MobiZone: Personalized Interaction with Multiple Items on Interactive Surfaces

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ABSTRACT

Current interactive surfaces do not support user identification. Hence, personalized applications that consider user-specific access control are not possible. Diverse approaches for identifying and distinguishing users have been investigated in previous research. Token-based approaches – e.g., which utilize the user's mobile phone – are especially promising, as they also allow for consideration of the user's personal digital context (e.g., stored messages, contacts, or media data). However, existing interaction techniques are limited regarding their ability to enable users to manipulate (e.g., select or copy) multiple items at the same time, as they are cumbersome when the number of files exceeds a certain amount. We present MobiZone, a technique that enables users to interact with large numbers of items on an interactive surface while enabling personalized access by using the mobile phone as a token. MobiZone provides a spatial zone that can be positioned, resized and associated with any action according to the user's needs; items enclosed by the zone can be manipulated simultaneously. We present three interaction techniques (FlashLight&Control, Remote&Control, and Place&Control) that enable users to control the zone. Additionally, we report the results of a comparative user study in which we compared the different interaction techniques for MobiZone. The results indicate that users are fastest with Remote&Control, and they also rated Remote&Control slightly higher than the other techniques.

Categories and Subject Descriptors

[**Human-centered computing**]: Interaction techniques; Human computer interaction.

General Terms

Human factors.

Keywords

Mobile phone; interactive surface; spatial control.

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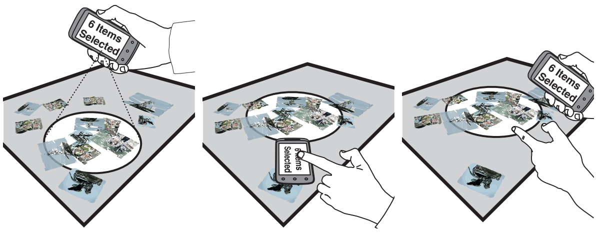


Figure 1: Using MobiZone, the user can control the position and size of the zone, which enables personalized interaction with multiple items via different techniques (FlashLight&Control, Place&Control, and Remote&Control).

1. INTRODUCTION

Interactive surfaces are promising devices for many kinds of applications, such as managing large amounts of files which are displayed on the surface. For instance, the form factor of table-top surfaces enables users to access and manipulate data simultaneously, and thus facilitates collaborative applications (e.g., [28]). While it is possible to distinguish users [8], there is no standard technology for user identification. As a result, it is not possible to automatically personalize applications on interactive surfaces efficiently. Therefore, many research efforts have been devoted to approaches for identifying users on interactive surfaces (e.g., [3, 15, 19, 20]).

One category consists of *token-based approaches*, which use the user's personal mobile phone for identification (e.g., [21]). This has the advantage that the mobile phone can also be used as a storage device of the user's personal digital context, which allows for pick-and-drop interactions as first introduced by Rekimoto et al. [18]. For example, this supports the selection or manipulation of a specific target on a surface. However, such techniques are limited, as they do not allow users to select multiple items at the same time. This may be the case when a user wants to select and copy a larger number of photos from the surface to their phone.

In this paper we present MobiZone, a novel approach for supporting effective and personalized interaction with multiple items on interactive surfaces (see Figure 1). MobiZone provides each user with a *spatial zone*, which is linked to the mobile phone and acts as a visual representation of the user on the surface. The zone can be positioned and resized, and it can be associated with any action (e.g., copy, cut or delete items). Multiple items such as photos or contact cards, which are located within the spatial zone on the surface, can thus be manipulated simultaneously. This limits the grouping of items to those which are spatially close to one another, and therefore makes our approach applicable to arbitrary item types that are not known in advance.

We present three options for the implementation of this concept, which results in three interaction techniques to control the zone: FlashLight&Control, Place&Control, and Remote&Control (see Figure 1). We further contribute the results of a user study in which we compared the three techniques in order to gain insight as to which option is best suited to support users in a variety of generic interaction tasks. A simple blackboard application was implemented for this purpose, allowing users to share personal items with each other via the tabletop surface. In particular, it allows users to move items from one position on the surface to another, as well as to copy items from the personal phone onto the surface, and vice versa.

2. RELATED WORK

There exists a large body of work related to the presented MobiZone approach.

Early work by Rekimoto and Saitoh envisioned and explored how to attain seamless interaction *across devices of multiple classes* in order to achieve a spatially continuous interaction space [18]. Ballagas et al. present a design space for interactive systems based on the use of smartphones as versatile personal input devices [1]. The high expressiveness of this design space is reflected by the amount of work that has been published within this space. One approach is work which integrates personal and shared devices that support cross-device interaction without considering the spatial relation between the different devices. Chehimi et al. explored an interaction technique based on the gesture of "throwing" items towards the surface, in order to share photos from a personal mobile phone on a shared interactive surface [6]. This approach includes a *proxy*, a visual representation of the user's phone on the surface, which acts as the link between phone and surface. For example, when the user *throws* a photo towards the surface, the photo appears on the surface within this proxy. By not considering the spatial relation of the mobile device and the surface, the devices are connected only in the sense that data can be transmitted. This approach is adapted by our work with the interaction technique Remote&Control.

