UbiCompass
IoT Interaction with Wearables

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Abstract

As the number of connected devices around us increase through the development of Internet of Things (IoT), the need for interaction with these devices increase. This thesis aims to examine the benefits of using wearables to achieve fast at-a-glance interaction. A functional prototype, UbiCompass, was developed for a smartwatch that exploits the direction of the connected devices relative to the user. To demonstrate a wide area of functionality and to open up for further development, the prototype integrates with the Z-Wave standard. The concept was evaluated against an existing mobile application through a user study concerning smart home product interaction. 32 participants tested both devices, following a scenario, and the results were gathered through interviews, observations, System Usability Scale forms (SUS) and Nasa TLX forms. The results indicate that the smartwatch is generally preferred over the mobile, especially regarding simpler tasks.

Keywords: wearables, IoT, interaction, smartwatch, smart home products

Sammanfattning

Då antalet uppkopplade enheter omkring oss ökar genom utvecklingen av Internet of Things (IoT), ökar även behovet av interaktion med dessa enheter. I detta projekt undersöks fördelarna med att använda ”wearables” för att uppnå snabb ”at-a-glance”-interaktion. En funktionell prototyp, UbiCompass, utvecklas för en smartklocka och utnyttjar de uppkopplade enheternas riktning i förhållande till användaren. För att demonstrera bred funktionalitet och för att underlätta vidare utveckling, integrerar prototypen med "Z-Wave"-standarden. Konceptet utvärderas mot en existerande mobilapplikation genom användartester rörande interaktion med smartahem-produkter. De 32 testdeltagarna testade båda enheterna, genom att följa ett scenario, och resultatet sammanställdes från intervjuer, observationer, System Usability Scale-enkäter (SUS) samt Nasa TLX-enkäter. Resultatet visar att smartklockan generellt föredras framför mobilen, särskilt för enklare uppgifter.

Keywords: wearables, IoT, interaction, smartwatch, smart home products

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Contents

Chapter 1
Introduction

Imagine this scenario: You finally arrive at your hotel after a long train trip. You have had a frustrating conversation with the hotel receptionist but finally got your key card. It is awfully hot in the room so you glance at your watch that reads 30 degrees Celsius. You point your watch at the climate system and lower the temperature to more comfortable 21 degrees. You turn to the lamp to dim the lights and finally take control of the audio system to turn on some music. A glance at your watch again shows that you can easily interact with the TV as well but you decide to leave it off.

1.1 Context

More and more products that we use on daily basis get connected to the Internet. Many newer televisions and audio equipment are connected and many new smart home devices hit the market. Alarm systems, lamps, appliances, power outlets etc. get thereby new possibilities of interaction. These units are usually controlled through, quite technical, web pages or mobile applications. At the same time, wearable devices in different form factors get more advanced and popular. Can these be used for interaction in the smart home?

1.2 Purpose & Goal

There are two main objectives with this report regarding:

- *Discoverability* A fundamental factor in interaction with smart home devices is *discoverability*; the user must in some way be informed of what devices that actually are interactable [1].

- *Controllability* To control a simple device, e.g. a lamp, you may want to use a simple control method providing fast and mentally non-demanding interaction. The term ”controllability” is not established in interaction design literature, but is in this report used to make a practical distinction between the discover and the control phase of an interaction.

The goal with this thesis is to find out if the benefits of wearables can be used to achieve these two objectives and thereby provide *at-a-glance interaction* with smart home devices. A functional prototype that is integrated with an existing smart home system is developed to demonstrate the concept. This concept is evaluated against a mobile application through a user study.

1.3 Related Work

Much research regarding IoT (Internet of Things) has been made on the technical and communicational areas, e.g. "The internet of things: A survey" by Atzori, Iera and Morabito [2]. On the other hand, very little research effort has been made with focus on interaction. Roughly, IoT interaction can be split up between *explicit* and *implicit* interaction [3]. Explicit interaction refers to ”old-fashioned action-reaction” systems. Every time you want to turn on the light you have to flip that switch on the wall, no matter who, when or why. In contrary, implicit interaction can e.g. light up the room automatically when you enter it and the existing light is below a certain level. The interaction is executed depending on different parameters in the context. The break-up between implicit and explicit IoT interaction is explained by Poslad [3]. Weiser proposes a vision where interaction will shift from explicit to implicit [4], due to more affordable and smaller devices, while Rogers argues that we in the future will need more explicit interaction as the number of interactable devices increases [5].

