Extending Large Pen-Based Displays With Small Devices

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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Hagenberg, July 30, 2014

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Kurzfassung

Smartwatches stellen eine neue Kategorie von mobilen Endgeräten dar, diese werden auf unaufdringliche Weise getragen und verwendet. Diese Eigenschaften stellen sich als besonders interessant in kollaborativen Multi-User Umgebungen dar. Benutzer benötigen in kollaborativen Umgebungen eigene Arbeitsbereiche, in welchen sie die Arbeit einer anderen Person nicht stören. Im Rahmen dieses Kontexts ermöglichen Smartwatches neue Interaktionsmöglichkeiten, weil sie als persönliche, tragbare Endgeräte zur Unterstützung individueller Arbeit von Benutzern verwendet werden können.

Diese Arbeit exploriert die Grenzen und Chancen der verschiedenen Kombinationsmöglichkeiten von Smartwatches in Verbindung mit großen, stift-basierten, interaktiven Whiteboards. Wir untersuchten die gemeinsame Verwendung von diesen Endgeräten, mit dem Ziel neue Interaktionstechniken zu entwickeln. Diese Interaktionstechniken ergeben sich durch das Tragen der Uhr auf der dominanten oder der nicht-dominanten Hand und durch die Bedienung der Smartwatch mit einem Stift oder Finger. Wir entwickelten eine Smartwatch Anwendung, welche die Interaktionsmöglichkeiten von Whiteboards erweitert. Eine empirische Anwender-Studie wurde durchgeführt um die Interaktionstechniken und die Benutzeroberfläche der Smartwatch zu evaluieren, sowie Beobachtungen, Gestaltungsvorschläge und Orientierung für zukünftige Arbeiten zu bieten. Die Resultate der Studie zeigen, dass die von uns entwickelte Interaktionstechnik namens „Pen Pen“ die Eingabemöglichkeiten auf der Benutzeroberfläche verbessert. Der Datenaustausch zwischen den beiden Endgeräten mit dem Stift ist für die Benutzer am natürlichsten.

Abstract

Smartwatches represent a new category of personal devices that can be worn and used in a non-intrusive way. These characteristics are especially interesting within collaborative multi-user environments. Collaborative environments require individual workspaces in which an action of one person does not interfere with another person's work. Smartwatches create new interaction options within this context as they can be used as personal wrist worn tool palettes to support users' individual work.

For that reason, this work explores the limits and possibilities of combining smartwatches with large pen-based interactive whiteboards. We investigated various ways for combined use of these devices in order to create new interaction techniques. This interaction techniques evolve from wearing the watch on the dominant or non-dominant hand and using a pen or touch as input on the display of the smartwatch. We developed a smartwatch application, which expands the interaction space of whiteboards. An empirical study was conducted to evaluate the interaction techniques and interface of smartwatches as well as to provide insights, observations, design recommendations and guidance for future work. Results revealed that our interaction technique, called "Pen Pen", improved the input accuracy on the smartwatch's interface and that data transfer with pen on both devices was more natural for users.

Chapter 1

Introduction

With recent improvements in processing, sensing and displays in ubiquitous mobile computing new form factors became possible. Devices, which fit into our pockets, can be worn on the body or can be embedded into our clothing are available.

Besides this, large interactive surfaces such as tabletops and interactive whiteboards populate workspaces and schools. Whiteboards support co-located group work, including corporate boardrooms, work groups and classrooms at all levels of education. The ubiquitous access to personal devices leads to situations where several people interact on multiple devices in the same room [6, 25].

Smartwatches represent a new category of personal devices that can be worn and used in a non-intrusive way. These characteristics are especially interesting within public environments that are equipped with large interactive surfaces. At present, Multi-Display User Interfaces (MDUI) scenarios primarily focused on using a secondary mobile device such as a smartphone as pointing device [26] or remote control [2] for a large display. The availability of smartwatches creates new interactions because they can be worn on the wrist and used without attracting attention.

Hence, this work explores the limits and opportunities of combining smartwatches with large interactive whiteboards. To approximate this vision, we started by defining the use case that smartwatches can be joined with interactive pen-based whiteboards in order to enhance the selection of menu-items or the storage of items on the watch. Specifically, our goal is to explore various ways for the combined use of these devices to create new interaction techniques for users. These interaction techniques arise from the different uses (wearing the watch on non- or dominant hand) and input possibilities (pen and touch). To realise this vision, we developed a smartwatch application, which allows users to transfer data onto a whiteboard. We compared the different interaction techniques within a study.

1.1 Smartwatches

First watches were kept in pockets and since the invention of the wristwatch in the early 1900s they have been a wearable technology. Wristwatches undergo continuous development since that time [14]. In 2000, IBM demonstrated the first watch running a full operating system [20]. Recently, wristwatches with additional computer functionalities, so called smartwatches, have experienced a revival of interest because late improvements in computing allow miniaturisation of mobile devices. They provide a wireless connection to a phone or to the Internet. One of the main advantages is that they can be worn and used in a non-intrusive way.

Besides popular crowd funded smartwatches (Pebble[1], Omate[2], Kreyos[3]) prominent manufacturers such as Sony[4], Samsung[5] and Qualcomm[6] have recently released their own smartwatches. These devices rely on voice and/or small buttons and/or touch screens for input.

Product comparisons have shown that there are basically two types of smartwatches: Most smartwatches on the market today act as companions for mobile devices, so called *addon smartwatches*, letting users view smartphones' notifications or app content on their wrist. *Standalone watches* do not need an additional device to operate with its full feature-set.

1.2 Combining Smartwatches With Whiteboards

MDUI enable people to take advantage of different characteristics of display categories. Many smartwatches were originally intended as an extension for smartphones in order to show notifications or incoming calls. Smartwatches are not only suitable as enhancement for smartphones, as users can benefit from extending large public whiteboards with smartwatches in MDUIs.

Collaborative environments require individual workspaces, where an action of one person does not interfere with another person's work [25]. Onscreen solutions for each user occlude valuable screen space on public whiteboards. On these grounds, whiteboards are extended with external devices or tool palettes. Pen-based tool palettes are often misplaced and they are unnatural to use because of the missing feedback. Smartwatches promise to bring improved convenience to this context as they can be used as wrist worn tool palettes to support users' individual work. Their use solves the problems of on-screen menus and additional pen-based palettes.

In order to support joined use of these devices we explored various tech-

[1] More information about the Pebble smartwatch is available at https://getpebble.com.
[2] Omate TrueSmart: www.omate.com
[3] Kreyos Meteor: www.kreyos.com
[4] Sony smartwatches: www.sonymobile.com/gb/products/accessories/smartwatch/
[5] Samsung Gear: www.samsung.com/at/consumer/mobile-phone/wearables/galaxy-gear
[6] Qualcomm Toq smartwatch: https://toq.qualcomm.com/

(a) (b)

Figure 1.1: Setup ERiC project (a) and small segment of signs for emergency planning (b).

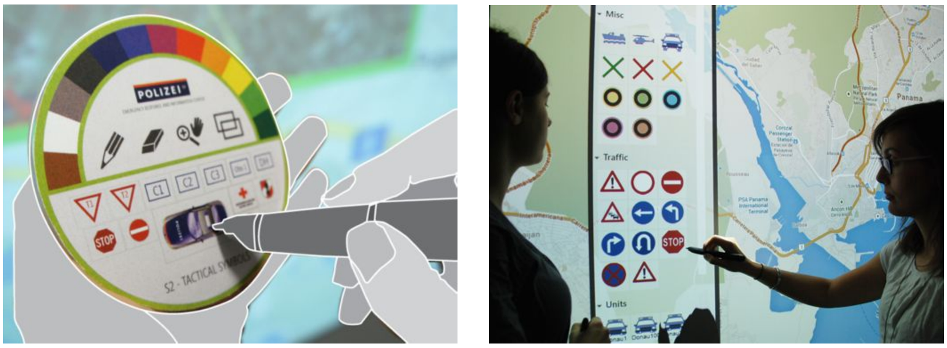
niques for combining smartwatches with whiteboards. These techniques arise from wearing the watch on non- or dominant hand and using pen or touch as input on the smartwatch's interface. The names of the techniques (*Bimanual Pen Touch*, *Pen Pen* and *Pen Touch*) derive from the hand and input on the watch. We compared the different interaction techniques and interfaces for the smartwatch within a study.

Combined use of whiteboards with smartwatches can be interesting in numerous application scenarios, in the following part we like to discuss the use of smartwatches in our main scenario a *digital emergency control centre* as well as a *clipboard in MDUI*.

1.2.1 Smartwatch as Tool Palette in a Digital Emergency Control Centre

In order to support planning and decision-making, a digital emergency control centre was developed for the Austrian police, cf. Figure 1.1 (a). The name of the emergency control centre is ERiC [9, 10]. It supports the coordination of police operations with large interactive maps.

Operators at an emergency response centre work in a stressful environment. They often need to coordinate rescue teams from different organisational units on varying levels of detail within a short time. Geographic maps play an important role for coordinating emergency situations. A vertically orientated wall-sized whiteboard map provides an overview for the command group. Pen input supports quickly annotating the map by drawing.



(a) (b)

Figure 1.2: Pen-based palette (Courtesy of Media Interaction Lab) (a) and on-screen menu (b).

Besides the large maps additional information alleviates the planning of emergency situations. *Symbols* such as different cars, traffic and danger signs can provide additional information. Therefore different signs have to be allocated in order to describe the situation, cf. Figure 1.1 (b). The signs create a common ground for the description of situations and the accomplishment of operations. Especially when numerous operators collaborate in case of an emergency the embedding of meaningful signs is important. Research on perception of traffic signs indicates that as long as symbols are well designed, they can be processed as well as text or even more effectively than text [5]. Operators already learned the meaning of the signs, hence, the use of those is more effective than drawings or handwritten annotations on the map.

Two different approaches, tangible tool palette and on-screen menu, for the selection of signs were used in the ERiC project. During the use of these approaches some limitations were detected. First, the developers used external *pen-based tool palettes* for the selection of items, cf. Figure 1.2 (a). As the physical palettes were often misplaced, the search for them slowed down the planning of operations. Through the limited space on the palette not all relevant signs could be provided for selection on it. Enlarging the palette could not solve this problem, because a larger form factor would be uncomfortable for users. Moreover, palettes provide a fixed layout, therefore, the palettes cannot be personalised. Also, users were confused through the missing visual feedback of the static palette. In the second approach they used an *on-screen menu* on the board. The position of the menu can be changed on the screen. As visualised on Figure 1.2 (b) this menu occludes a quarter of the map, therefore, the menu hides valuable screen space. All users accomplish selection of signs on the menu. Menus for different users can be offered, but the personalisation of them would be tricky.

Our approach to solve these problems is to extend large pen-based displays with small high-resolution touch devices. Thus, we use *smartwatches as external tool palettes* for whiteboards (see Figure 1.3). We mainly focus on the selection of signs on the smartwatch and the transfer of these signs to the whiteboard. Smartwatches can be worn on the wrist, therefore, they cannot be misplaced. The touch display responses with visual feedback to users' actions. The smartwatch can be paired with a pen, thus, user identification and personalisation is possible. Smartwatches support simultaneous work of numerous operators on the whiteboard. Using the smartwatch as tool palette operators could not interfere in the work of others. Hence, a fluent planning of operations is possible.

Figure 1.3: Combined use of smartwatches with whiteboards.

1.2.2 Smartwatch as Clipboard in MDUI

Workspaces are equipped with numerous devices, such as personal computers, tablets, smartphones and large interactive displays. There is a need within these workspaces to exchange digital data between the devices.

For example in meetings or other collaborative scenarios participants want to share their personal information with others on a public display. For this reason, they usually have to connect their computer to a projector, or find a shared folder to put the document into. A more natural and faster way to share digital objects is to store them on a personal device. On these grounds, our suggestion to enhance the data transfer of objects between different devices is to extend MDUI with smartwatches as digital clipboards.

Users can select objects on their personal computer or tablet and then the selected object is stored on their smartwatches, cf. Figure 1.4 (a). Users can select on their smartwatch, which data they want to pass on the public display, cf. Figure 1.4 (b). After selection on the smartwatch they insert the item on the surface of the public display and the object is dropped at that location, cf. Figure 1.4 (c).

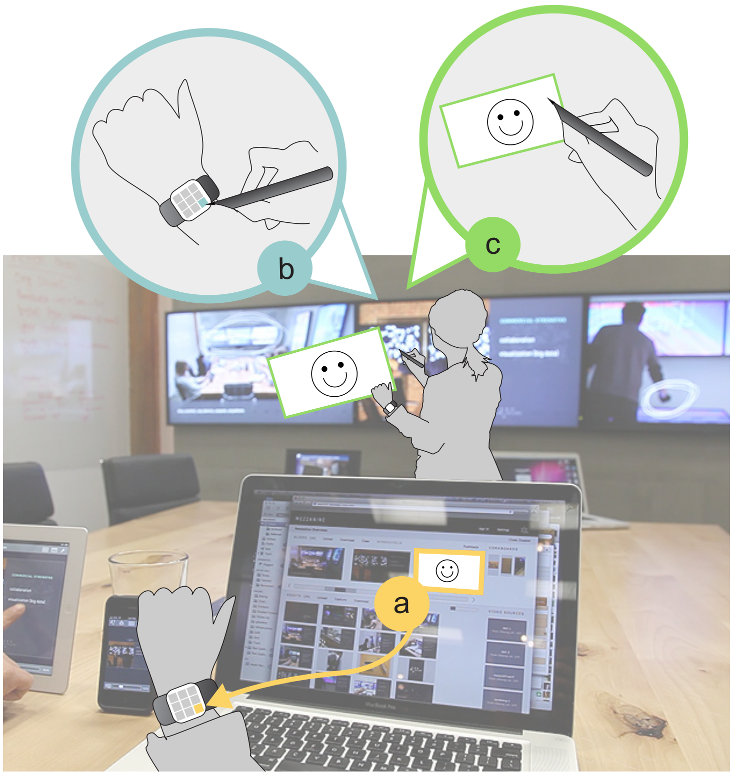


Figure 1.4: Save icon from personal computer on watch's clipboard (a), selection of icon on watch (b) and placement of selection on public display (c).