However, taking into account the *spatial relation* between personal and shared devices yields a number of different advantages and benefits. For instance, placing a mobile phone on an interactive surface in order to connect both devices for sharing of data such as photos [27], allows for the use of both hands for further touch interactions on the surface. Bringing different (i.e., personal and shared) devices physically close together in order to trigger actions such as picking up or sharing data is also a well-investigated approach. For instance, Sugimoto et al. present the system Caretta, which supports co-located collaborative tasks such as city planning [25]. Users gather around a shared surface while each user is equipped with their personal device ("personal space") for individual work phases. In order to share results of individual work created on the personal device, users can touch a position on the shared surface, whereupon the data is transferred to that location. In our interaction technique Place&Control, placing the mobile phone on the surface is also used to establish a connection between the two.

Other recent work considered touching the surface with mobile devices in order to gain sophisticated control of the content displayed on the shared surface [24], and as a means for supporting effective co-located collaboration [23]. *Spatially-aware hand-held displays* enable, for instance, the exploration of volumetric data that is displayed on and above a tabletop device [11]. Other researchers investigated the versatile possibilities that result from taking into account the spatial relation between mobile devices and shared displays when interaction takes place over a distance. Boring et al. present Shot&Copy that allows the transfer of data from a shared public display to the user's mobile phone [4]. Furthermore, [5] investigated the approach of using a hand-held mobile device to apply touch interactions to a remote public display. Baur et al. present the concept of virtual projection [2], whereby a mobile phone located in front of a display "virtually" projects a frustum towards it. The rectangle that results from the frustum's intersection with the display acts as a virtual projection screen, controlled by the user's mobile phone. The resulting possibilities of interacting with and controlling the virtual projection inspired our FlashLight&Control interaction techniques, which allows for the modification of the MobiZone's visual representation with a spatially-aware mobile phone.

Interaction and information visualization *above tabletop devices and surfaces* have been investigated intensively. This space offers versatile design opportunities for combining interaction in a continuum with interactions on surfaces [13]. For instance, Benko et al. explored multi-modal, touch-based interactions on an interactive surface [3]. They combined the surface sensing with electromyographic data measured on the user's arm. This data enables continuous interactions starting on the surface and ending above the surface, such as picking up an item. Other related work used depth cameras to track the user's hands, and sense gestures above the surface (e.g., [10, 17]), which does not, however, support user identification or personalized interactions. Identifying users of interactive surfaces is of particular interest in order to support *collaborative settings* wherein each user is granted specific rights to access information or actions. Dietz et al. presented DiamondTouch, which distinguishes users but it not able to identify them [8]. Similar, Martinez et al. used a depth camera to correlate touch events with the user's body to distinguish between different users [14]. These approaches however do not support identification but only user distinction.

Meyer and Schmidt proposed wrist bands worn by the user, which are equipped with infrared LEDs that send a code to the surface when the user's hands come close to a touch [15]. Schmidt et al. presented *hands-down*, a biometrics-based approach [19] whereby users place their hands on the surface and the contours are used for identification, thus e.g. enabling access to a personal clip board. In addition, mobile phones have been used as tokens to identify users of a shared interactive surface; an approach which enables diverse interactions (e.g., [21, 22]). However, none of these papers considered opportunities for applying such interaction techniques to *multiple items* on an interactive surface.

Only few publications addressed the option for touch-based interaction with *multiple items* on surfaces. For example, North et al. present *one-handed hull-selection* and *two-handed transport* [16]. The latter is a bi-manual technique by which a rectangle is spanned over multiple items on a surface to select and move them. Other related work focuses on managing and aligning multiple items on a surface (e.g., [26, 9]). However, none of them considered possibilities of *personalized access* for manipulating items on the surface. MobiZone combines personalized access with manipulation of multiple items by using the mobile phone as a token which allows for user identification.

3. CONCEPT

The concept of MobiZone is based on the observation that users often have the need to select and manipulate multiple items on a surface simultaneously (e.g., two-handed transport as introduced by North et al. [16]). At the same time, user identification for managing access to items on the surface is a key requirement in many application contexts such as collaborative settings (e.g., [15]).

To address both requirements, MobiZone enables users to select and interact with multiple items on an interactive surface by providing a visual zone that is connected to the user's mobile phone. Hence, the user first has to connect the phone to the surface. The mobile phone serves as a token that allows for identification to the surface, thus enabling personalized access to specific items. At the same time, the phone serves as a versatile tool to perform different kinds of actions that can be customized with the phone. Users can change the zone's *X/Y position* and *size*, as well as the *actions* (e.g., transferring items from the phone to the surface) which are applied to the items within the zone.

In order to take advantage of the ability to select and manipulate multiple items simultaneously, users require effective and efficient interaction techniques for controlling the zone. In the following, we introduce three different approaches that allow for MobiZone-based interactions. We explain the techniques by means of the exemplary action of moving multiple items from one surface position to another. Please note, however, that any other action can be performed on a selection of items. For instance, the user could cut items and store them, making the phone a *personal clipboard* as introduced by Schmidt et al. [20].

