PinchPad: Performance of Touch-Based Gestures while Grasping Devices

Katrin Wolf[1], Christian Müller-Tomfelde[2], Kelvin Cheng[2], Ina Wechsung[1]
[1]TU Berlin, Quality and Usability Laboratories, E.-Reuter-Platz 7, 10587 Berlin, Germany
[2]CSIRO ICT Centre, Cnr Vimiera & Pembroke Rd, Marsfield NSW 2122, Australia
katrin.wolf@acm.org, {christian.mueller-tomfelde, kelvin.cheng}@csiro.au, ina.wechsung@telekom.de

ABSTRACT
This paper focuses on combining front and back device interaction on grasped devices, using touch-based gestures. We designed generic interactions for discrete, continuous, and combined gesture commands that are executed without hand-eye control because the performing fingers are hidden behind a grasped device. We designed the interactions in such a way that the thumb can always be used as a proprioceptive reference for guiding finger movements, applying embodied knowledge about body structure. In a user study, we tested these touch-based interactions for their performance and users' task-load perception. We combined two iPads together back-to-back to form a double-sided touch screen device: the PinchPad. We discuss the main errors that led to a decrease in accuracy, identify stable features that reduce the error rate, and discuss the role of 'body schema' in designing gesture-based interactions where the user cannot see their hands properly.

Author Keywords
Pinch, grasp, gesture, mobile devices, body schema, offset.

ACM Classification Keywords
H5.2. User interfaces: Interaction styles.

General Terms
Performance, Design, Experimentation, Human Factors.

INTRODUCTION

Novel mobile devices are being developed to resemble the form factor of physical daily objects such as books or newspapers. E-readers, tablets, foldable and flexible displays all have one thing in common: they come without mouse and keyboard, promoting touch and multi-touch interaction. With most of these devices, the surface that faces the user hosts the input and output components. Some parts of this surface are always touched by the user while holding the device.

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Figure 1 shows the prototype double-sided touchscreen. We used two devices to build the PinchPad, stacked them together back to back, and implemented an experimental application.

The main recurring problem with this kind of device is that the grasping hand occludes the visual content on the display, in particular the user's fingers [22]. From reading traditional newspapers, we are used to handling this situation (see Fig. 2.A) through grasping the paper where we are not reading and changing the grasp position when our visual focus is hindered by the grasping fingers. Moreover, while grasping the device, the hands are used for navigating the newspaper by turning the pages without releasing it. Small and complex finger movements are performed to turn the pages whilst holding the newspaper. In this paper, we investigate what we can learn from this human-artifact interaction that can be transferred as embodied knowledge into the design of novel forms of human-computer interaction. To this end, we are focused on user interaction with grasped devices through finger movements.

In the following we describe possible ways of interacting with grasped objects using finger movements and explain how body schema could be applied to interactions whilst grasping. Afterwards, we present a user study that transfers this idea into the design of experimental tasks. We discuss the results and outline future work.

CONFIGURATION OF GRASPED DEVICES

Traditional information devices (e.g. newspapers, books) allow navigation through content by turning pages. While the navigation options of digital devices are very different, they can be freely configured and are not constrained physically. Often, the interface with these digital devices mimics real world interactions such as pressing a button. We designed finger-based interactions with grasped devices for three different types of actions: discrete, continuous, and combined commands. These categories cover all common commands for navigating through media, such as skipping forward or backward (Fig 2.B), scrolling pages (Fig. 2.C), and modifying a value (Fig. 2.D) such as display brightness or contrast. These actions may be combined for use in parallel or in sequence.