Mann explains the wearable concept and its properties [6]. Mentionable papers about wearable interaction are Leda et al. [7] who present "proxemics-aware" controls where spatial relationships between the user’s handheld device and surrounding appliances are used to create a dynamic appliance control interface. Chen et al. [8] used a head-mounted display (HMD) for selecting and controlling smart devices.

Chapter 2
Background

This thesis relies on theories from several areas, both pure technical, e.g. smart home devices and their protocols, and less technical, e.g. cognitive ideas. Some areas are left out, e.g. software programming theory and detailed hardware specifications, while the most fundamental areas, necessary for the reader to absorb the big picture of the following report, are summarized below. The sections of this chapter are *Internet of Things (IoT)*, *Interaction Overview*, *Wearables* and *Z-Wave*.

2.1 Internet of Things (IoT)

There are several definitions of IoT, e.g. ”The Internet of things (IoT) can be perceived as a far-reaching vision with technological and societal implications.” [9]. The "Internet of Things Global Standard Initiative" recommends the definition: ”as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.”[10].

A few years ago, computers and mobile phones were connected to the Internet, yesterday our TVs and alarm systems got connected and today we begin to see connected jewelry, watches, refrigerators, cars, motion detectors or other sensors. Many of these devices have earlier been regarded as ”dumb”, but can now, due to their connectivity, offer improved functionality. [3] The exact purpose to connect all these devices differ, of course, but a common factor are the new possibilities of controllability and automation that emerge. The devices can e.g. be controlled or monitored by its owner (a smart lamp in your living room), by its producer (your car or auto-updatable TV) or by each other (a smart thermometer that turns on the engine heater for your car at a specified temperature).

There are several standards for communicating with devices and many smart home products use a smart home controller as a bridge. The controller itself is connected to the Internet, while the devices connected to the controller often follows another standard e.g.

Nexa [11], Z-Wave [12] or ZigBee [13]. With a few exceptions, all communication with the devices are performed through the controller, often via web pages or mobile applications. There are, for the standards named above, several third-party devices available on the market compatible with each system respectively.

Several other companies are also working on their own IoT solutions for example Samsung (SmartThings) [14], Apple (Homekit) [15], Microsoft AllJoyn [16] or Google (Weave) [17].

In-door positioning is a well known issue for IoT in general and much effort are put to solve it. Sensors or beacons can be used, e.g. BeSpoon [18], but also existing network infrastructure. One interesting project is Chronos, developed by MIT's Computer Science and Artificial Intelligence lab (CSAIL) [19]. The project exploits phase differences at different channels, i.e. different frequences, in the Wi-Fi nodes to approximate the distance. The units require a slight unit firmware modification but no additional hardware is needed.

2.2 Interaction Overview

How we interact with different devices around us is an extremely wide research area impossible to cover in this report. On the other hand, there has not been made much research regarding IoT interaction, especially with wearables, since most IoT research has been focused on more technical issues. However, below the most common terms and ideas, relevant for this project, are described under *Discoverability*, *Controllabillity* and *Implicit and Explicit Interaction*.

2.2.1 Discoverability

One of the objectives with this project is to make the user aware of the surrounding and interactable devices - how can the system let the user discover what is interactable? A flashlight with one big button named "ON/OFF" offers good *discoverability*, since the design lets you know that you can interact with the lamp using the button.

A not as good example is when you enter a room with a ceiling lamp. You assume that you can control it in some way and start searching the walls for the lamp switch, but the lamp itself does not tell you that it is interactable. Nor does it offer good mapping. Assume that you already know that the lamp is interactable, there is no logic in that you should control it using a wall switch a few meters away without any visible connections to the actual lamp (100 years ago, when the household possibly had only one switch with one wire to one lamp, it was more logical).

Though, wall switches are commonly accepted to use when interacting with ceiling lamps but new interaction methods with new interactable devices open up for smarter solutions including good discoverability.