3.1 FlashLight&Control

The first technique allows users to control the position and size of the spatial zone by holding the mobile phone in the hand and moving it over the interactive surface. To control the size, the movement of the phone along the Z-Axis in the 3D space over the surface is tracked and mapped to the zone size (see Figure 2(a)). The X/Y position of the zone can be controlled by moving the phone in parallel to the surface plane (see Figure 2(b)). Similar to a real flashlight, for which both its position and orientation determine where the light cone appears, the position and size of the zone additionally depend on the *orientation of the phone.*

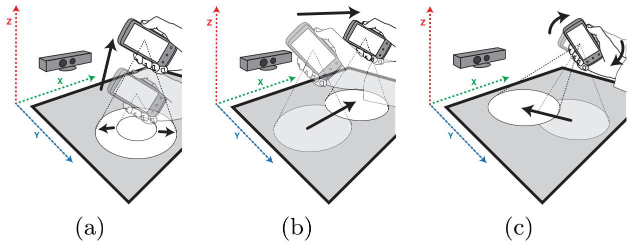


Figure 2: Using the FlashLight&Control interaction technique to (a) control the size of the spatial zone as well as its position by (b) translating or (c) rotating the mobile phone.

In order to move multiple items on the surface with FlashLight&Control, the user first locates and adjusts the size of the zone over the desired items (see Figure 3(a)). Using a *hold* button on the phone, all items that are located within the area of the zone are bound to it until the user releases the button again. Once a selection of items is bound to the zone, the user can relocate them freely on the surface by moving the phone towards a new position (see Figure 3(b)).

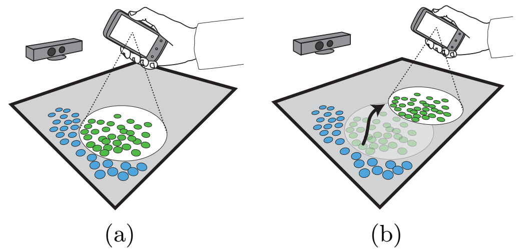
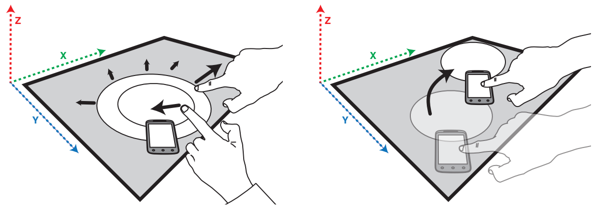


Figure 3: (a) FlashLight&Control enables the selection of multiple items by placing and resizing the zone over the items. (b) Using a *hold* button on the phone, items are bound to the zone for interaction, e.g. to move them to a new position.

3.2 Place&Control

The interaction technique Place&Control allows users to control the size and position of the zone by first connecting the mobile phone with the interactive surface and then placing it on the surface at a desired position. The phone has a visual marker attached to its back, and the zone appears next to the top of the phone when it is lying on the surface. To change the size of the zone, the user applies a *pinch gesture* on the surface (see Figure 4(a)). To change its position, the user moves the mobile phone (either by picking it up and placing it on the surface at a different position, or by dragging it along the surface). The zone follows as long as the phone is lying on the surface (see Figure 4(b)).

To move items, the user follows the same steps as with FlashLight&Control. First, the user adjusts the position of the phone, and therewith the position of the zone. Optionally, the user can also change the size of the zone to enclose a larger or smaller number of items. Finally, to move the selected items to another position on the surface, the user merely has to push a *hold* button, move the phone to the new position and push the button again to release the items.



(a) (b)

Figure 4: (a) Place&Control allows to control the spatial zone by placing the phone on the interactive surface; its size can be adapted with a pinch-gesture. (b) The position of the zone is bound to the mobile phone and follows the device.

3.3 Remote&Control

The third approach for controlling the size and position of the zone on the interactive surface is called Remote&Control. In contrast to the previous techniques, the position of the mobile phone is disjunct from the position of the spatial zone that is shown on the surface. Therefore, after initially establishing a connection between mobile phone and interactive surface to start a session, the zone appears at a random position on the surface (see Figure 5(a)). If the size of the interactive surface is too large to allow users to reach the randomly positioned zone, a further step would be required to select an initial position of the zone.

As with Place&Control, the user can change the size of the zone by using *pinch* gestures (see Figure 5(b)), while the mobile phone may either be placed on the rim of the surface or remain in the user's hand. To control the position of the zone, the user can drag it to a new position and release it there (see Figure 5(c)).

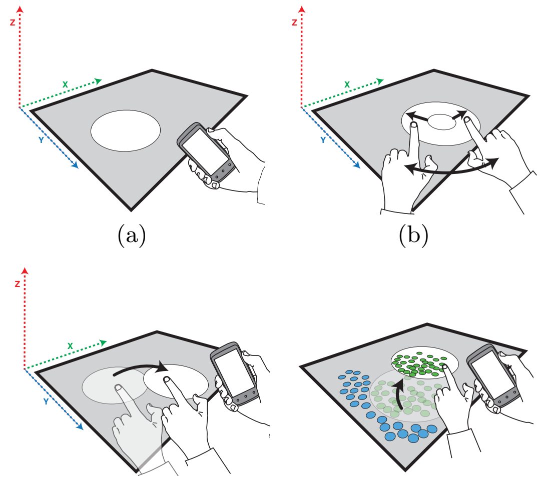
Accordingly, in order to move items to a new position on the surface, the user first makes a selection by positioning and resizing the zone over the desired items. Afterwards, the user pushes a *hold* button on the mobile phone to bind the selected items to the zone. Finally, the user drags the zone to its new position and releases the button. Throughout the interaction, the position of the mobile phone in relation to the surface is of no relevance.