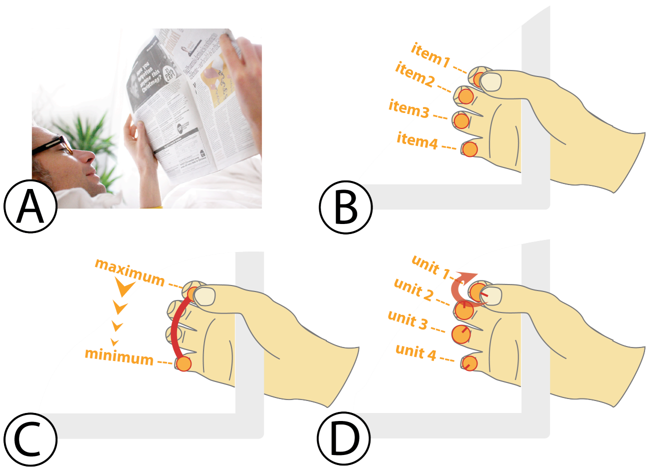

Figure 2 demonstrates how people naturally navigate through information "devices" (A) and how this embodied knowledge can serve for interaction design for: discrete commands (B), continuous commands (C), and a combination of a discrete and continuous gesture (D).

APPLYING BODY SCHEMA TO INTERACTION DESIGN

Embodied knowledge about what fingers are doing and where fingers are spatially positioned, even when we do not see our hands, is explained by psychologists through a rich internal model of the body's structure: the 'body schema' [5, 14, 20, 21, 23]. This term is described as an implicit knowledge structure that encodes the body's form, configuration constraints, and configuration consequences on touch, vision, and movement [5].

We aim to exploit this embodied knowledge for supporting and guiding gestures, especially finger movements, particularly those that are invisible because they are performed behind a grasped device.

Body schema is an internal, globally consistent model of a multisensory (visual, tactile, and proprioceptive information) representation of spatial position and ownership of human body parts as well as how the 'peripersonal' space immediately around the body is constructed [14]. Usually, the process of hand movements relies more on vision than on proprioception [23]. But under varying conditions (light, spatial direction) the weighting of these senses, vision and proprioception, can vary [20]. Van Beers found about secondary tasks that proprioception is relied upon more than visual senses when performing visual demanding primary tasks such as driving, typewriting or page-turning in natural conditions.[20]. These findings support an integrated and consistent model, which suggests a flexible modality weighting according to the situational requirements.

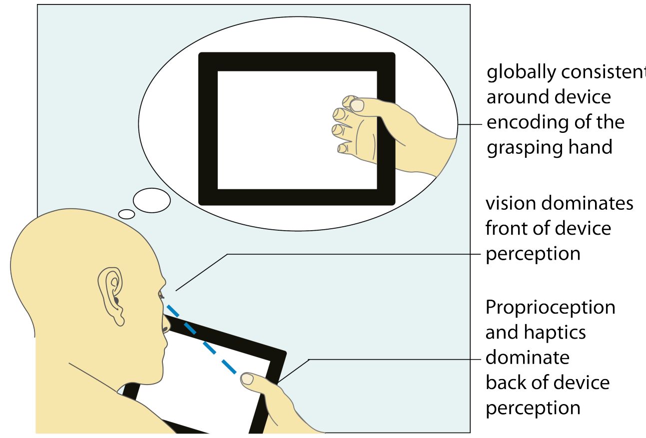

Figure 3 illustrates how different input modalities represent the integrated internal model of 'body schema' and change their weightings situation-dependently.

The modality weighting of a users' body schema may be flexible and can be optimized to varying situational constraints.(see Fig. 3). This phenomenon may be the answer to the questions that this study poses: Does the body schema allow users to guide their touch interaction on the device surfaces when fingers are not seen? And how do users perceive this interaction technique (double sided touch device)?

RELATED WORK

In the past few years novel user interfaces for behind, under or around device interactions have been developed. Widgor et al developed 2006 [25] a touch table that measures touch events on the top surface as well as on the under side and explored new genre of bimanual input, such as oppositional input, and asymmetric overlapping of two-handed operations. The performance of beneath-table interaction was analyzed from a user study. One year later Wigdor et al. developed Lucid Touch [24], a hand-held prototype that measured touches on its back side through a camera. This work was mainly motivated by the desire to find a way to allow touch events that avoided covering the displayed content, thus solving the fat finger problem [24]. More work was done in developing interfaces that investigated gestures which are performed behind an object or around it when it is held: Kim [12] investigated grip pattern recognition; Wimmer developed handSense [27] for classifying grasps while holding a phone size device; Döring [2] investigated driving performance while executing touch-based gestures on a touch sensitive surface that is integrated in a steering wheel; Essl et al. [3] built a prototype that allowed interacting with a mobile device on the front and on the backside through grabbing, sliding, twisting, and turning. Other research focused on interfaces with a specific form factor that realizes grasp-based user input, such as Holman [8] and Schwesig [15]. These

Organic User Interfaces [7] support input that is more akin to real object manipulation, such as bending or folding paper.