1.3 Contributions

The contribution of this thesis includes the exploration of constraints and benefit of combining smartwatches with large pen-based interactive whiteboards. We developed a smartwatch application, which allows the selection of numerous icons. In addition, we created new interaction techniques for the combined use of smartwatches on whiteboards. The different interaction techniques arise from wearing the watch on the non- or dominant hand and using a pen or touch as input on the smartwatch. These different approaches give the techniques their name: *Bimanual Pen Touch*, *Pen Pen* and *Pen Touch*.

We evaluated an extended smartwatch tool palette for whiteboards and the different interaction techniques for the transfer of data between the devices within a user study. We summarised the results of the study and derive suggestions for the design of applications combining whiteboards and smartwatches.

1.4 Outline

A short overview about the structure of this work is given here. In the beginning the background knowledge and related work will be presented in Chapter 2 in order to give a better understanding about this topic. The application design is presented in Chapter 3. The workflow, as well as the interaction techniques for joined use of smartwatch and whiteboard are also explained in this chapter. In Chapter 4, a look into the implementation of the system is presented. The study design is presented in Chapter 5. Chapter 6 includes details on results and discussion of the study, as well as design recommendations. Chapter 7 gives a conclusion of the thesis and an outlook on future work.

Chapter 2

Related Work

There are several projects that worked on similar issues within the field MDUI. Less research was conducted on combining smartwatches with large public displays. Our interaction technique for the transfer of data between smartwatch and whiteboard was most influenced by Rekimotos [22, 23] work and the interface design for the smartwatch application was influenced by Roudaut et al. [24].

This chapter reviews papers and projects that focus on different aspects and provide different solutions for MDUI, as well as different interaction techniques for small devices.

2.1 Multi-Display User Interfaces

MDUIs enable users to take advantage of the characteristics of different display categories. For example, combining mobile and large displays enables users to interact with user interface elements locally while simultaneously having a large display space to show data [21]. Several publications [4, 16, 23] show different approaches for MDUIs.

Rekimoto [23] proposed a multiple-device approach that provides a hand-held computer for each participant, cf. Figure 2.1 (a). The hand-held computer serves as a tool palette and data entry palette for the whiteboard. This hand-held device offers an easy way to create a new text/stroke object, to select existing data from a network or to control the whiteboard application.

Myers [16] investigated many ways in which a hand-held computer can serve as a useful extension to the desktop computer in different situations. He created a wide range of applications, for example: Remote Commander's keyboard, Slide Show Commander, remote clipboard, Slide Show Commander and Multi Cursor.

Duet [4] is an interactive system that explores a design space of interactions between a smartphone and a smartwatch. Based on the devices' spatial configurations, *Duet* coordinates the motion and touch input of smartphone

(a) (b)

Figure 2.1: MDUI approaches for whiteboards with hand-held computers (a) and for smartphones with smartwatches (b). Images from [4, 23].

and smartwatch, and extends their visual and tactile output to one another. This transforms the watch into an active element that enhances a wide range of phone-based interactive tasks, and enables a new class of multi-device gestures and sensing techniques, cf. Figure 2.1 (b).

Even though there is a large potential gain in performance and comfort through MDUI, the visual and physical separation of information between different devices can lead to problems. The separation requires from users to perform visual attention switches between displays, which lead to a cognitive overhead. Furthermore, Rashid et al. investigated that the distance between displays slows down the movement of data across displays. [21]

2.2 Interaction Techniques for Transfer of Data in MDUIs

In the following section different interaction techniques [15, 23] for the transfer of data in MDUIs will be discussed.

Pick-and-Drop [23] is an extended concept of drag-and-drop. With this technique, users pick up an object on one computer display with a stylus and then drop it on a different computer display, cf. Figure 2.2 (a). For example, users can select or create a text on their own PDA and pick-and-drop it to the desired location on the whiteboard.

Sparsh [15] is an interaction technique from Mistry et al., which explores a seamless transfer of data among multiple users and devices in an intuitive way. The technique is similar to *Pick-and-Drop* but touch input is used instead of the stylus. Users touch a data item, which they wish to copy from a device to another, and then simply touch a position on the other device's display where they want to paste/pass the saved item, cf. Figure 2.2 (b).

(a) (b)

Figure 2.2: Interaction techniques for transfer of data in MDUIs: *Pick-and-Drop* (a) and *Sparsh* (b). Images from [15, 22].

Nacenta et al. [17] carried out experiments that compare different attempts to make the transfer of digital media more tangible and interactive, such as Pick-and-Drop, Radar Views, Pantograph and Slingshot. Their results show clear evidence that techniques like the *Pick-and-Drop* work better than other techniques.

2.3 Interaction Techniques for Small Devices

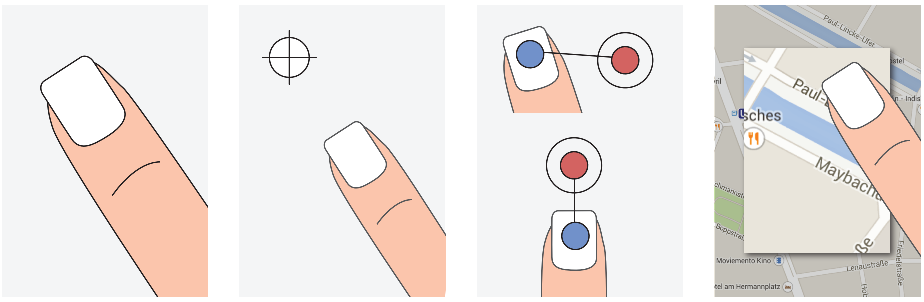
Several publications show different approaches to interact with small devices. In the following part touch-, back-of-device- and sensor-based interaction techniques will be present.

2.3.1 Touch Interaction

Selection with direct touch input on small devices leads to visual occlusion and accuracy [24]. Therefore, researchers have created different techniques that alleviate these problems. These are discussed in the following section.

Additional Tools: A *stylus* can help to overcome the occlusion and accuracy problems of direct touch. However, the use of a stylus requires too much attention (especially if users are moving) and forces users to use both hands (one hand holding the device while the other manipulates with the stylus) [24].

Dragging Techniques: They come from the take-off paradigm [19], which consists in whenever users make contact with the screen, a cursor appears slightly above the fingers. Dragging the cursor, and lifting the finger is used to validate the selection. The cursor marks the specific position of selection. This gives this technique the name *Offset Cursor*. It was designed to avoid finger occlusion on large touch-screens and to solve the accuracy problem of direct touch.



(a) Direct Touch (b) Offset Cursor (c) Shift (d) TapTap

Figure 2.3: Comparison of interaction techniques for small devices. Adjusted from *Roudaut* et al. [24].

Hybrid Techniques: When users touch the screen *Shift* [27] creates a window showing a copy of the occluded screen area and places it in a non-occluded location. The window also shows a pointer representing the selection point of the finger. Using this visual feedback, users guide the pointer into the target by moving their finger on the screen's surface and commit the selection by lifting their finger. The results of a user study showed that with *Shift* participants can select small targets with much lower error rates than an unaided touch screen and that *Shift* is faster than *Offset Cursor* for larger targets.

Zooming Techniques: In order to help users acquire small targets, researchers proposed a variety of ways to increase targeting accuracy, such as by zooming. An example for zooming interfaces is the principle that the first tap defines an area of interest on the screen. This area is then enlarged and displayed as a popup on the centre of the screen. The second tap selects the desired target in the popup. The two taps needed for the selection give this technique the name *TapTap* [24]. It was conceived as an improvement of direct touch in order to solve its accuracy and accessibility problems.

To sum up, several solutions have been proposed to overcome problems with target ambiguity and occlusion on the touch screen (see Figure 2.3). *Styli* have been used to overcome the occlusion and accuracy problem [24], as well as techniques that offset the finger with respect to the target, cf. *Offset Cursor* [19], or the target with respect to the finger, cf. *Shift* [27]. In order to help users acquire small targets, user interfaces dynamically grow in size in response to users' focus of attention, cf. *TapTap* [24]. The evaluation of these techniques from Roudaut et al. [24] showed that those techniques, which increase the targeting accuracy (*TapTap*), are more effective than *offset cursor* and *Shift*.

2.3.2 Back-of-Device Interaction

Baudisch et al. [1] explored a back-of device interaction for small devices (see Figure 2.4). Back-of-device interaction avoids interference between fingers and screen by keeping users' hand on the back of the device. A pointer on the screen informs users about their fingers' position on the back. They compared the back-of-device interaction with front-touch combined with *Shift* in a user study. The study showed that back-of-device interaction works independent of device size, while *Shift* fails for screen sizes below one inch.

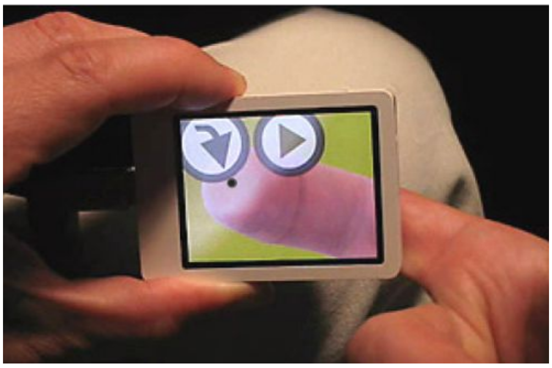


Figure 2.4: NanoTouch [1] as example for back-of-device interaction.

2.3.3 Sensor-Based Interaction

Using touch input for small devices can lead to fingers occlusion. The following part discusses sensor-based interaction techniques, which alleviate occlusion problem.

Xiao et al. [28] expanded the input expressivity of smartwatches with 2D panning and twist, as well as binary tilt and click. (see Figure 2.5). They used the watch face as a multi-degree-of-freedom, mechanical interface.

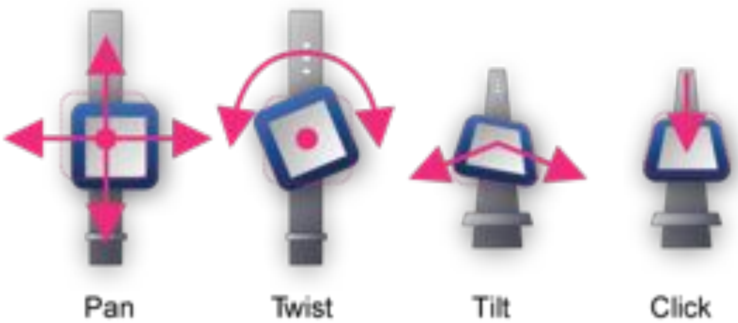
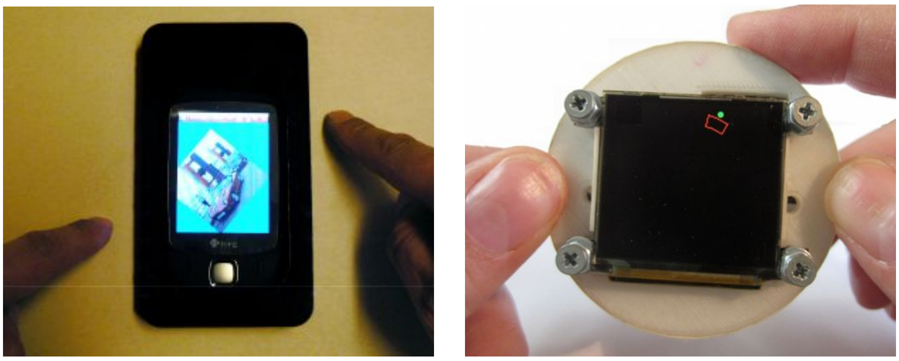
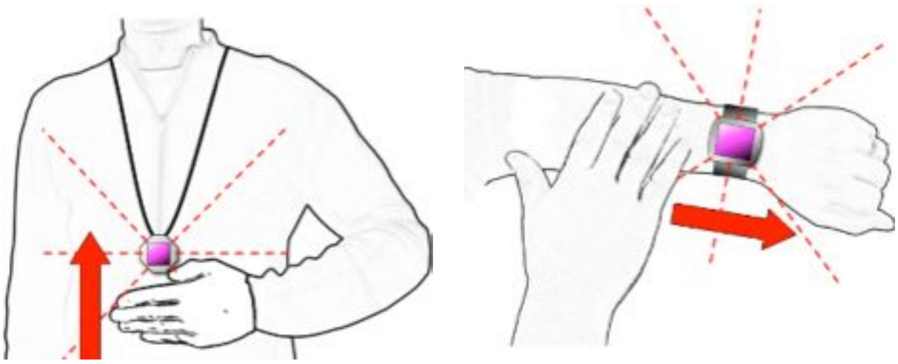


Figure 2.5: Smartwatch with mechanical pan, twist, tilt and click [28].



(a) (b)

Figure 2.6: Sensor-Based interaction techniques for small devices: *SideSight* (a) and *EdgeTouch* (b). Images from [3, 18].



(a) (b)

Figure 2.7: *HoverFlow* [12] expands the interaction space around the device. For example it can be used with digital necklets (a) and smartwatches (b).

SideSight [3] enables virtual interaction around the body of a small mobile device, cf. Figure 2.6 (a). When the device is rested on a flat surface users can carry out single and multi-touch gestures using the space around the device. Optical sensors allow fingers to be sensed as they approach the device from the sides.

EdgeTouch [18] senses touches to the perpendicular edges of a device featuring a front-mounted screen, cf. Figure 2.6 (b). The use of such offset contact points ensures that users' fingers and the device screen remain clearly in view throughout a targeting operation.

Kratz et al. [12] presented *HoverFlow*, a technique that allows mobile devices to track hand gestures performed above the device's screen (see Figure 2.7). HoverFlow can help to solve occlusion problems and scales down to very small devices.

