Capacitive Touchscreens Using Convolutional Neural Networks. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces (ISS '17)*. ACM, Brighton, United Kingdom, 220–229. DOI: http://dx.doi.org/10.1145/3132272.3134130

31. Sven Mayer, Huy Viet Le, and Niels Henze. 2018. Designing Finger Orientation Input for Mobile Touchscreens. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'18)*. ACM, New York, NY, USA, 9. http://doi.acm.org/10.1145/3229434.3229444

32. Sven Mayer, Michael Mayer, and Niels Henze. 2017. Feasibility Analysis of Detecting the Finger Orientation with Depth Cameras. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct (MobileHCI'17)*. ACM, New York, NY, USA, 82:1–82:8. DOI:http://dx.doi.org/10.1145/3098279.3122125

33. Jörg Müller, Robert Walter, Gilles Bailly, Michael Nischt, and Florian Alt. 2012. Looking Glass: A Field Study on Noticing Interactivity of a Shop Window. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 297–306. DOI: http://dx.doi.org/10.1145/2207676.2207718

34. Don Norman. 2013. *The design of everyday things: Revised and expanded edition*. Basic Books (AZ).

35. Simon Rogers, John Williamson, Craig Stewart, and Roderick Murray-Smith. 2011b. AnglePose: Robust, Precise Capacitive Touch Tracking via 3D Orientation Estimation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2575–2584. DOI: http://dx.doi.org/10.1145/1978942.1979318

36. Yvonne Rogers, Helen Sharp, and Jenny Preece. 2011a. *Interaction design: beyond human-computer interaction*. John Wiley & Sons.

37. Anne Roudaut, Eric Lecolinet, and Yves Guiard. 2009. MicroRolls: Expanding Touch-screen Input Vocabulary by Distinguishing Rolls vs. Slides of the Thumb. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 927–936. DOI: http://dx.doi.org/10.1145/1518701.1518843

38. Dean Rubine. 1992. Combining Gestures and Direct Manipulation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '92)*. ACM, New York, NY, USA, 659–660. DOI: http://dx.doi.org/10.1145/142750.143072

39. Jaime Ruiz, Yang Li, and Edward Lank. 2011. User-defined Motion Gestures for Mobile Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 197–206. DOI: http://dx.doi.org/10.1145/1978942.1978971

40. Jeff Sauro and James R Lewis. 2016. *Quantifying the user experience: Practical statistics for user research*. Morgan Kaufmann.

41. Ben Shneiderman, Catherine Plaisant, Maxine Cohen, Steven Jacobs, Niklas Elmqvist, and Nicholas Diakopoulos. 2016. *Designing the User Interface: Strategies for Effective Human-Computer Interactio* (6th ed.). Pearson.

42. Yoshiki Takeoka, Takashi Miyaki, and Jun Rekimoto. 2010. Z-touch: An Infrastructure for 3D Gesture Interaction in the Proximity of Tabletop Surfaces. In *ACM International Conference on Interactive Tabletops and Surfaces (ITS '10)*. ACM, New York, NY, USA, 91–94. DOI:http://dx.doi.org/10.1145/1936652.1936668

43. Katia Vega and Hugo Fuks. 2013. Beauty Tech Nails: Interactive Technology at Your Fingertips. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI '14)*. ACM, New York, NY, USA, 61–64. DOI: http://dx.doi.org/10.1145/2540930.2540961

44. Feng Wang, Xiang Cao, Xiangshi Ren, and Pourang Irani. 2009. Detecting and Leveraging Finger Orientation for Interaction with Direct-touch Surfaces. In *Proceedings of the 22Nd Annual ACM Symposium on User Interface*

Software and Technology (UIST '09). ACM, New York, NY, USA, 23–32. DOI: http://dx.doi.org/10.1145/1622176.1622182

45. Feng Wang and Xiangshi Ren. 2009. Empirical Evaluation for Finger Input Properties in Multi-touch Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 1063–1072. DOI: http://dx.doi.org/10.1145/1518701.1518864

46. Jingtao Wang and John Canny. 2004. FingerSense: Augmenting Expressiveness to Physical Pushing Button by Fingertip Identification. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems (CHI EA '04)*. ACM, New York, NY, USA, 1267–1270. DOI: http://dx.doi.org/10.1145/985921.986040

47. Jacob O. Wobbrock, Leah Findlater, Darren Gergle, and James J. Higgins. 2011. The Aligned Rank Transform for Nonparametric Factorial Analyses Using Only Anova Procedures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 143–146. DOI: http://dx.doi.org/10.1145/1978942.1978963

48. Robert Xiao, Julia Schwarz, and Chris Harrison. 2015. Estimating 3D Finger Angle on Commodity Touchscreens. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces (ITS '15)*. ACM, New York, NY, USA, 47–50. DOI: http://dx.doi.org/10.1145/2817721.2817737

49. Jingjie Zheng and Daniel Vogel. 2016. Finger-Aware Shortcuts. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4274–4285. DOI: http://dx.doi.org/10.1145/2858036.2858355