2.2.2 Controllability

Another objective with this project is to offer simple *control abilities* with devices. To achieve fast at-a-glance interaction all interaction steps, from discovering to controlling a device, should be few and quick. *Affordance* is important to draw the user's attention to the control interface and make the user want to use it [1]. *Feedback* is important to make the user aware of that interaction has been made and about the results.

2.2.3 Implicit and Explicit Interaction

A simple interaction can either be *explicit* or *implicit*, but more complex interactions can be mixes of both. For example, the light level adjusts automatically when you flip the switch. Also, the discoverability part of the interaction can be implicit while the controlling part is explicit. You automatically get informed about your possibilities of interaction in the room, but you need to continue to the controlling part explicitly.

In the early 90s, Mark Weiser proposed a vision regarding a shift from explicit to implicit interaction [4]. The vision has partly been realized and implicit interactions has became more common, due to e.g. smaller and more affordable technology. Yvonne Rogers on the other hand, foresees an increasing need for more explicit interactions to provide easy, efficient and comfortable interactions also when the number of connected devices increases [5].

2.3 Wearables

More devices in our surroundings get connected to the Internet and many new *wearables* hit the market [20]. These devices can be for example smartwatches, smart bands or jewelry with additional functionality. Common properties for wearables are that they always are intended to be "on", they should provide at-a-glance access to information and they should sense the surrounding environment to offer a better interface to the real world [6].

Most wearables are synced with the wearer's mobile phone to extend the mobile phones features but many devices also have sensors and stand-alone functionality. Smartwatches for example, forwards your phone's notifications and informs you about incoming calls and messages. Additionally, many watches hold their own sensors like step sensors or GPS.

2.4 Z-Wave

Z-Wave is a wireless protocol for communication within the smart home communicating at around 900 MHz to avoid interference with other devices using the 2.4 GHz band e.g. WiFi, Bluetooth or 3G. It was originally developed by a Danish startup called Zen-Sys and was later acquired by Sigma Designs [12]. It is one of the wider spread protocols and many third-party devices are available following the standard.

Most Z-Wave systems are built around a controlling unit, e.g. Fibaro Home Center 2 [21], that acts as a hub for the communication. All smart devices are connected to this providing implicit internet connection for the devices. Handhelds and web pages can then be used to communicate with the system.

In Figure 2.1 a typical controller web interface is shown, more specific the page for Fibaro Home Center 2. The corresponding mobile application is shown in Figure 2.2.

Figure 2.1: A typical Z-Wave controller web page (here the Fibaro Home System 2 administration page). The devices can be accessed in many ways e.g. depending on their type or location. The interface also offers scripting for automation. The device inclusion and exclusion are also managed here as well as more detailed device parameter settings.

Figure 2.2: A typical Z-Wave controller mobile application (here an Android application from Fibaro). The devices can be accessed in many ways e.g. depending on their type or location. The interface is less advanced than the web page, but still offers some advanced operations. To the left, the main screen is shown. In the middle a specific room is selected and corresponding devices are shown. To the right, a dimmable lamp with colour adjustments is selected.

Chapter 3
Approach

This chapter explains how the objectives of this project are approached, both from an interactive design perspective as well as from a technical design perspective. Here the prototype development is in focus while the evaluation is described under Chapter 4 User Study. The chapter is divided into *Hypothesis*, *Method*, *Conceptual Design* and *Technical Design*.

3.1 Hypothesis

As seen in Figure 2.1 and 2.2, typical interaction concepts are relatively advanced and best suitable for more complex solutions including advanced interaction with devices or automation. They are for example good for programming the engine heater to turn on below a given temperature or to control the devices at greater distance, for example from another room or building. They are also good in situations when an overview of all the connected devices' status in a household is desirable. The connected devices can also be listed in different categories as e.g. ”Lights” or ”Livingroom”. Though, since the interfaces are complex and provide wide functionality, they are not optimized for simpler controlling at-a-glance.

Wearables have some possible advantages and disadvantages in contrast to mobile phones or computers. First, they are designed to be weared, i.e. the user always have the device within reach and are thereby suitable for at-a-glance interaction. Also, they are often equipped with a number of sensors that can be used with interaction purposes. On the other hand. they are not always equipped with a touchscreen and even if they are, the screen is relatively small compared to a mobile phone or a computer. This fact restrains the possibilities of interaction and must be taken into consideration later on in the design process.