Chapter 3

Application Design

Extending whiteboards with smartwatches can be interesting in numerous application scenarios. In this work we focus on the application design of a digital emergency control centre. Therefore, we considered the application design of the whiteboard map application ERiC. We developed a prototype of a whiteboard map application that focuses on the connection between smartwatch and whiteboard. Our prototype can also be used in other application settings.

The focus of this work is on the interaction techniques for MDUIs and interface design for smartwatches. The functionalities of the whiteboard application are described in the second section of this chapter.

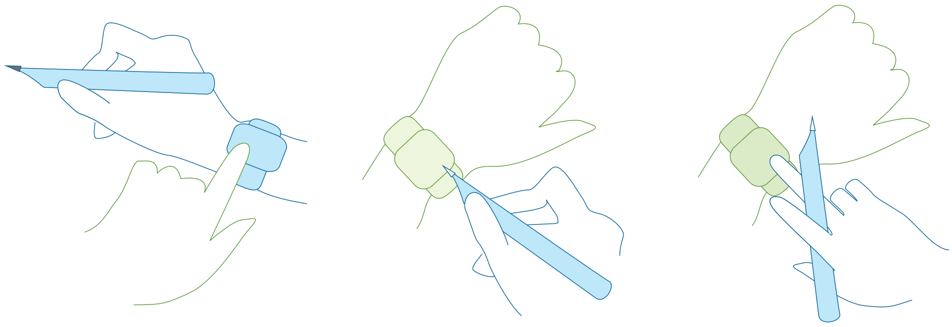
3.1 Interaction Techniques for Transfer of Data Between Whiteboard and Smartwatches

The general idea is that users select a sign on the smartwatch and then insert it on the whiteboard (see Figure 3.2).

In order to support joined use of smartwatches and whiteboards we created three techniques using the smartwatch as extended tool palette for whiteboards. The techniques emerge from the following factors:

- Users can wear the watch on the *non- or dominant hand*, and
- they can use *touch or pen input* to select a sign on the smartwatch.

These different factors give the techniques their name: *Bimanual Pen Touch*, *Pen Pen* and *Pen Touch*. In the following sections we present those techniques in more detail.



(a) (b) (c)

Figure 3.1: Interaction techniques for combining whiteboard with smartwatch: *Bimanual Pen Touch* (a), *Pen Pen* (b) and *Pen Touch* (c).

Bimanual Pen Touch

In this context, users wear the watch on the dominant hand and also hold the pen in the same hand, cf. Figure 3.1 (a). The selection of signs on the watch is conducted with touch input from the non-dominant hand on the watch. They use the pen to place the selected signs on the whiteboard.

We called this technique *Bimanual Pen Touch* due to the fact that both hands can be used simultaneously to interact with the pen on the whiteboard and touch on the smartwatch.

Pen Pen

Using *Pen Pen* users wear the watch on the non-dominant hand and hold the pen in the dominant hand, cf. Figure 3.1 (b). They use the pen for the selection on the smartwatch and also for the insert on the whiteboard. This fact gives the technique the name *Pen Pen* .

Pen Touch

Here users wear the watch on the non-dominant hand and hold the pen in the dominant hand, cf. Figure 3.1 (c). They use touch input to select signs on the smartwatch and the pen to insert the signs on the whiteboard.

The use of pen on the whiteboard and touch on the watch gives the technique the name *Pen Touch*.

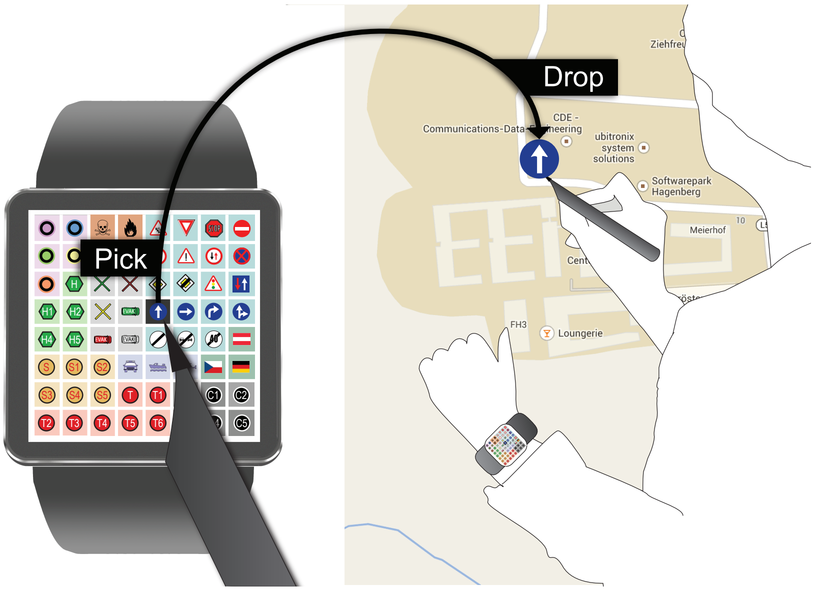


Figure 3.2: Selection of the sign on smartwatch (Pick) and insert sign on whiteboard (Drop) by example of *Pen Pen*.

3.2 Multi-User Interaction

A vertically orientated wall-sized map provides overview and space for simultaneous multi-user interaction. Coordination of emergency situations benefits from the possibility that users can work simultaneously (see Section 1.2).

In the situation of a flood a special force of the police would be in charge of evacuating people in homes while another team would be blocking streets, which are affected by the flood. The coordination of the emergency situation would benefit from operators, which can work simultaneously on the map. This requires individual workspaces, where an action of one person does not have any influence on another person's work.

On-screen solutions for each user occlude valuable screen space and maybe even important parts of the map, cf. Figure 1.2 (b). For these reasons, whiteboards are extended with external devices or tool palettes. Pen-based tool palettes are often misplaced and they are unnatural to use because of the missing feedback, cf. Figure 1.2 (a).

Smartwatches are very interesting in this context as they can be used as wrist worn tool palettes to support the individual work of users. Their use solves the problems of the on-screen menu and the additional pen-based palette.

Figure 3.3: MDUI extending whiteboard application with smartwatch tool palette.

3.2.1 ERiC Whiteboard Application

The map application was realized on a large interactive whiteboard with pen input for the ERiC project. Multiple users can interact with the map application. The setup is similar to *NiCE Discussion Room* [8].

The application provides the following different tools for describing the situation and the operation planning:

- Overview- and detail map [9],
- all maps can be panned or zoomed (Navigation) [9],
- annotations (Text or Drawings) can be placed on the map [10],
- colored strokes can be added to any map for individual annotations (Pen),
- all strokes and symbols can be removed by crossing them (Eraser), and
- sign symbols can be added to a map by tapping the desired location.

3.2.2 Whiteboard Application for Smartwatch Extension

The description of situations with additional information on the map is important because it supports operators' decision-making in extremely stressful circumstances. Arranging the huge amount of information for the planning

Figure 3.4: Smartwatch's user interface for ERiC divided in different button categories.

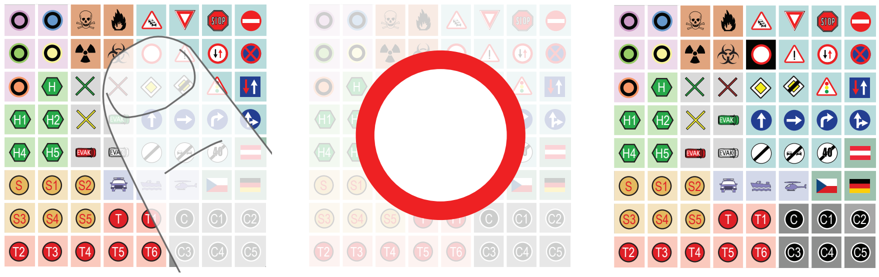
of operations can be challenging, as the information should always be visible and not occluding important regions of the underlying geographic map. The situation can be described with the placement of meaningful symbols on the map (see Figure 3.3) because these signs occlude less space on the map than annotations with pen. The arrangement of the symbols supports collaborative group work and decision-making.

In this work, we focused on the selection of signs on an external device and the transfer of signs between devices. Therefore, we developed a simplified whiteboard application, which supports the placement of signs on the whiteboard.

3.2.3 Smartwatch Application

Signs are important to describe emergency situations. It is highly important to provide a solution that offers a fluent and efficient selection of them on external devices.

We developed *paletteApp* a smartwatch application that provides different signs for emergency situations. The signs are divided in different categories (see Figure 3.4). The categories are grouped by assigning the same background colour. Grouping the categories is important, because it clarifies the group membership.



(a) (b) (c)

Figure 3.5: Selection of a sign on the normal interface: First the sign is selected with a tap (a). Then, a short overlay animation of the selected sign is shown (b) and after this the selected sign is highlighted in black (c).

Selection with direct touch on small devices leads to visual occlusion and accuracy. Hence, we created a zooming interface for touch input and a normal interface for the use of a stylus to overcome these problems.

Touch interaction and related interaction techniques for small devices are presented in Section 2.3. The techniques back-of-device and sensor-based interaction enhances the problem with finger occlusion on touch-devices. However the main disadvantage of these interaction techniques is, that users' movements could be misinterpreted from the system as user input. For this reason, the combination of these techniques with smartwatches in MDUIs is not advisable, because it can lead to input errors.

Interface Design

Thus, we considered two approaches for interaction (e.g. selection of items in a menu) with the small display of smartwatches:

- *Normal interface:* We dwell the approach that a pen is used to select the items (see Figure 3.5). The use of a pen overcomes occlusion and accuracy problem of small devices, which are described in Section 2.3.1.
- *Zooming interface:* In order to help users acquire small targets, first tap enlarges the signs and with the second tap a sign can be selected (see Figure 3.6). Our approach to increase the area of interest's size is inspired by *TapTap* (see Section 2.3.1).

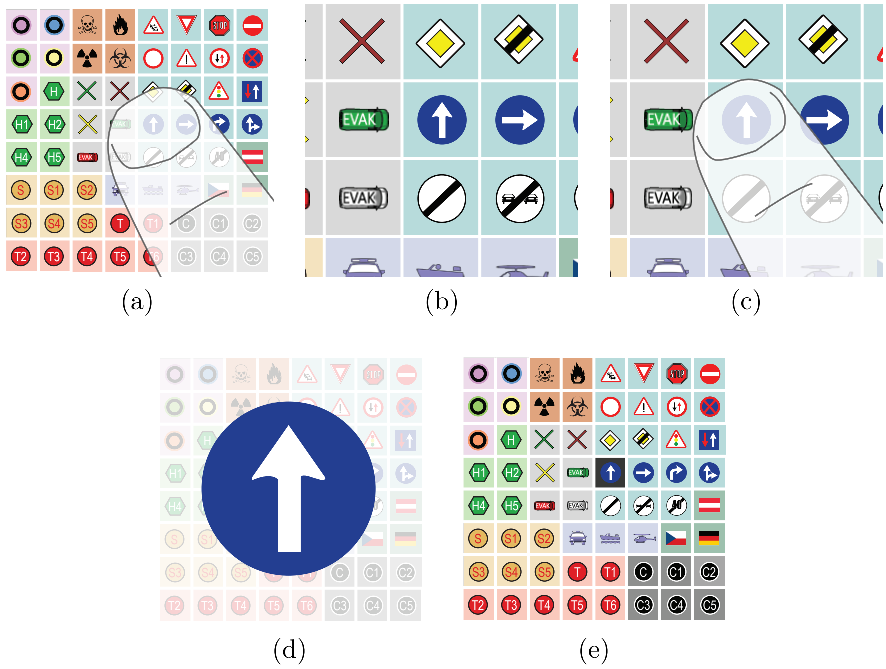


Figure 3.6: Selection of a sign on the zooming interface: First users have to select the area of interest with a tap on the overview (a). After this the area is resized (b) and users can select the sign with a second tap (c). Then, a short overlay animation of the selected sign is shown (d) and after this the selected sign is highlighted in black (e).

Chapter 4

Implementation

This chapter presents details on the implementation of the whiteboard- and smartwatch application, as well as the used hardware.

4.1 Hardware

The whiteboard was operated by a Vivitek D795WT[1] short throw projector and is driven by a PC with an Intel Core i7-3770 CPU, 8GB of RAM and a Nvidia Quadro K2000. It measures $2m \times 1.25m$. Anoto digital pens (ADP 601) are used for input, cf. Figure 4.1 (a). Each pen has an integrated camera that sends position information by recognizing a dot-pattern[2].

The selection of a smartwatch as well as their product details and the extension of Anoto pens for capacitive use are described in detail in the following sections.

[1]More information at www.vivitek.eu/Category/Education-Projectors/39/D795WT-.
[2]www.anoto.com/the-technology-1.aspx

(a) (b)

Figure 4.1: Hardware used for the implementation: Anoto Pen (a) and Smartwatch AW-414.Go (b).

4.1.1 Smartwatch

Numerous smartwatches are designed for different scenarios on the market. Product comparisons have shown that there are basically two types of smartwatches:

- *Addon smartwatches* unfold their full functionality only in cooperation with a second device. Usually, addon watches offer limited hardware resources because their main functionality is displaying short messages or incoming calls from a smartphone. These devices use the operating system of the host smartphone. They mainly receive their data via Bluetooth.
- *Standalone watches* run their own applications and are not depending on a second device. In general standalone watches offer more features and hardware resources than addon watches since these cannot use the features and the computing power of a host device.

We used the smartwatch AW-414.Go[3] from hardware manufacturer Simvalley, cf. Figure 4.1 (b), because it is a standalone watch, which does not need an additional device to operate with its full feature-set. It also offers interesting hardware- (e.g. WLAN module, high resolution colour display) and software specifications (Android SDK), which makes it a reasonable choice for developing. In order to connect the smartwatch with a whiteboard the standalone use of the smartwatch was a crucial criterion as it simplified the development processes considerably.

The AW-414.Go has a case with the dimensions of $45.3 \times 44.3 \times 14.1mm$ ($width \times depth \times height$) and a weigh of $91grams$. The $1.5inch$ display has a resolution of $240 \times 240pixels$, which results in a pixel density of $226ppi$ for the square panel.