Beside those research works that focused on developing novel interfaces, which in turn enabled the investigation of novel interactions techniques, other research was also done that focused more on how humans perform touch-based and grasp-based interactions, as well as the parameters that affect them. Holz [9] investigated touch performance and identified visual features of the users' fingers that serve as guidance feedback for placing fingers on a touch surface. Karlson [11] investigated one-handed input using the thumb for touchscreen-based mobile devices. Wimmer [26] defined situation sensitive parameters that influence how users grasp objects. Wobbrock [28] conducted user studies that focused on the performance of certain fingers for touch-based interactions on the front and back of PDA-sized devices. He also investigated which display orientation is favored on the back of the device. Shen [16] investigated double-sided multi touch providing a see-through vision of the fingers position on the rear surface.

As described previously, our approach focuses on applying body schema to interaction design for grasped objects. We concentrate on the visibility of the thumb and the fingers in gesture-based interaction, and guidance feedback of common graphical interfaces. We also investigate other modalities such as haptic and proprioception, apart from vision. Therefore this paper aims to answer the question: How accurately can the user simultaneously position the fingers and thumb whilst executing finger gestures if only their thumb is visible? Is the subjective self-assessment correlated with objective measurements of accuracy in terms of pointing and trajectory paths such as length and direction? And what gesture performance parameters are the most stable ones and therefore suitable to serve as features for classification?

DESIGN

We, as human beings, understand that seeing the fingers while performing a gesture and receiving information about their spatial position through other modalities (haptic, proprioception) acts as a form of guidance feedback. Our guidance feedback is not a computer system output but one that is contained within an embodied human system. We use the term "guidance feedback" for any perceivable information changes that result from human-computer interaction and which help to make the interaction more transparent to the user. For finger gestures, this concerns the position of the thumb and fingers in relation to the interface that gathers the gestural data. For grasping interfaces, the information changes are movements around and touch-based actions on the grasped object or device. Assuming that guidance feedback usually affects task performance and perceived task performance affects frustration, we aim to explore both variables when the guidance feedback is embodied and not provided by the device.

Interaction Design

In the *atomic level of interaction design* that concerns the finger movements, which are the building blocks for gestures, we decided to use tap and drag gestures for touch-based interactions on grasped devices because those have been identified as being the most practical ways of using all the fingers and the thumb while grasping objects [29]. To extend the gestures, we added thumb movements, because the thumb has a higher level of movement-dependent degrees of freedom than any of the other fingers [17].

Regarding the *design of interaction feedback* especially *guidance feedback*, we assumed, from a theoretical consideration, that users feel more comfortable and perform gestures more accurately behind grasped objects when they use the thumb as a point of reference. This device-pinching action, which we named *pinch-through*, relies on the natural grasp and its potential for interaction design shall be informed by this study. Our interaction design applies body schema and embodied knowledge of how to move the thumb towards the fingers without seeing them. The embodied knowledge, which is based on learnt lessons from acting in the world, relies on experiences with a proprioceptive referencing grid that is created by the fingers and guides the thumb trajectories.

To refine our approach, we designed four exemplary *interaction techniques* that serve as test-commands for combining tap- and drag-gestures while pinching the device. These can easily be mapped onto discrete (Fig. 4 A, B), continuous (Fig. 4 C), and combined (Fig. 4 D) commands. We defined four gestures in our experiment, as shown in Fig. 4.