The hypothesis of this project is that wearables can be used to provide at-a-glance interaction with IoT.

3.2 Method

This chapter regards the prototype development and is divided into *Choice of Equipment* and *Project Process*. The first describes what hardware that was used and why while the latter explains the methodology for the process.

3.2.1 Choice of Equipment

There are several types of wearables available on the market, but early in the design process the choice fell on using a smartwatch. This because of its interaction capabilities i.e. a touchscreen and multiple available sensors such as compass and accelerometers.

To make the prototype adaptable to other wearable devices in the future, a smart phone acts as a routing device to forward commands from the watch and to update the watch's interface depending on the connected devices' status. This way, the wearable application is focused on interaction and simple communication with the mobile phone, while the phone is responsible for the communication with the smart home controller. The wearable-phone communication is performed via Bluetooth.

An initial thought with the project was to make this prototype more scalable than an earlier version where an Arduino with relay shields and lamps was used. More and different devices should be possible to add to the system without bringing the soldering iron. This issue was targeted by using one of the existing standard solutions available for smart homes. Without too detailed studies of the different systems the choice fell on the Z-Wave standard. It is a wide spread standard and plenty of third-party devices are easily available and relatively affordable, and it seemed to suit the needs for this project. The Z-Wave communication between the devices and the controller is made on the 868 MHz band to avoid interference with other equipment such as Bluetooth or Wi-Fi on the 2.4 GHz band. The controlling communication with the controller, such as web pages or smart phones, are made through the network via the Wi-Fi router.

Below are the hardware equipment used for the project:

- 1 wireless router Asus RT-N56U for internet and LAN communication
- 1 Fibaro Home Center 2 as Z-Wave controller [22]
- 1 Sony SmartWatch 3 running Android Wear [23]
- 1 Samsung S6 Edge running Android [24]
- 1 Sonos PLAY:1 for playing music [25]
- 1 Zipato LED bulb [26]
- 1 Aeotec LED bulb [27]
- 1 Popp Wall plug indoor switch [28]
- 1 Fibaro eyeball multisensor as thermometer [29]
- 1 table fan connected to the wall plug switch above

Below is a brief sketch over a possible setup with two lamps (Figure 3.1):

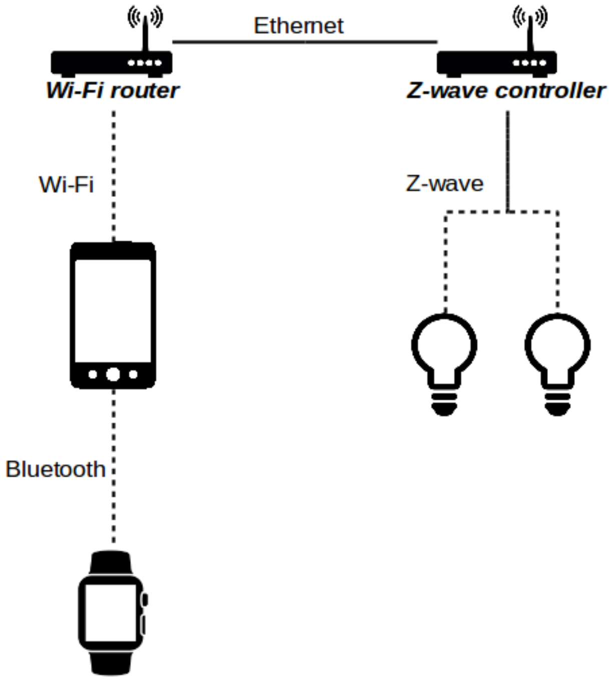

Figure 3.1: A simple setup with two connected Z-Wave lamps.

3.2.2 Project Process

To get an overview of the research field and of what already has been made, the project process began with literature studies. Some interesting already existing interaction concepts were also examined and, if possible, evaluated, mainly on the mobile phone platform. Mentionable sources found during this step in the process are referred to under Chapter 1.3 Related Work and under Chapter 2 Background.