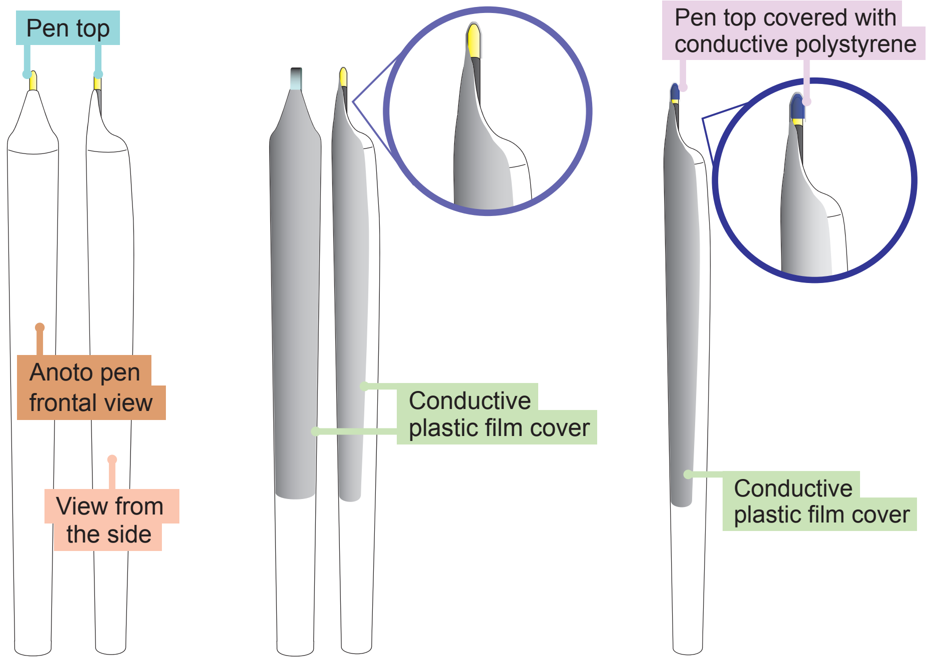
The watch's communication features can be compared with an entry-level smartphone. The WLAN module supports the IEEE standards 802.11 b/g/n in $2.4GHz$ networks.

4.1.2 Extending Anoto Pen for capacitive use

The interaction technique for data transfer *Pen Pen* requires users to interact with the Anoto pen on the smartwatch. Anoto pens cannot be used to interact on the capacitive touch screen of a smartwatch. Capacitive touch screens are intended to work with the electrically conductive power of a plain human finger. The Anoto pen blocks fingers' small electrical charge causing the touch screen react erratically or not at all.

In order to operate both devices with the same pen, a conductive connection between pen tip and human hand, which is holding the pen, has to

[3] More information about the AW-414.Go is available at http://www.simvalley-mobile.de/1-5-Android-Watch-REF-17901-919.shtml.



(a) (b) (c)

Figure 4.2: Anoto pen's frontal and side view (a); Anoto pen with polystyrene cover (b); Anoto pen's body encased with a cover and pen's top covered with conductive polystyrene (c).

be created. It was important that the extension of the Anoto pen has no influence on the performance of the pen on the whiteboard.

We created two prototypes for the use on the smartwatch and whiteboard:

- *Polystyrene cover prototype:* A Conductive plastic film encases the Anoto pen, cf. Figure 4.2 (b). The plastic film cover starts at the top and ends at the bottom of the pen in order to generate electrical charge between the pen top of the smartwatch and the hand holding the pen.
- *Polystyrene pen top and -cover prototype:* The pen top is encased with conductive polystyrene, cf. Figure 4.2 (c). The polystyrene and the body of the pen are coated with the plastic film cover from *polystyrene cover prototype*. Extending the pen top with polystyrene should give users the feeling that they interact with a touchscreen stylus.

(a) (b)

Figure 4.3: *Polystyrene cover prototype* detail view (a) and used with *Pen Pen* (b).

Several users tested the two prototypes on the smartwatch and the whiteboard. The pen top covered with polystyrene is softer than a normal pen top. This leads to input problems, since input with the soft pen top on the whiteboard is unnatural for users. A hard pen top works better on the whiteboard, because normal pens also have a hard top. Therefore, the best performance was realised with *polystyrene cover prototype*, cf. Figure 4.3.

4.2 Environment

4.2.1 Communication Between Whiteboard (Server) and Smartwatches (Client)

A server socket is provided by the whiteboard application. The socket receives information from the smartwatches. The smartwatch client is sending the watch's identification number and the icon's identification number with each selection. With the Anoto pen users can insert the selection on the whiteboard. In order to support user identification the watch has to be paired to the pen.

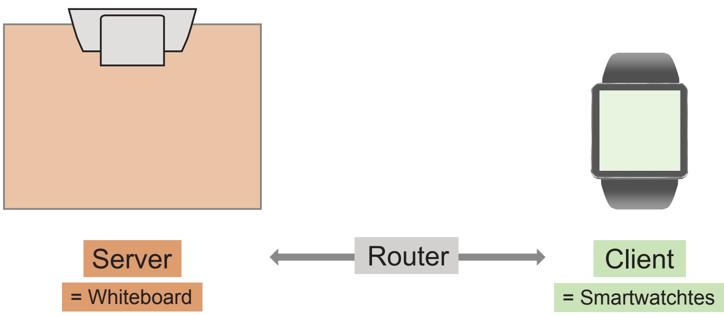


Figure 4.4: Overview over the currently implemented environment.

(a) (b)

Figure 4.5: Combining whiteboard with smartwatch: Selection item on smartwatch (a) and insert item on whiteboard (b).

4.2.2 Whiteboard Application

The whiteboard application is written in C#[4] using Windows Presentation Foundation (WPF)[5]. Basically, the application is responsible for handling the input from the Anoto devices and providing functionality to insert the selected icon with the pen on the whiteboard, cf. Figure 4.5 (b).

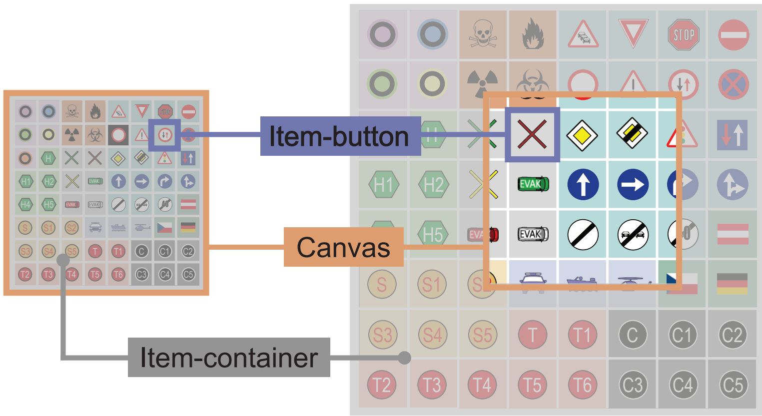
4.2.3 Smartwatch Application

The Simvalley Mobile AW-414.Go uses Google Android 4.2.2 Jelly Bean[6]. The smartwatch application creates `item-buttons` from a folder in the file system. The items are grouped according to naming conventions in the image name. The `item-buttons` were packed together in a grid view, which is called `item-container`. Additionally each `item-button` gets a unique identification number.

As described in Figure 3.5 on the *normal interface* users select an item with a single tab on it. After each selection an overlay animation of the current selection is show.

The *zooming interface* extends the normal interface. Users can zoom in to the enlarged detail view, cf. Figure 4.6 (b) and with the selection of a sign zoom out to the overview, cf. Figure 4.6 (a). In order to enlarge the area of interest the `canvas` size remains the same, but the `item-container` is positioned and resized depending on the position of the first tap on the display.

[4] http://msdn.microsoft.com/en-us/library/618ayhy6(v=vs.71).aspx
[5] http://msdn.microsoft.com/en-us/library/ms754130(v=vs.100).aspx
[6] http://developer.android.com/about/versions/android-4.2.html



(a) (b)

Figure 4.6: Overview (a) and detail view (b) of the *paletteApp*.

First, we calculated the top and left position of the touch point on the `item-container`:

$$containerLeft = touchPosX - containerPosX, \tag{4.1}$$

$$containerTop = touchPosY - containerPosY. \tag{4.2}$$

The width and height values of the `item-container`, as well as its top and left values are multiplied by the zooming factor. Then, we use the new top and left values of the `item-container` to calculate its position on the `canvas`:

$$containerPosX- = (canvasWidth/2) - resizedContainerLeft, \tag{4.3}$$

$$containerPosY- = (canvasHeight/2) - resizedContainerTop. \tag{4.4}$$

The enlarged view depends on the first tap on the overview. It is checked whether users select an item close to the corner or the border of the application. When so the enlarged view is bound to the corner or border of the application (see Figure 4.7).

With the second tap on the enlarged `item-container` the item is selected, followed by an overlay animation with the selected sign in centre. In order to show the overview the height and width of the `item-container` in the `canvas` are divided by the zooming factor and the container is positioned in the top left corner of the `canvas`.

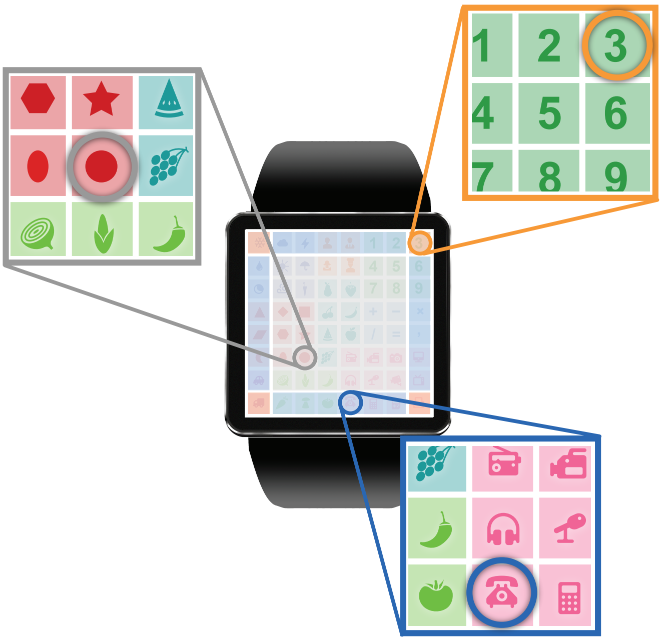


Figure 4.7: The enlarge view depends on the first tab (visualised as circle) on the overview. The regions on the overview in the middle (grey), in the corner (orange) and close to the border (blue) have influence on the enlarged view.

Chapter 5

Evaluation

This chapter presents the methodology used to evaluate the selection of items on a smartwatch application and the data transfer of the selected item with three different interaction techniques (called *Bimanual Pen Touch*, *Pen Pen* and *Pen Touch*) to the whiteboard.

The interaction techniques are described in Section 3.1 and the *paletteApp* with the normal and zooming interface in Section 3.2.3.

The main goal of this study was to find out which interaction technique and which smartwatch interface proves to be more effective at supporting the data transfer between smartwatch and whiteboard and also the selection of items on a smartwatch.

A repeated measures within-subject design was used. The selection of items on *paletteApp* with normal or zooming interface (smartwatch interface), the transfer of the selection to the whiteboard (interaction techniques) and the task position on the whiteboard were treated as independent variables. The study design is discussed in more detail in Section 5.3.

During the study participants' performance was captured through logging the task completion time and errors. Furthermore, measuring participants' preferences through questionnaires and an interview and therefore, acceptance of the tested techniques was critical to the study.

5.1 Participants

12 (7 female, 5 male) aged between 20 and 27 years ($M = 23.25$, $SD = 2.22$) from the University of Applied Sciences Upper Austria were recruited for the user study. 10 participants were right- and 2 left-handed.

On a background questionnaire completed at the beginning of the study, the majority of participants stated that they use computational devices such as desktop computers, tablets and smart phones frequently throughout the day. Participants were also questioned about their experience and usage of

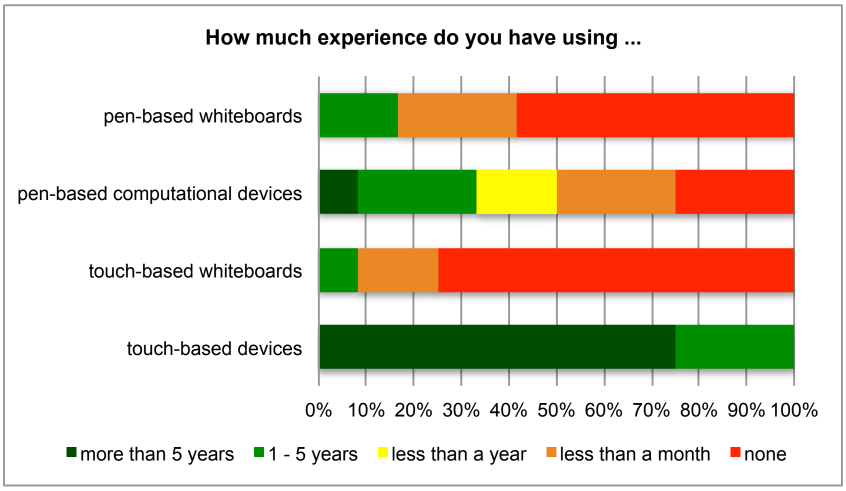


Figure 5.1: Participants' experiences with pen-based- and touch-based computational devices, pen-based- and touch-based whiteboards.

pen-based- and touch-based computational devices, pen-based- and touch-based whiteboards (see Figure 5.1). 58.3% of the participants referred having no experience with pen-based whiteboards and 25% reported having no experience with pen-based devices.

75% of the participants reported having no experience with touch-based whiteboards. The majority of the participants were experienced with touch-based computational devices (tablet, smartphone). Finally, no participant reported any previous experience with smartwatches.

5.2 Apparatus

The study was conducted on a large interactive whiteboard, measuring $2m \times 1.25m$ with a total resolution of $1280 \times 800 pixels$. The whiteboard was operated by a Vivitek D795WT short throw projector and input was given by Anoto digital pens (ADP 601).