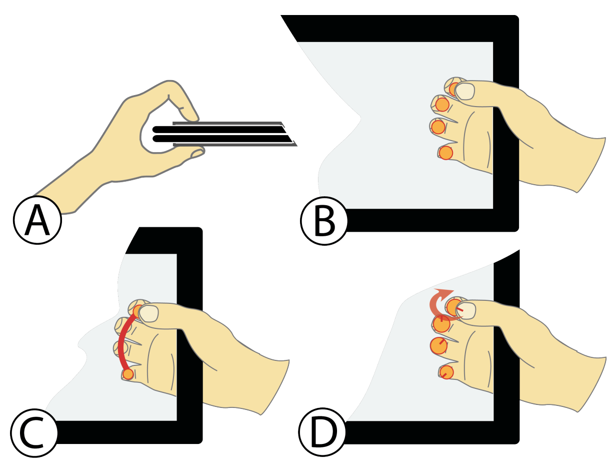

Figure 4 shows four pinch variations that the participants in our study are asked to perform while grasping the PinchPad: initial pinching with a released hand (A), targeting the resting fingers on the back side with the thumb (B), point one finger with the thumb and drag it to another finger (C), and circling fingers with the thumb (D).

EXPERIMENTAL WORK

We did not pre-define the features that identify performance because this study was meant to result in generic findings for finger-gesture interactions in the context of human abilities and strengths. This study explored a novel interaction technique and did not focus on the usage of any interface technologies for tracking interaction features to classify interaction commands. Therefore our two-sided touch-sensitive prototype (Fig. 1) is used only as a measuring instrument; we did not aim to focus on hardware development.

Measurements

In our analysis we aim to identify parameters that are stable over all participants and could serve as gesture classification features. Parameters that we measured over all conditions were: finger addressability, front and back screen mapping, positional pointing accuracy (local finger closeness to thumb), and pointing presicion (finger-thumb offset in terms of distance and positional relation, such as above or underneath the target). Some parameters are only applicable to certain interaction techniques. For initial pinching we also analyzed temporal pointing accuracy. For the circle pinch we analyzed the distance between the thumb position and the middle of the circle. For the pinch slider we analyzed the distance (precision) between the start and end point of the thumb position depended on the positions of the other fingers. Additionally, we analyzed the thumb-dragging length regarding the finger distance for exploring positional offset tendencies and the offsets in slider presicion.

To measure the addressed fingers we captured video recording from the front and rear side of the PinchPad. The touch events were written into a log-file to generate positional diagrams (see Fig. 7) and heatmaps (see Fig. 6). This in turn allowed us to display position-sensitive touch duration (in terms of time taken) for analyzing the actual performance of the four interaction techniques.

Besides identifying stable classification features, we aimed to understand how the users felt about interacting by pinching a grasped object. Therefore we measured perceived performance as well as frustration, effort, mental, physical and temporal demand in a post-test NASA-TLX questionnaire [6]. Moreover we asked open questions about participants' thoughts regarding the device, task or situational limitations as well as their confidence and suggested performance with the tested "blind" interaction techniques afterwards.

PinchPad

For the experiment, we developed the PinchPad, an interactive prototype (see Fig. 1) that tracks multitouch events using the TUIO protocol. We stacked two iPads together back-to-back and implemented software that allowed us to track touch-based finger movements (tap and drag) from a device-grasping hand. The front-facing touch-sensitive screen tracks the thumb position, while the back screen tracks the other fingers' touches.

Procedure

At the beginning of the experiment, the participants were asked to perform four interaction techniques (see Fig. 4) while holding the prototype as shown in Fig. 1 with all fingers. Each of the five sequences was performanced with each hand separately. The following are sample instructions to the subjects:

Initial pinch: Pinch the device between your thumb and each of your fingers of the left hand in parallel and release the pinch after a second before continuing with the next finger. Do this thumb-pinch five times sequentially with index, middle, ring, and little finger, and name those that you use.

Rested pinch: Point your thumb to the index finger, the middle, the ring and the little finger while they rest on the device's back.

Circled pinch: Make a circle with your thumb around each of your fingers iteratively five times.