4. IMPLEMENTATION

For the implementation of the three interaction techniques discussed in the previous sections, we built a simple blackboard application that allows users to share personal items via an interactive surface. We used Microsoft PixelSense as the surface device. For the communication between mobile phone and surface, a socket connection is established. In order to track the phone's position in space above the surface for the FlashLight&Control interaction technique, we used a Kinect sensor which was mounted close to the surface.

4.1 System Architecture

The three main components of the system are the tabletop surface, the mobile phone and the Kinect sensor (see Figure 6). The connection between the mobile phone and the surface is established via TCP, and the Kinect sensor forwards data to the surface via USB. The application developed for the Microsoft PixelSense is based on the Surface 2.0 SDK. It controls the adaptation of the view based on the user's interaction with the display, and it also processes the Kinect sensor data.



(a) (b) (c) (d)

Figure 5: (a) Remote&Control initially places the spatial zone at a random position. Users can (b) resize the zone using gestures and (c) drag-and-drop it to a new position. (d) Enclosed items are bound using a hold button on the phone and repositioned using touch interactions on the surface.

The messages which are delivered between surface and mobile phone belong to one of four different categories, depending on the type of the exchanged data: interaction data of the user on the mobile phone, system information, data of transferred objects to and from the tabletop, and phone sensor data. The user's messages which arrive at the tabletop contain the identification number of the mobile phone, which is used to associate the phone with the correct user. The mobile application is based on the Windows Phone 7.5 SDK, and it handles interactions on the phone display as well as the processing of the socket messages over the phone manager. Additionally, the orientation of the phone, which is determined via its bult-in accelerometer, compass and gyroscope sensors using the combined motion API, is forwarded to the surface if required.

The mobile phone is represented on the surface with a visual zone as described in Section 3, which is a circle that can be positioned and resized by the user with one of our proposed interaction techniques. It our current prototype application, the items on the surface are represented with rectangles containing textual information as well as an image showing the item category.

4.2 Implementation of Interaction Techniques

FlashLight&Control . For this interaction technique, the user's body is tracked with the Microsoft Kinect sensor and processed via the Kinect SDK 1.0. Taking the distance above the tabletop into account, an additional axis is created

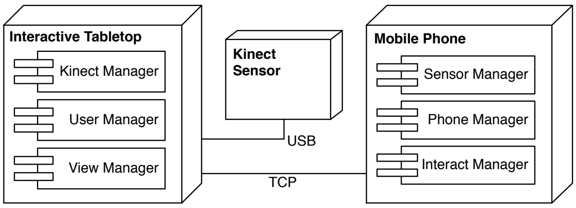


Figure 6: Component diagram of MobiZone.

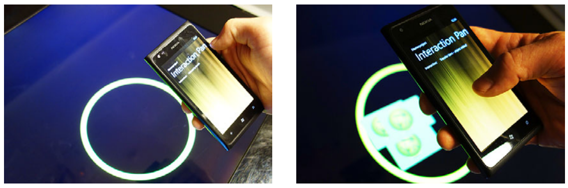
to enhance the interaction space. The application needs to map the coordinates of the sensor to the surface display, and they need to be scaled to match the display resolution. With these scaled coordinates, the position of the phone can be visualized with the zone on the surface as depicted in 7(a).

The data forwarded by the sensor consists of so-called *joints*, which represent twenty different points of the human body. As the user holds the mobile phone in their hand while performing interactions on the display, we assume that the hand position is equal to the position of the phone. This means that the joint position of the hand can be used to represent the phone's position on the display. The system provides the possibility to switch between left and right handed persons. The application receives the information regarding the tracked person from the sensor via the Kinect ID. This requires a mechanism which allows the system to determine which user corresponds to which Kinect ID. Therefore, we implemented a gesture detection mechanism to identify users to the system. After the mobile phone has been connected, the user has to perform a simple waiving gesture, which allows for the association of the ID of the mobile phone with the respective Kinect ID. This provides the possibility that multiple users can interact with the system at the same time.

To be able to detect the user's position in front of the tabletop surface, the boundaries of the display need to be defined. A *calibration program* helps to estimate the edge positions of the display in relation to the Kinect data, and map them to the coordinate system of the surface. The resulting data needs to be scaled to match the resolution of the screen. The resulting coordinates can then be used to position the spatial zone on the surface. The X- and Y-axis, as well as the Z-coordinate are used to adapt the size of the zone. If the distance grows larger, the diameter of the circle also increases to allow the selection of a greater amount of objects. The inaccuracy of the Kinect sensor required a low-pass filtering of the raw sensor data.