During the following *prototyping phase*, experience from the above mentioned studies and the results from a small pilot study from an earlier prototype were taken into consideration. To make the process iterative, weekly appointments with my supervisor took place to receive feedback as well as a focus group meeting every two weeks. The focus group consisted of representatives from EASE (The Industrial Excellence Centre for Embedded Applications Software Engineering) [30], an applied software research facility for embedded software applications. The representatives were both academic, the Design Department at Lund's University [31] and MAPCI (Mobile and Pervasive Computing Institute Lund University) [32], as well as industrial, Axis [33] and Sony Mobile [34]. The focus meetings bred new ideas through brainstorming and discussions but also gave valueable feedback through the project's progress.

How many and how advanced controlling functions for each device that should be implemented in the prototype was extended during the whole process. In the beginning, the focus was to get simple ON/OFF functionality of the lamps and the switch. Later on, dimming functions, simple Sonos control functions and the ability to check the temperature were added.

The last step in the prototyping phase consisted mostly of fixing bugs and to make the system reliable enough to perform the user study (Chapter 4 User study).

3.3 Conceptual Design

Below, the different design choices for the prototype development are explained. The chapter is divided into *Initial Design Crossroads*, *Mental Models*, *Graphics* and *Feedback*.

3.3.1 Initial Design Crossroads

Early in the process, the choice of wearable hardware stood between using a Google Glass [35] or a smartwatch.

Form Factors and Hardware

Google Glass is a revolutionary device for most users and offers new ways of interaction. The user wears Google Glass on its head, as ordinary glasses, and visual information is displayed in a small prism in the upper front of the right eye. This in combination with a touch area on the frame replaces a traditional touch screen. Besides that, the device holds the same sensors as all modern mobiles phones, except for GPS.

Sony SmartWatch 3 is a smartwatch with a touchscreen, microphone and all the sensors found in modern mobile phones including GPS. It does not have a loudspeaker so a connected Bluetooth headset is needed to output audio. As for Google Glass, it supports Java.

It would have been interesting to try out the Google Glass. On the other hand, the form factor might be an obstacle since very few users are used to it. The lack of a traditional touchscreen might also have a negative impact for providing simple controllabilty. Besides, the size of the prism should limit the field of view and possibly make the discoverability suffer.

The choice finally fell on the smartwatch. It has a form factor that most people are familiar with i.e. most people have weared a traditional non-smart watch before. It also provides a *touchscreen* that also most people are familiar with. Above that, more people may be *comfortable* with the idea of wearing it everyday. To conclude, the smartwatch seemed to have all the fundamental properties to provide a possible smooth at-a-glance interaction.

App vs Watchface

The next issue was to decide whether to develop a ”traditional” application or building the prototype on the watchface i.e. the watch’s home screen. Here the watchface-based prototype was the obvious choice. The advantage of getting true *at-a-glance discoverability* and *decrease the number of interaction steps* is crucial to avoid the need of first finding and open up the right application to see if an interactable device is available. This decision would turn out to have huge impact on the software design later on. From the watchface, the user decides what to interact with and the actual controlling is made from an application, started from the watchface.

3.3.2 Mental Models

Early in the project, *the mental model of a compass* was adapted to give the user a convenient mental model ([1]) of the system. This model should exploit the positions (or at least the directions) of the devices relative to the user to make the user confident to discover the devices in the room. Fast and accurate discoverability is one of the main objectives. The obvious similarities between a traditional watch's face and a compass' rotating dial made the smartwatch's face ideal for having both the functionality of showing the time and the devices' position in the room. The model is illustrated in Figure 3.2. The different devices appears on the watchface as shown in Figure 3.3.

Figure 3.2: To the left: a compass. In the middle: a watch. To the right: a combination of both indicating one lamp straight ahead (north) and one at 3 o'clock (east).

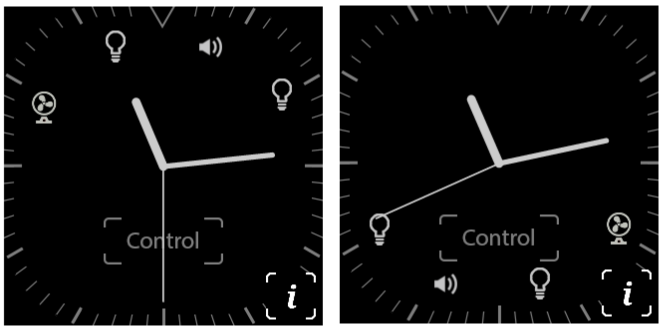

Figure 3.3: The different devices in the room are shown on the watchface. To the left, the devices are in front of the user. To the right, the user has turned around and now the devices are in back of the user.