The experiment was conducted using the *paletteApp* with normal and zooming interface.

5.3 Experimental Design

Interaction technique, interface of the smartwatch and task position were used as independent variables. The presentation order of the techniques was counterbalanced, as shown in Table 5.1. Summarizing, each participant completed a total of 144 trials (3 *techniques* $\times$ 2 *interface* $\times$ 2 *position* $\times$ 12 task trails).

Participants completed twelve blocks of different task combinations within the study. The first six blocks belong to Part 1 and the last six blocks belong to Part 2. One block had twelve tasks. Each block has different conditions in the category technique, interface and position. Tasks were not counterbalanced and appeared in a random order.

During a block the position of the task description remained the same or was changed after each task.

		Part 1						Part 2					
Partic.	**Block**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Technique	*B*		*PP*		*PT*		*B*		*PP*		*PT*	
1 & 7	Position	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*
	Interface	*z*	*z*	*z*	*z*	*z*	*z*	*n*	*n*	*n*	*n*	*n*	*n*
	Technique	*PP*		*PT*		*B*		*PP*		*PT*		*B*	
2 & 8	Position	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*
	Interface	*n*	*n*	*n*	*n*	*n*	*n*	*z*	*z*	*z*	*z*	*z*	*z*
	Technique	*PT*		*B*		*PP*		*PT*		*B*		*PP*	
3 & 9	Position	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*
	Interface	*z*	*z*	*z*	*z*	*z*	*z*	*n*	*n*	*n*	*n*	*n*	*n*
	Technique	*B*		*PP*		*PT*		*B*		*PP*		*PT*	
4 & 10	Position	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*
	Interface	*n*	*n*	*n*	*n*	*n*	*n*	*z*	*z*	*z*	*z*	*z*	*z*
	Technique	*PP*		*PT*		*B*		*PP*		*PT*		*B*	
5 & 11	Position	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*
	Interface	*z*	*z*	*z*	*z*	*z*	*z*	*n*	*n*	*n*	*n*	*n*	*n*
	Technique	*PT*		*B*		*PP*		*PT*		*B*		*PP*	
6 & 12	Position	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*	*c*	*f*
	Interface	*n*	*n*	*n*	*n*	*n*	*n*	*z*	*z*	*z*	*z*	*z*	*z*

Table 5.1: Counterbalancing of the independent variables *Technique* (*B* = *Bimanual Pen Touch*, *PP* = *Pen Pen*, *PT* = *Pen Touch*), *Interface* (*z* = *zooming*, *n* = *normal*) and *Position* (*f* = *fixed*, *c* = *changing*).

Interaction Technique

Three techniques for combined use of the smartwatch and whiteboard were compared: *Bimanual Pen Touch*, *Pen Pen* and *Pen Touch* (see Figure 5.2). The techniques are described in Section 3.1.

(a) (b) (c)

Figure 5.2: Techniques for combined use of the smartwatch and whiteboard: *Bimanual Pen Touch* (a), *Pen Pen* (b) and *Pen Touch* (c).

(a) (b) (c)

Figure 5.3: Normal- (a) and zooming interface (b) of the smartwatch. After the selection a short overlay animation of the selected sign is shown (c).

Interface of the Smartwatch

The interaction techniques were tested with two different smartwatch interfaces, a zooming and normal interface. Each interface type is described in Section 3.2.3. For the study a simplified icon set was used (see Figure 5.3).

On the normal interface (overview of zooming interface) 64 icons are shown, on the zooming interface between nine and sixteen icons are visible depending on the first tap on the overview. Displaying sixteen icons on the zooming interface is possible, though icons close to the board are cut off.

5.4 Task

Participants were instructed to select an icon on the smartwatch, cf. Figure 5.4 (*b*). The icon, which has to be selected, was shown on the whiteboard, cf. Figure 5.4 (*a*). To finish the task participants have to insert the selected icon with an Anoto pen on the grey box below the icon on the whiteboard, cf. Figure 5.4 (*c*). For the false or correct selection of the sign the box below

(a) (b) (c)

Figure 5.4: The sequence of a task from the task description (*a*) to the selection on the watch (*b*) until the insertion of the selection on the whiteboard (*c*).

the icon is changing its colour to red or green. In each block the task was repeated twelve times.

5.5 Procedure

The study consisted of 3 main parts: the introductory part, main part, and the finishing part.

Introductory part

First, in the introductory part, participants were welcomed and given a brief overview about the project and the experiment procedure. After signing the consent form (see Appendix A.1), they filled out the background questionnaire (see Appendix A.2.1).

Then, the procedure and all conditions were explained and shown. To get familiar with the setup, participants selected icons on the different interfaces of the smartwatch with touch- und pen-input. Thereafter a training block with all conditions was completed. Participants were instructed to complete the tasks as accurately and fast as possible.

Main part

The main part consisted of 12 blocks. A block started with a visual explanation of the technique (see Figure 5.5). Then, they had to perform 12 tasks per block with different conditions within each block. The combination of conditions for each block is shown in Table 5.1. The main block took about 25 minutes to complete.

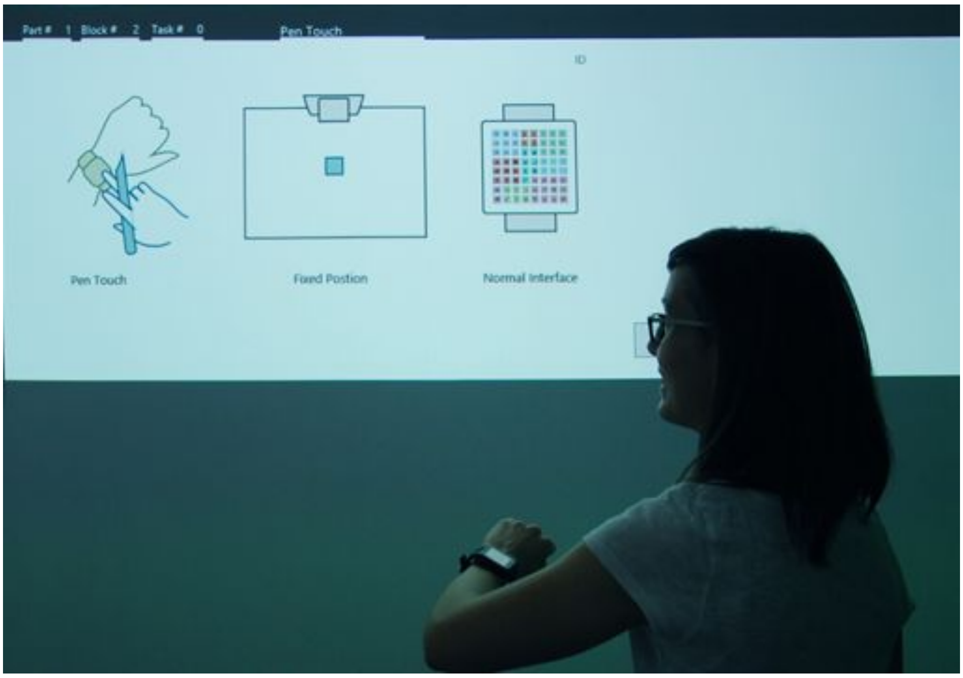


Figure 5.5: Visual explanation of the task before each block.

Finishing part

After the completion of the blocks, participants were asked to fill out the exit questionnaire (see Appendix A.2.2) and were interviewed about their overall preference concerning different conditions.

The study was completed in one session lasting approximately 55 minutes.

5.6 Data Collection

Data and selections were captured through computer logs. Preference data were collected through background- and exit questionnaires.

Task Completion Time

The time spent for a trial was recorded in milliseconds. The timer started with fading in the icon to select on the whiteboard and ended on placing the selected icon on the grey box blow the icon on the whiteboard.

Error Rate

For the selection of the item one tap is needed on the normal smartwatch interface. With the zooming interface two taps for selecting an item are needed (as visualised in Figure 3.6). The two taps are measured as one click on the zooming interface. Combining the error- and click rate, the task was rated according to the following categories:

- The task was a *success* when the correct item was selected with one click on the smartwatch.
- When participants inserted the correct item but needed more clicks on the smartwatch the task was *satisfiable*.
- The task was an *error*, when participants inserted a wrong item on the whiteboard.

5.7 Hypotheses

We expected that *Pen Pen* is the preferred technique *(H1)* especially in combination with the normal smartwatch interface *(H4)*. We assume that *Bimanual Pen Touch (H2)* is the most difficult technique to learn, but that it can outperform the other techniques when the position of the task on the whiteboard is fixed *(H3)*. *Pen Touch* is expected to be the preferred technique in combination with the zooming interface *(H5)*.

We explored the following hypotheses, which were assigned to the categories *Interaction Technique*, *Posture* and *Input on smartwatches*.

Interaction Technique

H1. Pen Pen is the easiest technique for the transfer of data between smartwatch and whiteboard.

Pen Pen is based on the *Pick-and-Drop* [23] technique from Rekimoto. As described in Section 2.2, research on different approaches to make the transfer of data between devices more tangible points out that *Pick-and-Drop* performs better than the other techniques [17].

Conforming to that, we expected that *Pen Pen* is the easiest technique for the selection of items on the watch and also for inserting the selected item on the whiteboard. This is because participants can interact on both devices with the pen.

H2. Bimanual Pen Touch is the most difficult technique to use.

Input with the non-dominant hand is unnatural for participants. Conforming to that, we expected that this had an influence on the performance and acceptance of *Bimanual Pen Touch*.

Posture

H3. Bimanual Pen Touch Technique using the normal interface is better with fixed position than with changing position.

This is because the arm wearing the smartwatch can stay close to the whiteboard, or even can be stored on the whiteboard. This allows participants to see smartwatch and whiteboard simultaneously.

In line with that, research from Rashid et al. [21] on human factors in MDUI (see Section 2.1) found that the separation of information on different devices require from participants to perform attention switches between the displays. Furthermore, Rashid et al. investigated that the distance between displays slows down the movement of data between them. Therefore, we assume, that having the watch and the whiteboard simultaneously in view reduces the task completion time.

Input on smartwatches

H4. Pen input is better on the paletteApp with normal interface (than with zooming interface).

To overcome problems with occlusion of the finger and accuracy on small devices styli can be used [24]. Thus, we expect that pen input is better on the normal interface with small buttons because the pen is more accurate and creates less overlay on the display than a finger.

H5. Touch input is better on the paletteApp with zooming interface (than with normal interface).

As already presented in Section 2.3.1, touch input on small devices leads to visual occlusion and accuracy. Hence, researchers had created different touch interaction techniques for small devices that alleviate these problems.

The evaluation from Roudaut et al. [24] showed that techniques, which increase the targeting accuracy, are more effective. With this evidence, we expect that touch input on the zooming interface is natural for participants.

Chapter 6

Results and Discussion

The first part of this chapter presents the quantitative results of the user study. The methodology is described in Chapter 5 and the Application Design is covered in Chapter 3. The qualitative results are described in the second part of this chapter. The third part discusses the results.

6.1 Quantitative Results

Trial completion times and click rates were analysed using a repeated measures ANOVA ($\alpha = 0.05$) separately for each technique. The Greenhouse-Geisser correction was used if the assumption of sphericity was violated. A repeated measures analysis of variance showed main effects for Post-hoc. Analyses on the main effects were conducted in order to confirm/reject the formulated hypotheses. These consisted of paired-samples t-tests with family wise error rate controlled across the test using Holms sequential Bonferroni approach. For all bar charts, the error bars indicate the range of two standard errors of the mean (above and below the mean).

No significant difference could be found regarding the error rate (see definition in Section 5.6) on the smartwatch. In total, participants made seven errors.

6.1.1 Task Completion Time

The task completion time was recorded in milliseconds, but is presented in seconds for better understanding.

Interaction Technique

A repeated measures analysis of variance of the completion time show that the task completion time of the three techniques are not significant ($F_{1,11} = 0.241$, $p > 0.005$) with average values of *Bimanual Pen Touch* $5.56s$, *Pen Pen* $5.63s$ and *Pen Touch* $5,56s$ ($M = 5.61s$, $SD = 0.63s$). Hence, the *H1* ("Pen

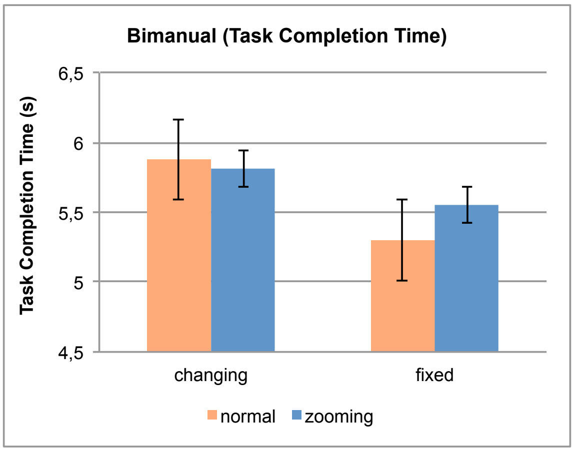


Figure 6.1: Overall completion time by *Bimanual Pen Touch* regarding position (fixed vs. changing) and interface (normal vs. zooming).

Pen is the easiest technique for the transfer of data between smartwatch and whiteboard.") and *H2* ("Bimanual Pen Touch is the most difficult technique to use.") have to be rejected regarding the task completion time.

Posture

Although, there is no significant difference between the techniques concerning the task's position on the whiteboard, Figure 6.2 indicates, that the techniques perform faster when the position of the task on the whiteboard was fixed.

However, a repeated measure analysis of variance showed main effects for *Bimanual Pen Touch* ($F_{1,11} = 35.731$, $p < .0001$) concerning the position of the task on the whiteboard. Therefore, the *H3* ("Bimanual Pen Touch using the normal interface is better with fixed position than with changing position.") can be confirmed. Figure 6.1 depicts the overall mean time for *Bimanual Pen Touch*. This figure shows that the *Bimanual Pen Touch* technique using normal interface has been significant faster when the position of the task was fixed $5.3s$ ($M = 5.68s$, $SD = 0.23s$) than when the position was changing after each task.