The user's interaction with the phone display is related to touch gestures. The three main gestures which were implemented are a flick gesture to transfer objects, a tab-and-hold gesture to move object as illustrated in 7(b), and finally a double-tab gesture to preview focused objects on the surface. In any of this interactions, the user always initiates the process on the phone. The items on the surface can be selected over phone touch interactions, as if they would appear there. Because of the direct connection between tracking and zone position, the interactions become intuitive.

The usage of the Kinect sensor for tracking users around the tabletop surface imposes mainly two limitations. First, the



(a) (b)

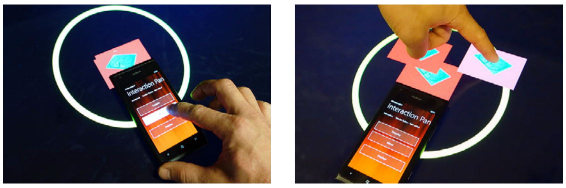
Figure 7: (a) The phone position is represented with a spatial zone on the surface using the FlashLight&-Control interaction technique. (b) With gestures on the phone, actions such as moving the focused items can be performed.

sensor requires a free line-of-sight to the persons' hands. Especially in a multi-user scenario with users standing around the surface, this might not be fulfilled at any time. Second, the used Kinect sensor is only able to recognize up to six people and track up to two by locating their skeleton joints. Possible solutions to this problem would be the use of an alternative tracking system mounted on the ceiling, or the use of multiple Kinect sensors placed diagonally above the surface.

Place&Control **.** In contrast to the FlashLight&Control approach, the Place&Control interaction technique allows for the placement of the phone on the interactive surface as illustrated in Figure 8(a). The Microsoft PixelSense supports marker detection using *byte tags*. Such a tag represents a specific ID that is connected to a certain phone. Hence, we attached the tag to the back of the mobile phone. PixelSense provides the X and Y coordinates of the tag on the display. This data can be further used to represent the zone of the user on the display. Additionally, the user has the possibility to adapt the size of the zone with the help of a pinch gesture on the surface display. The exchange of system information and interaction data is again forwarded over the established connection between the mobile phone and the surface application.

The interaction on the surface is realized via buttons in the phone application as depicted in Figure 8(b). In comparison to the other proposed techniques which provide gestures, the interaction based on buttons was introduced as the phone may be shifted when performing gestures on its display. Because of the direct relation between the phone and the zone position on the tabletop, the technique is very intuitive to use. As no additional tracking system is required, there is also no limitation regarding the number of simultaneously interacting users. Furthermore, users can freely position themselves around the surface.

Remote&Control **.** In the Remote&Control approach, the zone position on the display can be manipulated via touch input. Therefore, the system first draws the zone at a random position on the display once the connection between the mobile phone and the surface has been established (see Figure 9(a)). Based on the information from the Microsoft PixelSense about which UI element is currently being ma-

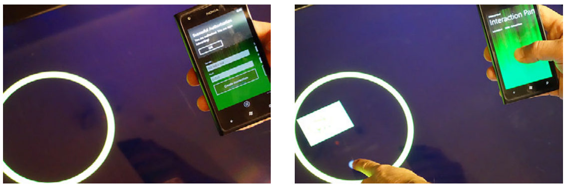


(a) (b)

Figure 8: Place&Control allows users to interact while the phone is placed on the surface (a). Furthermore, touch interaction on the surface can be used (a).

nipulated, the zone is repositioned if it is moved by the user on the surface. Furthermore, the user again has the possibility to adapt the size of the zone with the help of a pinch gesture on the surface.

Remote&Control provides gesture-based interaction on the phone display. The touch gestures flick for transferring, tab-and-hold for moving and double-tab for loading objects, are used in a similar way as in the FlashLight&Control approach. Figure 9(b) illustrates the tab-and-hold gesture on the phone's display and the repositioning of the zone using touch interaction on the surface. In contrast to the current implementation of the FlashLight&Control technique, there is no limitation concerning the number of people interacting on the tabletop surface and their arrangement around it.



(a) (b)

Figure 9: (a) The Remote&Control interaction technique represents the user with a zone that is randomly added to the surface. (b) Using the phone, the user can interact with objects that are located within the zone.

5. EVALUATION

We conducted a user study in order to compare the three different interaction techniques with each other. The aim of the study was to gain insights regarding the effectiveness and efficiency of the interaction techniques FlashLight&Control, Remote&Control and Place&Control, as well as about user acceptance and usability aspects. We decided to evaluate the interaction techniques in the context of the digital blackboard described in the previous sections.

5.1 Study Design

The user study was defined to gain quantitative measurement values collected by the system during the task execution. Besides the duration time of the tasks, some other quantities providing detailed feedback on the task completion were collected. The most important one is information regarding touch interactions on the surface and phone display, further quantities will be discussed in Section 6. Additionally, questionnaires were used to get additional information from the participants regarding the usability and handling of the interaction techniques.

The system application provides the possibility of collaborative interaction between multiple users, but the goal of the user study was the evaluation of the underlying interaction techniques. Therefore, we decided to conduct the study with just one participant at a time, thus allowing each one to perform the tasks on the system individually. This helps to exclude possible impacts of collaborative interactions on the study results. However, as our study mainly concentrates on the interaction between the system and the user device, we would expect similar results in a multi-user setting.