Slided pinch: Please put your thumb on a starting finger and then drag on the screen to a target finger. After that, drag it back to the starting finger. The starting and target fingers are: index – middle, index – ring, index – little, middle – ring, middle – little, and ring – little finger.

After the experiment, the participants filled in 3 questionnaires: the NASA-TLX, an open questionnaire, and a form concerning demographic data and their experience in manual tasks such as using computers and electronic devices, playing musical instruments, and doing arts and crafts.

Participants

We conducted the experiment with ten participants, all right handed, 6 female, 4 male, between 29 and 64 years of age. The participant group consisted of students, researchers (areas of computer science and information technology) and financial officers. The group was heterogenic in age (average=35.5, SD=13) but experienced in manual and computer skills.

RESULTS

Pinch-through metaphor

To solve the tasks, the participants were instructed verbally to move certain fingers that were occluded through the device or to point to them with the visible thumb. We recorded the task performance on video tape and analyzed the correctness of their finger gestures in locating and pointing. In all of the tasks, all participants were consistently able to locate their occluded fingers correctly when they were asked to move or point at them independently with the thumb. This confirmed that users pointed to fingers with the thumb in a manner similar to "pinching through" the device. This consistency in users' understanding of front and back gestures justified our experimental approach and drove the design of our data analysis: for any analysis of positional accuracy and presicion, we flipped the back screen data horizontally (see Fig. 6).

Pinch-through performance

We scanned our data for stable parameters that could be used to serve as features for grasping gestures, such as touch position and duration.

All gestures were based on the pinch-through gesture, which uses the thumb to touch the front screen while another finger touches the back. When using the fingers for representing menu items (see Fig. 2 B, D), it was necessary to identify the finger that the thumb was selecting with the pinch-through gesture. Three (see Fig. 4 B-D) of our four gesture commands consist of thumb movements while the fingers rest on the back of the device. For these gestures we analyzed the pointing accuracy through identifying the finger that was selected through thumb-based pinch-through. For initial pinching (see Fig. 4 A), which starts with a released hand and ends with moving the thumb and a finger simultaneously to a pinch-through pose, we also analyzed the synchronization of the thumb and finger touch.

For all users and over all five task sequences for each interaction technique we tried to find tendencies in accurate and precise pointing for task A-D: initial, rested, circled, and slided pinching. For each task, we visualized the accuracy and presicion in pressure contour maps that were generated from log-files captured by the PinchPad during the experiment (see Fig. 6). For initial pointing we also analyzed the touch time synchronization between the thumb and the selected finger (see Fig. 7).

Our interface is the human hand, consisting of a pointer (thumb) and a four "pixel" display (defined by four fingers as touch points) that are placed a small distance apart in tasks B-D (see Fig. 4B-D, 6.I-IV). The number of pointing opportunities is small (4 touch points in a row), the "pixel" size is large (one finger), and there is always some space in between each "pixel". Therefore pointing accuracy can be defined as a boolean parameter: if the thumb touch is located closest to the finger that it is meant to point at, the target is counted as hit for tasks B-D. For task A: initial pinching, there is always just one finger touching the screen. Therefore we can define a "pixel" as "pointed to" when a finger and the thumb are touching both sides of the device at the same time (see Fig. 4A, 6.V, 7).

The accuracy of the initial pinching (task A) can be identified by finger touches on the screen. This allowed us to analyze the time synchrony in addition to positional accuracy. Our initial data analysis revealed that the local accuracy for initial pinching (see Fig. 6.V) was poor, and that there was no discernible pattern to the presicion of placement. Consequently, we decided to limit the analysis