Input on Smartwatches

A repeated measures analysis of variance of the completion time showed that the normal and zooming interface of *Pen Pen* are significant ($F_{1,11} = 20.326$, $p < 0.001$) with average values of zooming $5.93s$ and normal interface $5.33s$ ($M = 5.63s$, $SD = 0.30s$). This result supports *H4* ("Pen input is better

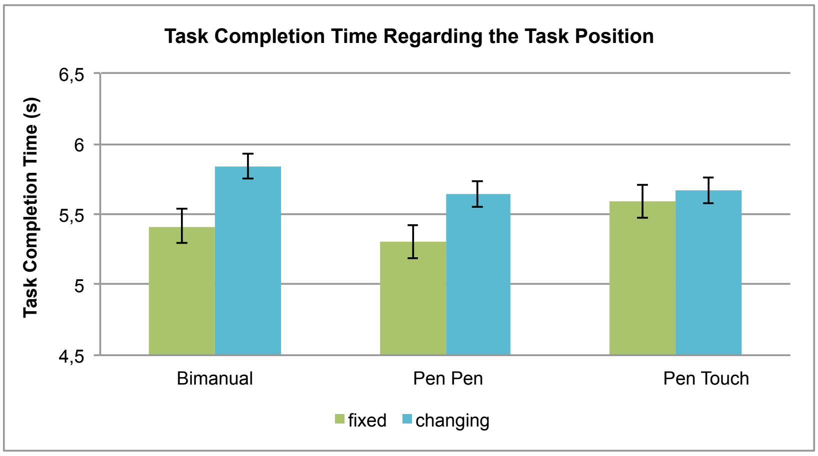


Figure 6.2: Overall completion time of all techniques regarding position (fixed vs. changing).

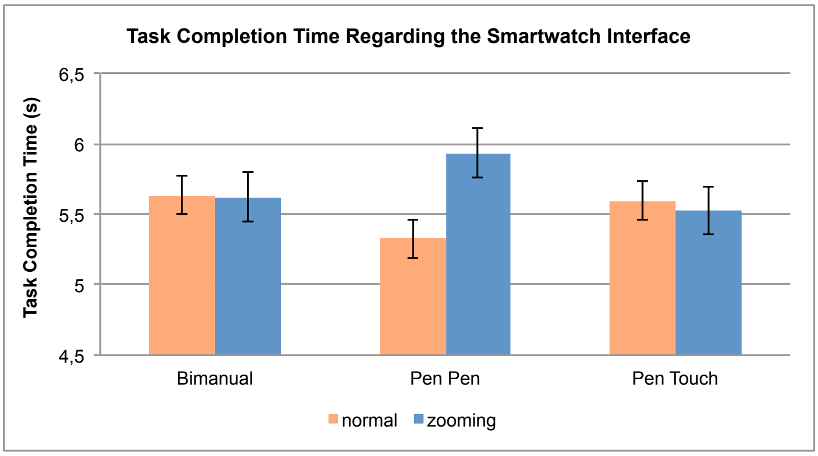


Figure 6.3: Overall completion time of the techniques regarding the interface (normal vs. zooming).

on the paletteApp with normal interface."). The task completion time of *Pen Pen* is shown in Figure 6.3. *H5* ("Touch input is better on the paletteApp with zooming interface.") has to be rejected because there is no significant difference ($F_{1,11} = 0.271$, $p > 0.005$) between the interfaces.

6.2 Qualitative Results

This section discusses the subjective participants' results collected in an exit questionnaire and interview. The third part of this section presents study observations.

6.2.1 Participants' Ratings

After the technique block, participants asked to rate the techniques and the different study conditions (position, interface). This questionnaire is included in Appendix A.

Figure 6.4 to 6.5 depicts significant main effects have been found for the participant rating for overall usage and usage with normal interface. No significant main effects could be found for usage with zooming interface (see Figure 6.6).

Interaction Technique

A Wilcoxon Signed-Rank Test comparing the techniques indicated that *H1* ("Pen Pen is the easiest technique for the transfer of data between smartwatch and whiteboard.") and *H2* ("Bimanual Pen Touch is the most difficult technique to use.") are correct ($z = -2.539$, $p = 0.011$). Due to the fact that, 75% (ME = 3.50) of the participants rated *Pen Pen* as the easiest technique, 33.3% ($ME = 4$) *Pen Touch* and only 8.33% ($ME = 5$) *Bimanual Pen Touch*. Figure 6.4 shows participants rating of the overall usage of the three techniques.

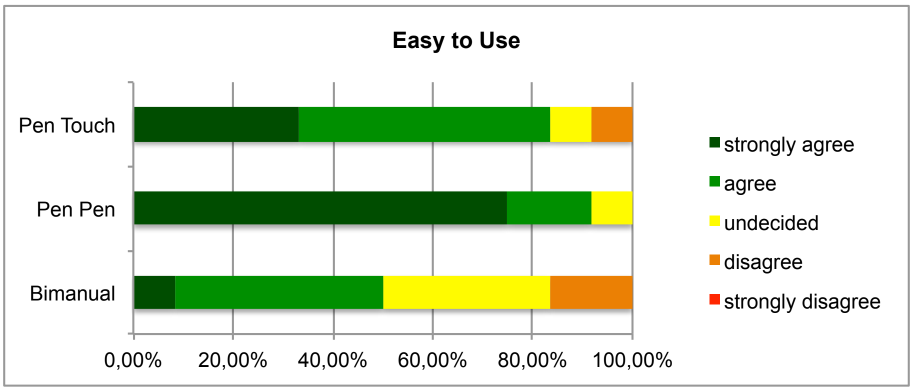


Figure 6.4: Overall usage.

Input on Smartwatches

H4 ("Pen input is better on the paletteApp with normal interface.") can be confirmed because a Wilcoxon Signed-Rank Test showed significant differences for *Pen Pen* and *Pen Touch* ($z = -2.547$, $p = .011$) regarding the usage of the normal interface. 91.67% (ME = 4.5) of the participants confirmed the statement that *Pen Pen* was easy to use with the normal interface and 41.67% (ME = 2.5) confirmed this statement regarding *Pen Touch* (see participant rating on Figure 6.5).

A Signed-Rank Test showed no significant differences for the three techniques regarding the usage of the zooming interface. Therefore, *H5* ("Touch input is better on the paletteApp with zooming interface.") could not be confirmed. As visualised in Figure 6.6 participants rated both, *Pen Pen* and *Pen Touch*, with 83.3% ($ME = 5$) as easy to use.

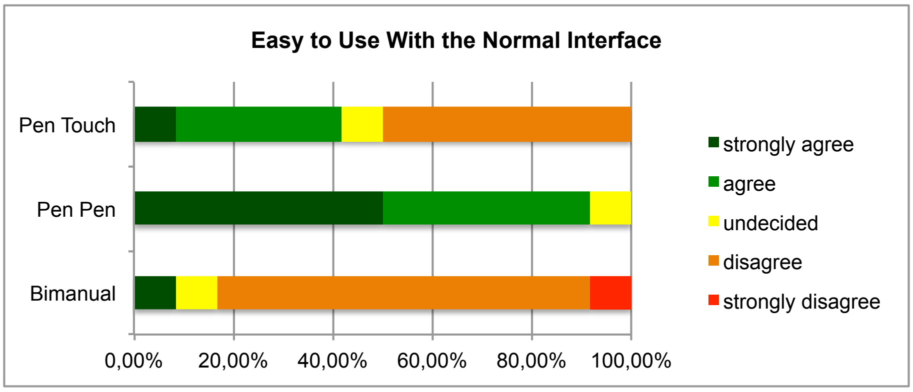


Figure 6.5: Overall usage with normal interface.

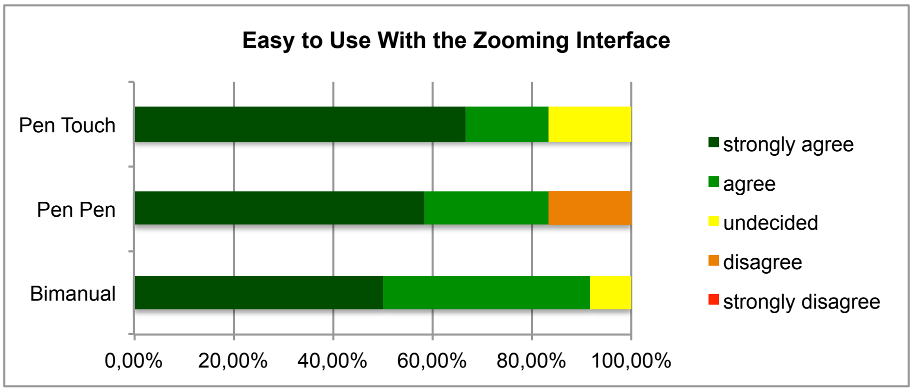


Figure 6.6: Overall usage with zooming interface.

6.2.2 Participants' Feedback

Participants were also interviewed about their preferences after having completed the exit questionnaire. The interview was informal. Participants were asked for statements which technique they preferred overall and for a short explanation why. In addition they were asked if they could name any positive or negative aspects of the techniques.

Bimanual Pen Touch

As presented in Section 6.2.1 participants rated *Bimanual Pen Touch* as the most difficult technique to use and confirming *H2* ("Bimanual Pen Touch is the most difficult technique to use."). The following statement summarises the disadvantages of this technique.

> "*Bimanual Pen Touch* was exhausting for me because I wear both devices (pen and watch) on the right hand (dominant hand). The weight of both devices is on this hand. It felt very unnatural to interact with the smartwatch with the left hand (non-dominant hand)." – Participant 7

Two Participants noted that their performance was faster with *Bimanual Pen Touch*. This statement supports *H3* and explains the performance gain.

> "*Bimanual Pen Touch* is really fast because with the left hand (non-dominant hand) the icons can be selected and with the right (dominant) the icons can be inserted on the whiteboard. When the position of the task description on the whiteboard was fixed I didn't change my position in front of the board during the task in order to improve my performance." – Participant 8

Pen Pen

As previously shown in Section 6.2.1, eleven participants rated in the exit questionnaire that *Pen Pen* was the easiest technique to use and therefore, confirming *H1* ("Pen Pen is the easiest technique for the transfer of data between smartwatch and whiteboard."). The feedback from the interview corroborates with the results from the questionnaire. In the interview eight participants stated explicitly that *Pen Pen* is the most accurate technique for the selection of items on the smartwatch. Five participants mentioned that they preferred *Pen Pen* because they could use the pen as input device on the smartwatch and the whiteboard.

> "An advantage of *Pen Pen* is that it is accurate on the normal interface and that the pen can be used for both devices (smartwatch and whiteboard). The zooming interface in combination with *Pen Pen* is not necessary because *Pen Pen* works fine on

> the normal interface. In my opinion using zooming interface with *Pen Pen* needs more time." – Participant 12

Although the majority of the participants preferred *Pen Pen*, two participants mentioned negative aspects regarding the pen input on the smartwatch display.

> "The selection of items on the smartwatch felt odd with the pen (*Pen Pen*) because it is unnatural for me to use a pen on a touch device." – Participant 1

Pen Touch

Seven Participants mentioned that they preferred the zooming interface in combination with *Pen Touch* and therefore they substantiate *H5*. One participant explained this as follows:

> "I'm used to interact with touch input on my smartphone. For this reason, I think the interaction with touch was for me more natural than with pen. I preferred the zooming interface in this condition because it was a natural way of interaction for me and my performance was faster." – Participant 12

An interesting statement by participant 6 is that he favoured the normal interface. In his opinion the zooming interface is not necessary because he was able to control the input with his right hand accurate. The need of switching between pen- and touch input on the devices was confusing for 4 participants.

> "The use of this technique (*Pen Touch*) was initially confusing for me, I tried once to use the finger on the whiteboard. I think that my performance was slower with this technique because I had to change between touch a pen." – Participant 7

In summary, overall participants preferred *Pen Pen* because the pen could be used for both interfaces. However, the input with the pen on the touch display felt unnatural for a few participants.

For the majority of participants *Bimanual Pen Touch* was the most difficult technique to use because the interaction with the non-dominant hand on the smartwatch display was unfamiliar for them. Two participants stayed close to the board and left their hand in the same position during the task, this results in an improved performance.

There were differences of opinion among *Pen Pen*. Some of the participants preferred its use, because they are used to interact on a touch display. However, the others mentioned that the switch between pen and touch input turned out to be confusing for them.

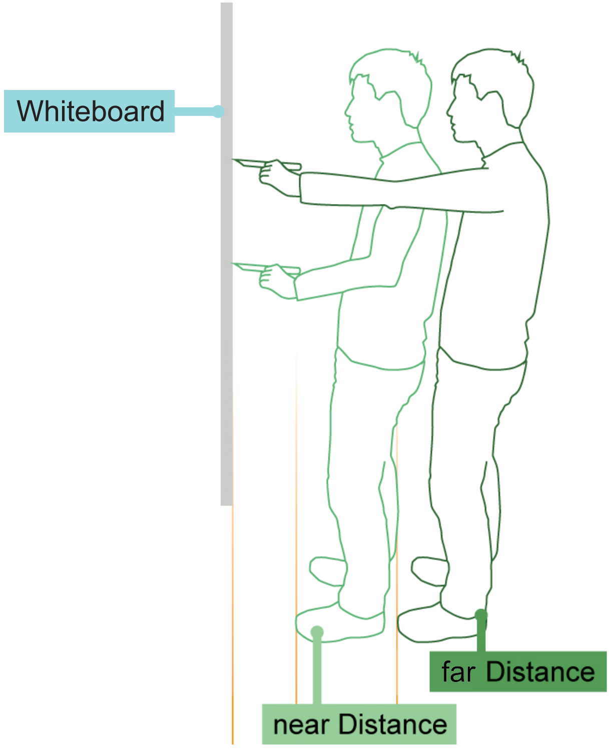


Figure 6.7: Participants' near and the far distance to the whiteboard during the placement of the icon on the board.