We used a within-subjects design; each participant evaluated each interaction technique. The user study tasks were performed twice for each of the three interaction techniques, once with three and once with ten items. The order of execution of the techniques and the number of items was counterbalanced using the Latin square approach. As a result, each of the twelve conducted participants started with a different order of tasks or amount of items.

The procedure of the user study was performed via several steps, starting with a short welcoming and introductory part, wherein each participant was informed about the practical tasks they were about to perform. After this step, the participant had to fill out a consent form giving us the right to further analyze the collected data. Afterwards, the first interaction technique was prepared and demonstrated, and the participant had the chance to learn how to perform the required interaction methods of the system in a short training session. The next step was to perform the three defined tasks with three and ten items at a time. To conclude the first interaction technique, the participants had to fill out a questionnaire. The evaluation process was continued by performing the task for the two remaining interaction techniques. At the end, the participants had to compare the different techniques with an additional questionnaire.

5.2 Tasks

The tasks for each participant consisted of (1) adding items from the phone to a certain position, (2) moving a specified quantity of items to another position on the surface, and (3) finding certain items out of set of randomly distributed items and transferring them to the phone. In the remainder of this section, these three tasks are described in more detail.

Evaluation task 1: Adding items. After connecting to the system with the mobile phone, the participant can start the first task. The application places a cross hair at a random position on the surface to which items from the phone are to be added. The participant can then start to add items to the zone position on the surface. If the final position of the zone does not overlap with the cross hair circle, the participant can adapt the position of the zone or that of individual items via multi-touch interaction on the surface. Figure 10 shows this task by means of the FlashLight&Control interaction metaphor. The participant adds items via a flick gesture (as

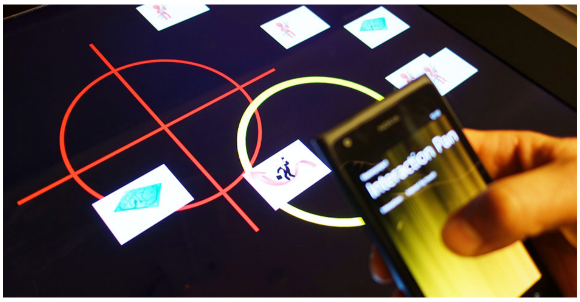


Figure 10: A cross hair marks the target location to which items are to be added from the phone.

suggested in e.g., [7]) to the target location represented by a red cross hair.

Depending on the interaction technique, there are different ways of adding items to the surface. In the case of FlashLight&Control and Remote&Control, participants perform a simple flick gesture on the interaction panel of the phone. In the case of Place&Control, adding items is performed via a button press on the phone, which we consider easier to use than a gesture as the phone is not held by the participant. After the required number of items – i.e., three or ten – has been added to the cross hair position, the task is finished. The participant will get immediate feedback both on the the mobile phone and on the surface display.

Evaluation task 2: Moving items. In the second task, the defined number of items (either 3 or 10) is randomly placed on the surface display, in addition to the cross hair which is also placed at a random position. These items belong to different categories that are visualized with a corresponding image, and the participant is informed via the mobile phone which category of items has to be moved to the cross hair position to finish the task. The participant can then start to move the objects to the specified cross hair location on the surface display. This task can be performed both using the *hold* button or the tab-and-hold gesture described in Section 3 and via multi-touch inputs on the surface display. The application recognizes when the correct number of items has been placed in the final cross hair location and informs the participant about the finished task.

Evaluation task 3: Finding items. The third task is about finding specific items that are placed on the surface. A defined number of items of different categories and with different textual information are randomly placed on the surface display. To finish this task, the participants have to find all items with the textual information "Find Me", which belong to a specific category known by the user.

To find the specified items, the participant has to move the zone position to an item to highlight it, or move the item via multi-touch interaction into the focus of the zone. The focused items which belong to the current position are shown with a preview functionality on the mobile phone.

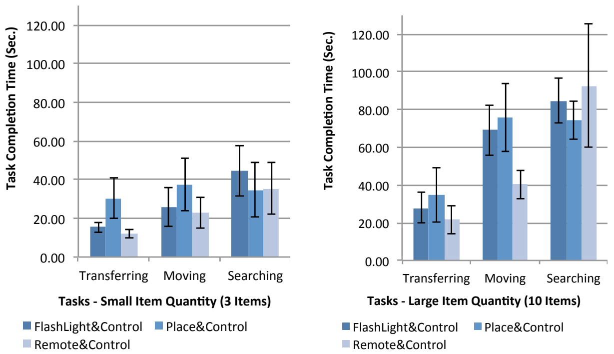
After browsing the preview information in the mobile phone application, the user can see if an item of interest has been selected or not. Finally, the required items have to be stored on the mobile phone by selecting them from the preview list, and saving them by confirming the information in the opened message box. The interaction for FlashLight&Control and Remote&Control is performed over the double-tab gesture, and for the Place&Control technique, a preview button is used to load the focused items.

5.3 Participants

We recruited 12 unpaid participants (11 male, 1 female). They were aged between 16 and 27 years (M=25, SD=2.9). All but one participant were right-handed. Most participants had a technical background: Five were members of the academic staff, six were students and one was a pupil. All participants were smartphone users and seven had prior experience with interacting with tabletop computers.