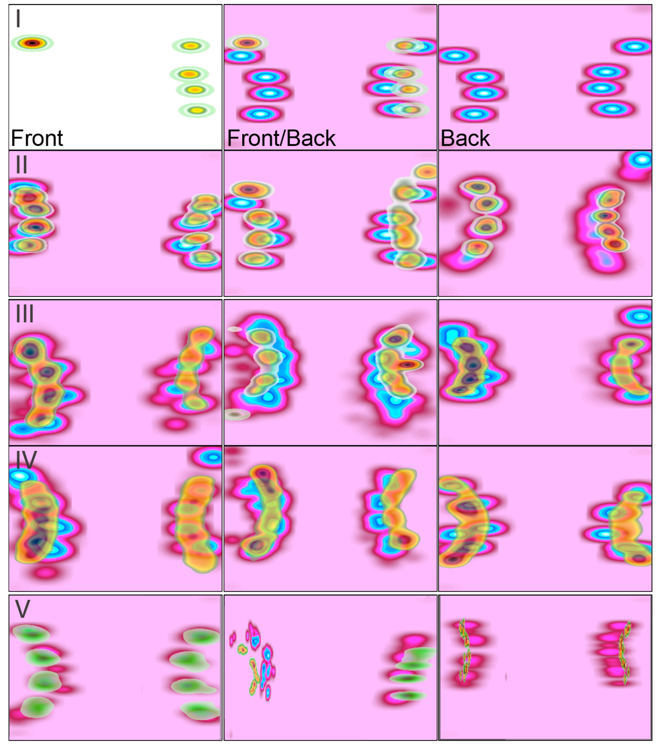

Figure 6. Row I shows the front and back touch events for rested pinching performed once with each finger of both hands. Row II shows the performance of 3 participants. Row III visualizes the slided pinch from index to all fingers. Row IV shows five circling sequences of three participants. Row V shows initial pinching. The interactions from rows II-V are performed five times per hand.

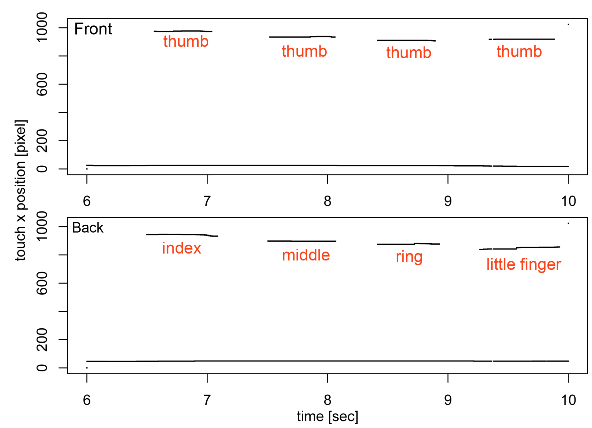

Figure 7 shows initial pinching. In contrast to the rested pinch, no finger is touching the device by default (just the grasping ones), but thumb and finger touch and release the PinchPad at the same time. Time synchrony between thumb and finger touch events has an extremely high accuracy and holds promise as a feature.

of the initial pinching to the time synchronization accuracy (see Fig. 7). For tasks where accuracy failed (B-D, see Tab. 1, row 1), we also analyzed the presicion to identify error patterns such as positional offset. These error patterns (in terms of positional offset) could provide richer information for classifying the gesture. Precision was determined in 2 stages: If four distinguishable areas per hand (one for each finger) could be defined over all five sequences, we took this data set as a pattern (see Tab. 1 row 2). In the second stage, we tried to explain the offset pattern for each participant and again tried to find a pattern that described the offset over all participants for task B-D: rested, slided and, circled pinching (see Tab. 1 row 3).

The average accuracy in time-based initial-pinch (ignoring positional accuracy) classification was 93.5 % (see Tab. 1). The errors were produced from 3 subjects (6.5%). Those error rates were 21%. 7 subjects performed the initial pinch correctly in all cases, when measured by time synchronization. The positional accuracy in the task that could not be classified by time was lower (see Tab. 1), but the presicion averaged over 84%. For errors that occurred during rested, slided, and circled pinching, we observed trends for pattern clusters, such as x-offset of the thumb position towards the hand palm for rested pinching, a y-axis down-scaled arc of the sliding thumb versus the fingers' arc, and a y-axis magnified arrangement of the circles versus the fingers' arc. For sliding and circling, some x- and y-offsets were also discovered, but not enough to form a pattern. Over all participants and all tasks, there was no performance difference in terms of error rates between the dominant and non-dominant hand of each subject. There were differences between users' abilities: some users performed better over all tasks. However, the performance ability between the two different hands was found to be quite similar.