6.2.3 Study Observations

Participants' Distance to Whiteboard

We observed, that participants' distance to the whiteboard varied. The distance and changing it during the task had influence on the task completion time and physical demand.

Influence on task completion time: 3 Participants were standing close (whiteboard to foot approx. $30 - 40cm$) to the whiteboard (see Figure 6.7). The analyse of this participants showed that their average performance ($M = 5.09s$, $SD = 0.45s$) was faster compared to the others ($M = 5.78s$, $SD = 0.59s$). The performance of the three participants standing close to the whiteboard was especially fast with the *Bimanual Pen Touch* on normal interface ($M = 4.86s$, $SD = 0.41s$) and on zooming interface ($M = 4.93s$, $SD = 0.29s$).

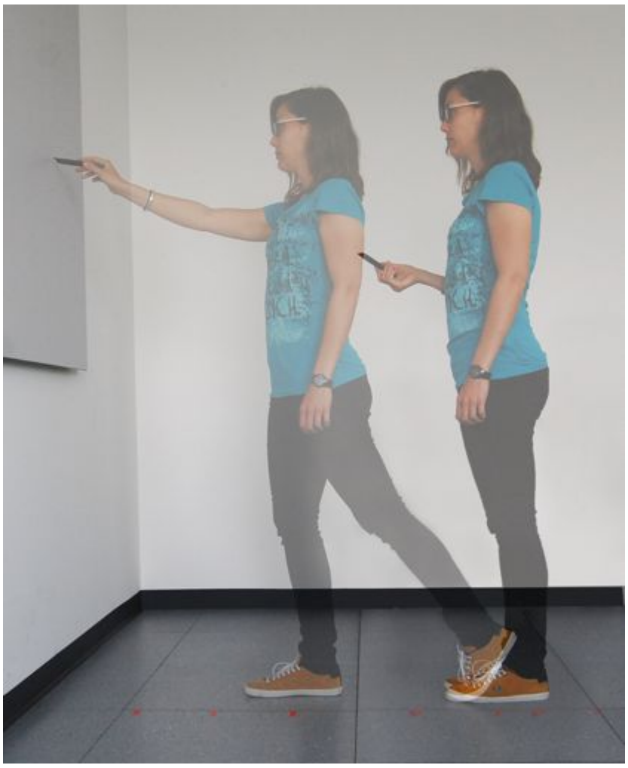


Figure 6.8: Participants had to change their position in order to reach the whiteboard with their hand during the task.

Changing distance during the task: The distance to the whiteboard during the tasks varied between the participants. Participants tended to step backwards to observe the task's new position when the position of the task was changing. Increasing the distance to the display conveyed a feeling of having better overview.

The distance of two participants was very large (see Figure 6.8). They have not been able to reach the whiteboard with their hand in the overview position (whiteboard to foot approx. $100 - 110cm$). In order to interact with the whiteboard they had to make a big step to come close to the whiteboard.

Participants were more likely to stand at a fixed position during the block, when the position of the task on the whiteboard was not changing.

Distance Influence on physical demand: One participant with a huge distance to the whiteboard stated "the right hand (dominant hand) hurts during the study". The reason for this is that he had to extend his hand to insert the selection on the whiteboard. It is less exhausting to bend the arm with the pen. Figure 6.7 showed participants bending and extending their arm.

(a) (b)

Figure 6.9: Wearing the watch on the front (a) or on the ventral side (b) of the wrist.

Simple and Complex Icons

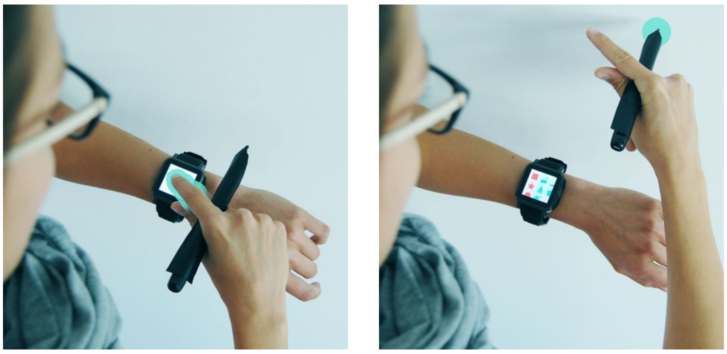
We observed during the study, that participants had problems recognizing icons. Later in the interview some participants stated that they could easily identify *simple icons* (numbers and mathematical signs) and that they had problems with more *complex icons* (geometric shapes, weather, persons, fruits etc.)

A repeated measures analysis of variance of the completion time showed that the results are significant ($F_{1,11} = 58.025$, $p < .000$) with average values of *simple icons* with $5.18s$ and *complex icons* with $5.75s$ ($M = 5.46s$, $SD = 0.48s$). The results of the time completion time for the different icons types confirmed the observations and the statements that it was more difficult to identify the complex icons than the simple ones.

The recognition of the *simple icons* was also easier because these characters were already known before the study. By learning the symbols, the selection of these is getting easier [5].

Wearing the Smartwatch

For one participant it felt uncomfortable wearing the watch's display on the front side of the wrist, cf. Figure 6.9 (a), during the use of *Bimanual Pen Touch*. The participant suggested wearing the smartwatch on the ventral side of the wrist, cf. Figure 6.9 (b), to keep it readily visible and accessible.



(a) (b)

Figure 6.10: Selection on the smartwatch (a) and insert selection on whiteboard (b) using *Pen Touch*.

(a) (b)

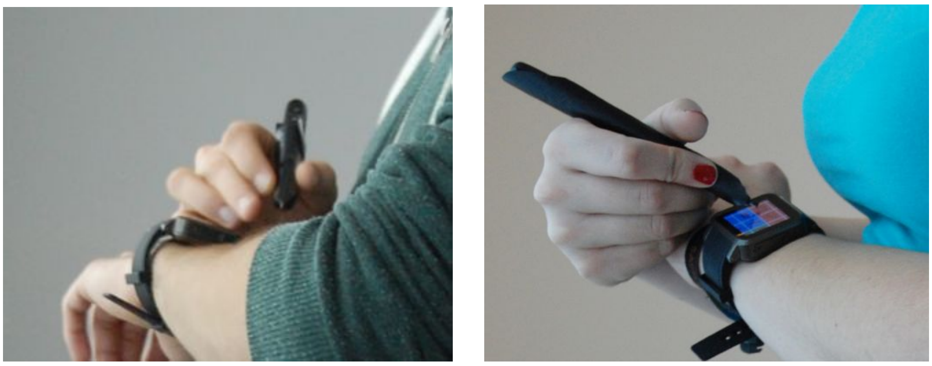
Figure 6.11: Interaction on watch (a) and whiteboard (b) using *Pen Pen*.

Hand and Finger Position

During the study we observed that the hand and finger position using *Pen Touch* was different to the other techniques. Participants tended to hold the pen loosely in their fingers to switch between pen and touch input faster.

Figure 6.10 and 6.11 visualize the different ways of holding the pen with *Pen Touch* and *Pen Pen*. While using *Pen Touch* one finger is not bent in order to use it for touch input on the smartwatch without changing one's grip, cf. Figure 6.10 (b).

Within the study it was possible for participants to accomplish the task by curling fingers loosely around the pen. However, this way of holding it would not be applicable for more complex tasks e.g. drawing on the whiteboard. In this scenario it would be necessary to hold the pen with thumb and index finger, cf. Figure 6.11 (b).



(a) (b)

Figure 6.12: Stabilising arm for touch input (a) and arm holding pen (b) for selection on smartwatch.

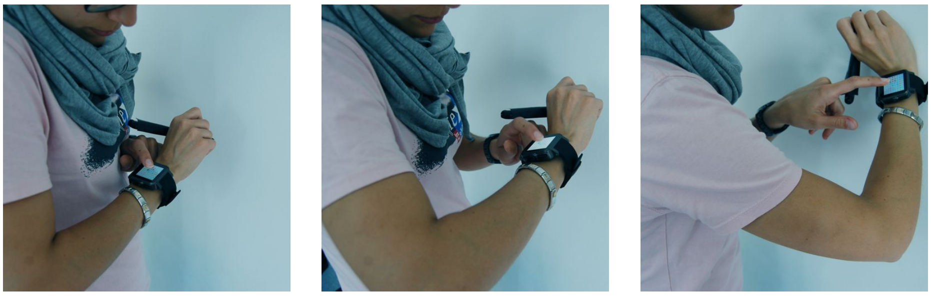
Arm Position During the Selection

In order to reduce the physical demand on the arm, which is wearing the watch, the participants tended to put their arm close to the body, cf. Figure 6.13 - 6.15 (a). Even when wearing the watch on the dominant arm (*Bimanual Pen Touch*), the arm was close to the body during the selection on the smartwatch, cf. Figure 6.13 (a). The arm was only moved in order to insert the icon on the whiteboard.

The majority of the participants were holding the arm between whiteboard and body. Thus, they have smartwatch and whiteboard simultaneously in view, cf. Figure 6.13 - 6.15 (b). This reduced attention switches between the displays.

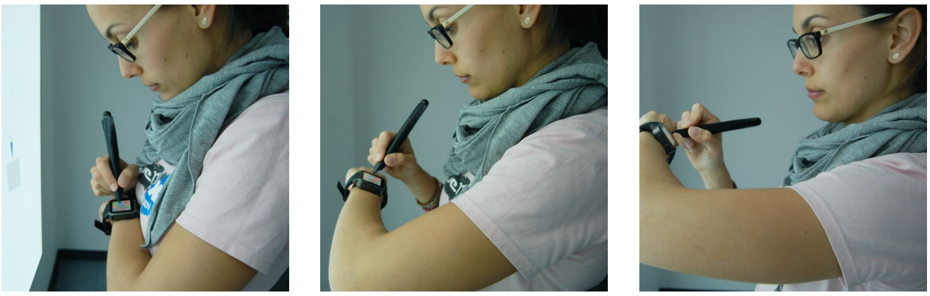
Participants holding the arm close to the whiteboard, cf. Figure 6.13 - 6.15 (c), ($M = 5.44s$, $SD = 0.60s$) performed in average 0.31 s faster than the others ($M = 5.76s$, $SD = 0.59s$) when the task position was fixed on the whiteboard.

Moreover, it was observed that participants put their arm holding the pen on the other arm in order to stabilize their finger (*Pen Touch*) or the pen (*Pen Pen*) for the selection of items (see Figure 6.12).



(a) (b) (c)

Figure 6.13: Different arm positions using *Bimanual Pen Touch* during the selection on the watch: close to the body (a), between whiteboard and body (b) and close to the whiteboard (c).



(a) (b) (c)

Figure 6.14: Arm position with *Pen Pen*: close to the body (a), between whiteboard and body (b) and close to the whiteboard (c).

(a) (b) (c)

Figure 6.15: Arm position with *Pen Touch*: close to the body (a), between whiteboard and body (b) and close to the whiteboard (c).

6.3 Discussion

Summarising, the results of this study indicate that *Pen Pen* is the preferred technique. *Pen Pen* was preferred with the normal interface because the selection of small buttons works effective with the pen. The main reason for the acceptance of *Pen Pen* was that there is no need to change input devices and the input accuracy with the pen.

It was expected that *Pen Touch* perform best with the zooming interface. The results for *Pen Pen* and *Pen Touch* have been very similar regarding the zooming interface because *Pen Pen* performs better than accepted with the zooming interface. This indicates that *Pen Pen* is also suitable for the zooming interface.

Participants disliked wearing the watch and holding the pen on the same hand (*Bimanual Pen Touch*). Additionally, they declined the interaction on the watch with the non-dominant hand. However, the observations and quantitative data analyses showed that three participants perform better with the *Bimanual Pen Touch* technique than the others. These participants stood close to the whiteboard and their arm with the watch was also close to the board. It can be assumed that the fastest use (standing close to the board) of this technique was for the other nine participants to exhausting or that they needed more distance to the whiteboard in order to keep an overview.

Although participants were using the same three techniques during the study, they created different strategies to accomplish the tasks. In order to have a better overview on the board participants changed their distance to the board. They were changing their arm's position to alleviate arm pain.

We also observed that the participants' different strategies had influence on the task completion time, but these influences were not statistically measured in the study.

6.3.1 Design Recommendations

Based on the results of this study, designers of applications running on large pen based whiteboards combined with smartwatches should consider the following design recommendations:

Provide a Pen Capable for Both Display Categories

The study indicates that *Pen Pen* works better on the normal interface and *Pen Touch* on the zooming. However, the results showed no significant different between the three techniques. On these grounds, we recommend providing a pen, which can be used for both devices, the whiteboard and the smartwatch. Thus, users can decide which technique they want to use.

Personalisation of the Smartwatch Interface

The study indicates that users have different preferences regarding the interface type (normal or zooming) and also the size of the buttons. We can recommend providing an interface with the option to personalise the size of the buttons and the zoom-factor.

Depending on the Need to Have an Overview of the Whiteboard

The results showed that the techniques performance and acceptance depended on the task. *Pen Pen* is suitable for tasks where the users have to change their position in front of the whiteboard and also when an overview of the whiteboard is important. *Bimanual Pen Touch* is applicable for tasks where the position of the user in front of the board is fixed.

Depending on Application Scenario

We assume that the techniques are more suitable for certain application scenarios. For example we suppose, *Bimanual Pen Touch* could be interesting for drawing applications on the whiteboard. During drawing on the board users could place their hand on the board and simultaneously select the icons with his non-dominant hand on the smartwatch. *Pen Pen* could be interesting for application where both devices are used often. For example a map application where users select items on the smartwatch and insert them on the whiteboard.

Chapter 7

Conclusion

In this work, we presented the combination of smartwatches with large public whiteboard. We identified the research of combined use of these devices as opportunity to improve multi-device interaction. The improvement of multi-device interaction is important, because the nature of our workspaces has become collaborative and distributed over multiple devices. In addition we presented two smartwatch interface types (*normal* and *zooming*) for extending the whiteboard.