6. EVALUATION RESULTS

In this section we report the results of the evaluation, starting with task completion times and followed by the questionnaire results.



(a) (b)

Figure 11: Task completion times for the three compared interaction techniques performed with (a) three items and (b) ten items.

Task completion times. We measured the time for completing the study tasks. Each task was performed twice by each participant (in counterbalanced order). An overview of the task completion times is given in Figure 11(a) for three items and in Figure 11(b) for ten items. Using one-way repeated-measures ANOVA, we tested for differences between the interaction techniques on a task level. In cases where the criterion of sphericity has been violated, we used Greenhouse-Geisser correction to adjust the degrees of freedom.

Analyzing the results of task one, *transferring items* with a small number of items, we found a significant effect ($F(1.15, 12.27)=7.69$, $p=.02$). Pair-wise comparison shows that participants need significantly more time to finish the task using Place&Control compared to Remote&Control ($p=0.25$), but not when compared to FlashLight&Control ($p=.10$). Looking at the same task with a large amount of items (ten items), the differences between the interaction techniques are not significant (*p>.05*). However, the overall tendency persists that Place&Control results in the longest task completion time.

One explanation for this result lies within the task: users had to transfer items from the phone to the surface, which required interaction with the phone. However, this is more time-consuming when the phone is lying on the surface rather than held in the user's hand.

In the second task, *moving selected items* on the interactive surface, Place&Control also appears to be the technique that results in the longest task completion times. However, testing for significance shows that the differences are not significant when the task requires moving only a small number of items (i.e., three items in our case). In contrast to the previous task where the larger number of items caused an alignment of the results, here the larger number results in a significant effect of the interaction technique ($F(2, 22)=8.50$, $p=.002$). The post-hoc pair-wise comparison shows that users were significantly faster using Remote&Control compared to FlashLight&Control ($p=.002$) and Place&Control ($p=.01$).

However, looking at the amount of items that were placed unintentionally in the target cross hair (i.e., items of other categories that users were not asked to move), it appears that users performed best using Place&Control ($M_{PC} = 0$) compared to FlashLight&Control ($M_{FL} = 1$) and Remote&Control ($M_{RC} = 2.5$). At the same time, participants used significantly less touch input on the surface using the FlashLight&Control technique (small task: $F(2,22)=15.05$, $p<.001$; and large task $F(1.16,12.80)=14.36$; $p=.002$). For instance, during the large moving task, they performed an average of 4.75 (SD=5.72) touches on the surface using FlashLight&Control, compared to touching 19.08 (SD=6.9) times using Remote&Control and 35.83 (22.42) times using Place&Control. Surprisingly, this did not lead to a longer task completion time and larger error rate for the FlashLight&Control technique. Accordingly, holding the phone in the hand over the surface does not inherently lead to a reduced performance.

The results of the third task, *searching items*, which required the inspection of items in order to find and store specific items on the phone, did not show significant differences for either the small or large number of items. However, in contrast to the previous two tasks, Place&Control did not result in the longest task completion times. In fact, in both task variants, Place&Control resulted in the shortest task completion times ($M_{small} = 34.75$; $SD_{small} = 28.37$; $M_{large} = 74.17$; $SD_{large} = 19.83$). One possible explanation for this finding is that the phone, on which the category of the currently inspected items is displayed, is spatially close to the item. Hence, the context switching (between item on the surface and detailed information on the phone) is quicker and less disruptive.

Post-hoc questionnaire. After finishing the practical tasks with each interaction technique, we asked participants to rate the tested technique regarding perceived *effectiveness*, *efficiency*, *comfort*, and *speed* while performing the tasks of *adding items*, *moving items*, as well as *searching items*. Accordingly, participants rated each technique with regard to 12 statements. However, using Friedman's ANOVA to test for differences shows that no significant differences can be identified. Therefore, we can conclude that subjective perceived differences are of minor importance for the choice regarding which interaction technique should be selected for a specific application.

In addition, we asked participants to fill out the Post Study System Usability Questionnaire (PSSUQ) [12]. Figure 12 gives an overview of the summarized and weighted results (weighting factor: 0.94) of the values *Overall*, *SysUse*, *InfoQual* and *InterQual*.

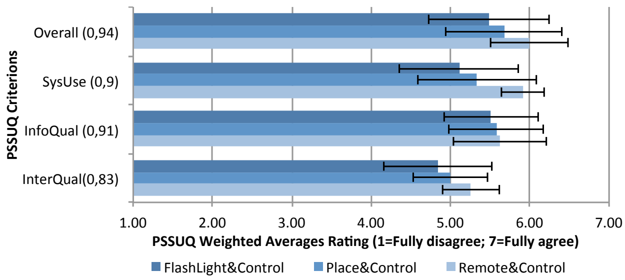


Figure 12: Weighted result of the PSSUQ values.

The *Overall* value summarizes all 19 questions of the PSSUQ. The small differences (no significance) between ratings for Remote&Control (6.00 points), Place&Control (5.68 points) and FlashLight&Control (5.49 points) are aligned with the previous user ratings. Regarding all four values, Remote&Control was rated slightly better than the other interaction techniques.