Perceived performance and frustration

Pinch:	Initial	Rested	Circled	Slided
Accura-cy	0.935	0.819	0.736	0.652
Preci-sion	-	0.861	0.903	0.847
Error-Pattern	-	x-value towards palm	Up-scaled at y-axis	Down-scaled at y-axis

Table 1. Accuracy, precision, and error patterns for pinch.

Under all conditions, the mean ratings of the NASA-TLX performance scale ranged between 4 and 6 (middle of the scale). However, a repeated measure "Analysis Of Variance" (ANOVA) showed a statistically significant effect, $F(1.57,14.17) = 4.51$, $p_{2\text{-tailed}} = .038$, *part. eta²*= .334. Means and standard deviations for each condition are presented in Figure 8. Post-hoc tests with Sidak correction revealed a marginal significant difference ($p_{2\text{-tailed}} = .061$) between condition B and D only. In condition D participants rated their performance worse compared to condition B. Regarding the frustration scale, mean ratings varied between 2 and 4, indicating a rather low level of frustration. A repeated measure ANOVA indicated an only marginal significant effect between the four condition, $F(3, 11.40) = 4.10$, $p_{2\text{-tailed}} = .06$, *part. eta²*= .313. Means and standard deviations are displayed in Figure 8. Sidak corrected post-hoc tests showed no further differences.

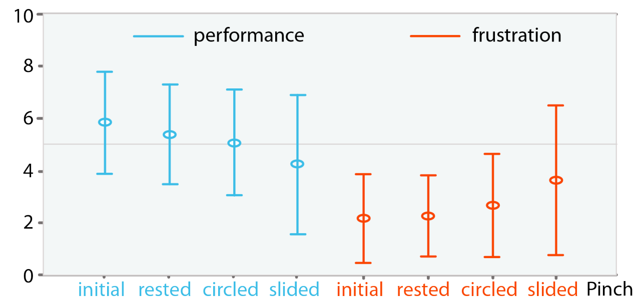

Figure 8 shows mean ratings (min=0/max=10) and SD of the perceived performance and frustration.

In a post-test open questionnaire, all participants agreed that the device form factor (weight, shape, depth) limits the gesture performance. They gave comments such as: "The weight of the device I felt limited the gesture after a certain amount of time." In regard to task confidence, the participants' answers varied more greatly. Three subjects answered positively (e.g. "Not a problem in terms of perception; in fact, easy" or "I was comfortable performing the task"), four neutrally and three negatively (e.g. "Blind and clumsy" or "Found this very difficult and did not feel confident"). All participants felt that they were not able to comment about their own performance, e.g. "No idea about accuracy!"

DISCUSSION

Using finger movements for interacting while grasping a device seems to be a promising technique in terms of *performance* even if no additional system guidance is offered. The pointing performance for initial pinch gestures is highly dependent on time synchrony. When compared to the positional accuracy of rested pinching, the initial pinch gesture is less precise. Also, gestures that start with a rested pinching (e.g. circled and slided pinch) lack accuracy. The reason seems to be that users are much better at moving their thumb and (hidden) fingers simultaneously than in statically positioning thumb and fingers when a device is in between them. A solution for increasing accuracy in slided and circled pinching could be to take the better performance in initial pinching as an "inspirational bit" [18] and replace the starting element of rested pinching with the initial pinching.

An alternative way to classify pinch gestures while keeping the rested pinch as the starting element would be to integrate error patterns in classification algorithms, such as identifying offset values and re-calculating touch positions. A reason for the offset might be the anatomy of users' hands. The middle-point offset in circling for outer fingers could be caused by the circle diameter, as it is not correlated with the closeness of finger anchoring in the palm of the hand. The offset for slided pinching is inversely proportional to the distance of the finger-tip from the palm, and the curves described by the sliding thumb are scaled-down versions of the true dimensions. This might be caused by the length of the thumb. The start and end point of the slider is defined through the grasp and the offset is stable within one data set per subject, and the offset might not have much effect if the slider collaboration is therefore performed dynamically when the grasp was first initiated. As long as the user defines their own slider dimension and refers to their self-defined interface layout, the absolute slider level could easily be measured by the relative distance between the start and end point, similar to the touch and turning point in dragging. Another way to deal with errors that appear through absolute pointing actions could be to rely more on relative commands. This may provide a better alternative compared to absolute commands when controlling volume or scrolling through content. However, if pinch-gesture performance lacks accuracy and therefore results in performance errors, these errors still could be corrected through integrating error pattern knowledge into gesture classification.