For finding the optimal technique and interface a user study was conducted. Results revealed that *Pen Pen* improved the input accuracy on the normal interface and that data transfer with pen on both devices was more natural for users.

Contribution

This work addresses the exploration of limits and distinction of combining smartwatches with large pen-based interactive whiteboards. We developed a smartwatch application, which allows the selection of numerous icons. In addition we created new interaction techniques for the combined use of watches with pen-based whiteboards. We evaluated the extended smartwatch tool palette for whiteboards and interaction techniques (*Bimanual Pen Touch*, *Pen Pen* and *Pen Touch*) for the transfer of data between the devices within a user study. The observations of the study indicate that there are many different factors influencing users' performance, e.g. distance to whiteboard, body posture, arm position, hands and finger position during selection on smartwatch and input on whiteboard. Based on the results, participants' feedback and observations we formalized design recommendations.

Future Work

This study was designed as an initial study to find out how to combine smartwatches with large pen-based whiteboards. Furthermore, study results were expected to point out areas requiring further investigation. As we found out that *Pen Pen* was the preferred technique it would be interesting to compare it with tangible tool palettes, smartphone and on-screen menus.

This work concentrated on touch input on the smartwatch. Interaction techniques for allowing users to combine direct touch on the smartwatch's display with sensor-based interaction techniques are to be researched.

Study participants were instructed how to use the interaction techniques. However, numerous differences in the use of these techniques appear during the study. Participants' distance to the whiteboard, body posture, arm position, hands and finger position during selection on the smartwatch or insertion on the whiteboard influences users' performance. In further research these factors must be taken into consideration.

Participants stated that view and input on the smartwatch display, when wearing it on the front of the wrist, was uncomfortable using *Bimanual Pen Touch*. Expanding the view and input possibilities on the watch could also improve the other techniques. Hence, exploring alternate in-/output modalities on the form factor of a watch (e.g. multi-display wrist worn system [13], combining smartwatch display with input from touch-sensitive wristband [7] or with sensor based around device control [11, 18]) combined with our techniques needs further investigation.

Currently, our work within MDUI focuses on the combination of smartwatches with whiteboards. Since the nature of our workspaces has become distributed over multiple locations and digital artifacts, the combination of other devices (e.g. smartphone [4], smart glasses or tablets) with the smartwatch needs further research.

In the future, it would be interesting how our interaction techniques could be extended from smartwatch and whiteboard towards a symphony of different devices.

Appendix A

Study Material

A.1 Consent Form

Einverständniserklärung

Studie zur Untersuchung von MDUIs

Bitte lesen sie sich dieses Dokument sorgfältig durch und wenden Sie sich bei möglichen Fragen direkt an die Untersuchungsleiterin Manuela Stieger.

Alle von Ihnen erhobenen Daten werden vertraulich behandelt. Nur die Mitglieder des Projektteams haben Zugang zu den von Ihnen erhobenen Daten. Die Darstellung der Untersuchungsergebnisse erfolgt ausschließlich in anonymisierter Form. Personenbezogene Informationen werden, falls erforderlich, so verändert, dass keine Rückschlüsse auf die Ursprungsperson möglich sind.

Ihre Teilnahme an der Untersuchung ist freiwillig. Sie können die Bereitschaft zur Teilnahme jederzeit widerrufen beziehungsweise die Teilnahme an der Untersuchung abbrechen.

Durch Ihre Unterschrift erklären Sie, dass Sie freiwillig an der Untersuchung teilnehmen und dass Sie den Inhalt der Einverständniserklärung gelesen und verstanden haben.

Bei Fragen zur Untersuchung und zu Ihren Rechten als Untersuchungsteilnehmer stehen Ihnen die Untersuchungsleiter/in Manuela Stieger (Manuela.Stieger@students-fh-hagenberg.at), Florian Perteneder (Florian.Perteneder@fh-hagenberg.at) sowie Dr. Michael Haller (michael.haller@fh-hagenberg.at) gerne zur Verfügung.

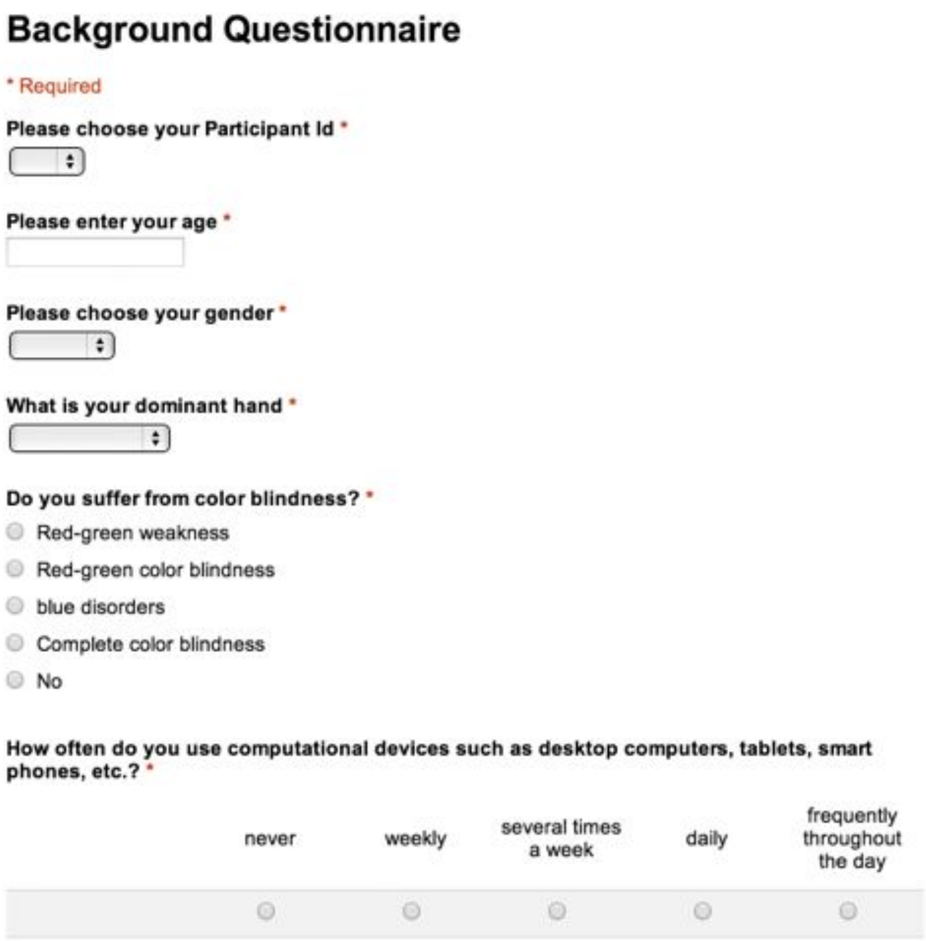
☐ Ich erkläre mich einverstanden, dass Fotos der Studie in wissenschaftlichen Publikationen verwendet werden.

Name, Datum, Unterschrift

Figure A.1

A.2 Questionnaires

A.2.1 Background Questionnaire



Background Questionnaire

* Required

Please choose your Participant Id *

Please enter your age *

Please choose your gender *

What is your dominant hand *

Do you suffer from color blindness? *

- Red-green weakness
- Red-green color blindness
- blue disorders
- Complete color blindness
- No

How often do you use computational devices such as desktop computers, tablets, smart phones, etc.? *

	never	weekly	several times a week	daily	frequently throughout the day
	○	○	○	○	○

Figure A.2: Background Questionnaire Part 1

How much experience do you have using ... *

	none	less than a month	less than a year	1 - 5 years	more than 5 years
... touch-based computational devices (Tablet, Smartphone)?	○	○	○	○	○
... touch-based whiteboards?	○	○	○	○	○
... pen-based computational devices?	○	○	○	○	○
... pen-based whiteboards?	○	○	○	○	○
... small touch-based computational devices (SmartWatch)?	○	○	○	○	○

Do you wear a clock? *

daily	1-3 times a week	never
○	○	○

Submit

Never submit passwords through Google Forms.

100%: You made it.

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Figure A.3: Background Questionnaire Part 2

A.2.2 Exit Questionnaire

Exit Questionnaire

* Required

Please choose your Participant Id.

The ... technique requires little time to learn. *

	Agree Strongly ++	Agree +	Undecided +/-	Disagree -	Disagree strongly - -
Bimanual					
Pen Pen					
Pen Touch					

The ... technique was easy to use. *

	Agree Strongly ++	Agree +	Undecided +/-	Disagree -	Disagree strongly - -
Bimanual					
Pen Pen					
Pen Touch					

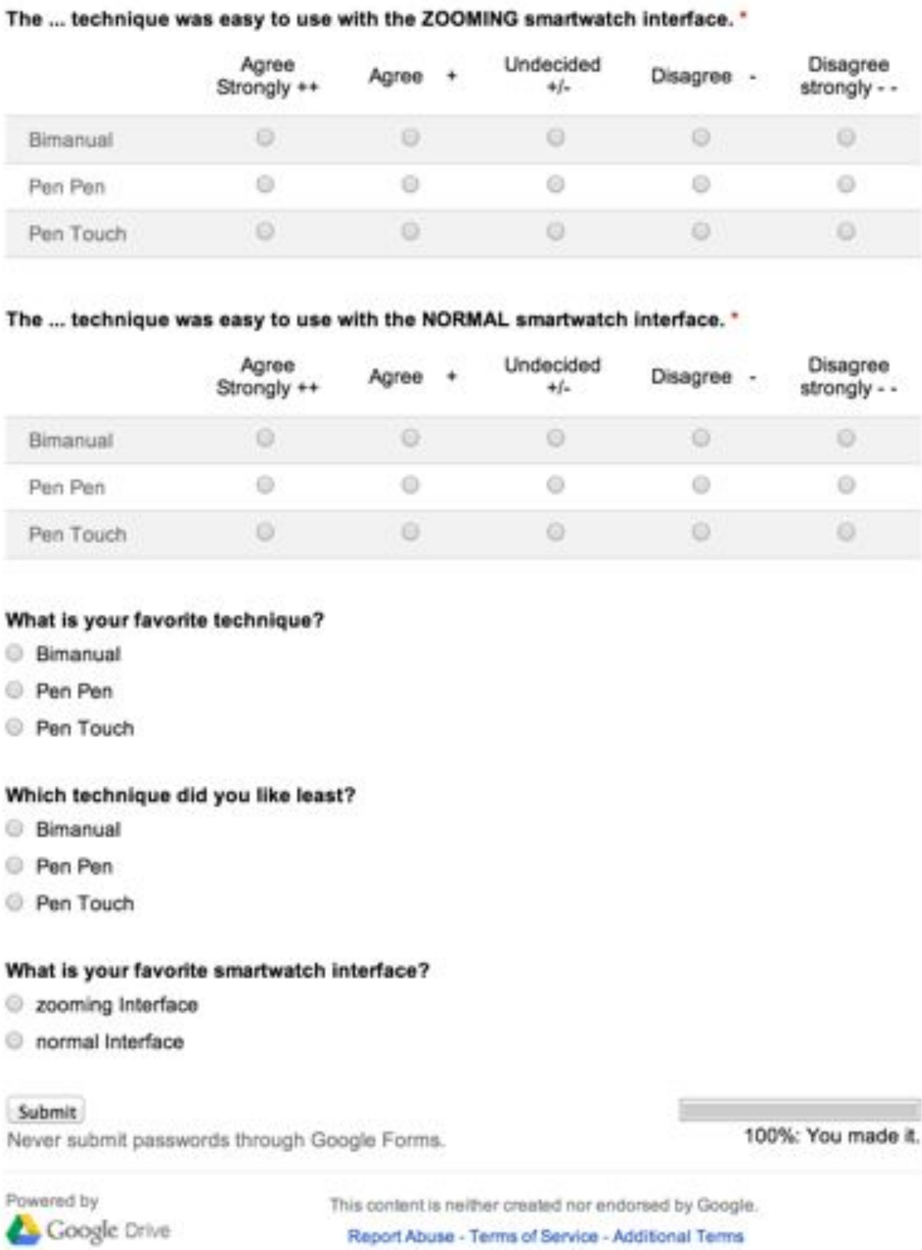
The ... technique was easy to use when the POSITION of the task was FIXED. *

	Agree Strongly ++	Agree +	Undecided +/-	Disagree -	Disagree strongly - -
Bimanual					
Pen Pen					
Pen Touch					

The ... technique was easy to use when the POSITION of the task was CHANGING. *

	Agree Strongly ++	Agree +	Undecided +/-	Disagree -	Disagree strongly - -
Bimanual					
Pen Pen					
Pen and Touch					

Figure A.4: Exit Questionnaire Part 1



The ... technique was easy to use with the ZOOMING smartwatch interface. *

	Agree Strongly ++	Agree +	Undecided +/-	Disagree -	Disagree strongly - -
Bimanual					
Pen Pen					
Pen Touch					

The ... technique was easy to use with the NORMAL smartwatch interface. *

	Agree Strongly ++	Agree +	Undecided +/-	Disagree -	Disagree strongly - -
Bimanual					
Pen Pen					
Pen Touch					

What is your favorite technique?

- Bimanual
- Pen Pen
- Pen Touch

Which technique did you like least?

- Bimanual
- Pen Pen
- Pen Touch

What is your favorite smartwatch interface?

- zooming Interface
- normal Interface

Submit

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100%: You made it.

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Figure A.5: Exit Questionnaire Part 1

Appendix B

CD Content

B.1 Thesis

Pfad: /

Thesis_Manuela_Stieger_2014.pdf Master's thesis as PDF file.

B.2 Study

Pfad: study/

study material/ . . . . . Questionnaires

study results/ . . . . . . Results from questionnaires and logged data completed by study participants.

study analysis/ . . . . . Analysis of questionnaires and logged data during the study (Microsoft Excel files and SPSS output).

B.3 Miscellaneous

Pfad: /

images/ . . . . various used images and illustrations

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