User feedback. In addition to the questionnaires, participants had the opportunity to highlight any aspect regarding the techniques which they particularly liked or disliked.

Six of the participants praised FlashLight&Control as a novel technique that "enables natural interaction" while controlling the spatial zone on the surface. Further, two participants highlighted that they found that FlashLight&Control enables efficient task completion. On the other hand, the majority of participants (8) expressed that the position tracking of the hand lacks accuracy and needs to be more robust.

Regarding Place&Control, four participants emphasized the positioning of the zone through placing the phone on the surface. For instance, P8 stated "moving items is fast" using Place&Control. Additionally they stated that the interaction technique was easy to use and could be a nice add-on for current mobile phone applications. As a downside, several participants criticized that controlling the exact position of the zone can be difficult in situations when working close to the surface rim, which could collide with the phone.

Concerning the Remote&Control technique, five participants praised the concept as easy to understand. Four participants expressed that they liked this interaction technique best. For instance, Remote&Control is "most intuitive, and best performing overall" (P6). In particular the aspect of precise positioning of the zone was highlighted several times (e.g., "It was easier to move the zone with the hand." P12).

7. DISCUSSION AND CONCLUSIONS

In this paper, we presented three interaction techniques, FlashLight&Control, Place&Control and Remote&Control, which enable users to interact with large numbers of items on an interactive tabletop surface by using their mobile phones. On the one hand, the use of this personal device allows for an identification of the user, which is important, e.g., to grant specific access rights to the users, and on the other hand, to share private data on the public screen, which can be transferred from and to the mobile device. The proposed interaction techniques provide state-of-the-art mechanisms for the simultaneous manipulation of multiple items on the interactive surface. At the same time, personalized access control can be supported by using the phone as a token.

With the three techniques, our aim was to utilize the spatial relation between the user's mobile device and the surface display. We presented the idea of a spatial zone to be displayed on the surface, which is connected to the user's phone and can be positioned, resized and associated with any action according to the user's needs. This means that the user can perform actions for all items that are enclosed by this zone, which provides a comfortable and flexible means of manipulating multiple items simultaneously. In order to tighten the perceived spatial relation between mobile phone and surface, we linked the phone's position to that of the zone in the techniques FlashLight&Control and Place&Control.

The presented interaction techniques were partially inspired by previous work as described in Section 2. We implemented them using the same, specific hardware setup, which allows for a direct comparison between the three techniques in the presented user study. However, we have not compared the results of our user study with that of related work yet, as they are not directly comparable due to the differences in the system implementation and the study design. As stated above, an advantage of our techniques is that they allow for personalized interactions in collaborative settings. Yet, the goal of the user study presented in this paper was the evaluation of the three interaction techniques with regard to their effectiveness, efficiency, and usability, as well as their comparison to each other. Hence, we conducted the user study with single user scenarios for now, in order to exclude potential effects from collaboration which could affect the results.

The insights concerning the interaction techniques and their performance during the user study require a closer look at the correlations of the recorded data. Especially the possible manipulation of objects via multi-touch interaction provides the participants with a second form of interaction. This relation can have a major impact on the result and it is therefore important to take multiple quantities into account for valuable feedback on the different interaction techniques. The Place&Control technique requires a longer task duration time to complete the task of transferring objects to the tabletop. This longer time can be explained by the fact that the participants have to place the phone at the specific location and use additional buttons instead of gestures. Performing interactions on the phone by holding the phone in the hand is more comfortable than placing it on the surface. The results of task 2 of the user study showed a faster task duration time for the Remote&Control technique. The participants felt comfortable positioning the items into the zone via multi touch interaction and then moving all objects to the cross hair position. The feedback from the questionnaires shows that Remote&Control provides the most comfortable interaction. Interestingly, the FlashLight&Control technique performed comparatively equal for the task duration time and error rates in relation to the other techniques during the whole study. Because of the low number of multi-touch interactions on the tabletop, it can be seen that the participants mainly used phone interactions to complete the tasks. The link of the hand with the zone position on the surface seems to hinder the participants in performing multi-touch interactions. Participants held the phone in their preferred hand, and thus used the non-dominant hand to perform the multi-touch interactions on the tabletop.

The basic intention of the proposed techniques was to provide a combination of body movements and multi-touch interaction, but the results showed that the technique was mainly used as a phone-only interaction technique. The user study was performed by single users on the tabletop. Extending the viewpoint to collaborative interactions, the user study could be performed again with the same tasks, in order to compare the outcome with the current results, and thus see the possible impact of collaborative approaches. Additional aspects such as the interference of users in their interactions could be analyzed for further findings.

The implemented techniques provide the possibility to interact with multiple items simultaneously. Also implementing techniques that are designed for single-object manipulation could help getting a better understanding of the impact of the item size. Analyzing the impact of the underlying system could be done by applying the same tasks and comparing different systems and their implementations in another user study. Finally, another open issue is the consideration of arm fatigue. It is an issue especially in combination with the FlashLight&Control technique where the user has to hold the phone over the surface for interaction, and could be investigated in future user studies with longer task duration times.

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