The ad-hoc grasping nature of the interface is both this technique's strength and weakness (see Fig. 9). On one hand, this permits the design of situation-aware interfaces that can be more dynamic, varying according to the needs defined by the grasp task and device. On the other hand, the analysis becomes harder. The dimensions of the grasp, which defined the interface layout, differ between users, because of differences in individual hand size or grasp styles. As explained by Wimmer [26], different people can grasp the same object differently. The grasp depends on individual parameters, such as hand size; but also on situational or object-dependent parameters. Therefore, an interface that uses finger movements optimally has its size and layout dynamically determined by the grasp and has to be calibrated dynamically and grasp-dependently.

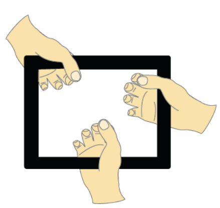

Figure 9 displays the dynamic character of grasping.

Beside log-file based performances analysis, we investigated participants' perceived performance. During the experiment, the participants were not given feedback as to whether they were successful. The perceived performance was therefore only an unconscious approximation. This may explain the reason why even when they had delivered a good performance that could serve as a feature, the participants estimated their performance to be mediocre. Frustration was low, because usually users feel frustration only when they fail a task goal. In this instance this information was not given, and the participants were not certain whether they had performed correctly or not; this is consistent with answers from the open questionnaires, such as "No idea about accuracy!".

CONCLUSION

Users are able to perceive external (vision, audio, haptic) and internal (proprioception) feedback about their actions. Gesture-based human-computer interactions usually rely not only on vision and proprioception, but also haptic feedback if touching or grasping devices are involved. In this paper, we investigated grasp-releasing interaction techniques that rely not only on proprioception and touch, when the gesture performance is partly obscured through the grasped device itself. We found that users can perform gestures without seeing them with a high level of positional presicion in terms of thumb-based pointing towards fingers on the device's rear and accuracy in terms of synchronous tapping the thumb and a finger on the surface of the hand-held device. For the positional pointing, we could identify error patterns, such as pointing offsets and undershooting when the outer fingers (index, little) were targeted by the thumb. These patterns could serve for classification. Gestures that rely on time synchronization have a high accuracy and therefore are most promising for interactions with a limited view of the gesturers' performing hands. If we generalize from the findings about users' performance of pinch-based interaction while grasping a device, the body's own feedback (proprioception and haptic) can adequately guide invisible gestures, especially if there is an embodied reference such as the thumb while pinching. However, users still do not know if the command was understood by a computer system: that is shown through a perceived performance which is much lower than the actual measured one. An interesting finding was the fact that the participants perceived their performance to be lower than the measurements show. Therefore the body's own feedback systems cannot replace end-of-gesture feedback in terms of notifying stimuli or immediate system changes. Users need this information to know if they are performing correctly.

FURTHER WORK

After identifying promising features for recognizing finger movements, it would be very interesting to develop wearable prototypes that are able to classify finger gestures based on time or movement-dependent parameters using sensors, such as accelerometers, magnetometers or gyroscopes that are worn on users' fingers. There has been some research on interface development using sensors [1, 4, 19]. Guidance or end-of-gesture feedback that users need for feeling comfortable with gesture interactions has still not been investigated deeply and will lead to our ongoing work.

Interpreting a grasp as a user interface could also improve interaction with devices that have unconventional form factors, such as organic user interfaces like flexible displays [8, 15]. Pinch-based gestures could give richer feedback for these interfaces, because the thinner the device is the more haptic feedback is felt while grasping the device.

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