Another mentionable mental model in the prototype is the function for adjusting the Sonos volume and the dimming level of a LED lamp. The precision of detailed actions, as changing the volume of the music, is limited due to the size of the touchscreen. Instead, the acceleration sensors were used to detect the twist movement of the wearer's wrist, as when turning a dial on the wall for adjusting the lights. The rotation direction in the control application was adapted from "traditional" dials and clockwise turning increases the intensity. With this implementation, the user does not need to look at the watch when adjusting the levels since the visual feedback is left out in favor of the wrist angle (Figure 3.4).

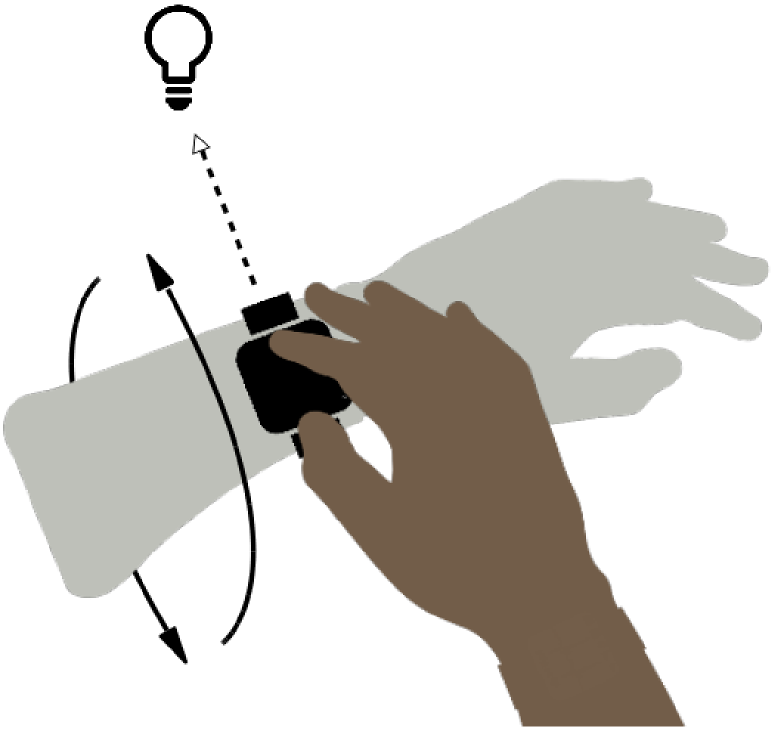

Figure 3.4: The level adjustment functions. Here, the user is dimming the light by tap and hold the lamp icon with the right hand and, at the same time, twist the left wrist. When twisting counterclockwise, the level decreases.

The mental model motivations for other parts of the prototype as icons etc. are left out in this section and, if necessary, explained under Chapter 3.3.3 Graphics.

3.3.3 Graphics

Here the graphical design choices for the watchface and the control application are exemplified and motivated.

Watchface

The watch's face is inspired by the Sony SmartWatch standard watchface and is monochrome, moderate and minimalistic in its design. The idea is to provide both an aesthetic appealing design as well as leaving room to emphasise other details of the prototype (Figure 3.5).

There are two buttons on the watchface: the "Control"-button and the "i"-button. When the "Control"-button turns untappable, i.e. when no device is in focus, it is greyed out and its contours are marked in the corners. When it turns tappable, its whole frame is drawn and the color increase in intensity. It is conveniently placed central on the screen to be well visible. The "i"-button is placed in the bottom corner since it is not needed for most of the possible interactions. It is always tappable and therefore always white. Its contours are only marked in the corners. This design is inconsistent to the ”Control”-button’s, but the affordance was suffered when the contours were lined.

The analogue clock function is retained to demonstrate that the watch still has its basic functionality.

Figure 3.5: The basic watchface with the analog clock, the ”Control”-button and the ”i”-button in the lower corner.

The small triangle at 12 o’clock indicates the focus area; when a device is in focus, i.e. at 12 o’clock, the triangle turns white. The device in focus is also highlighted with a bracket. Figure 3.6 shows the graphical differences whether when a device is in focus or not.

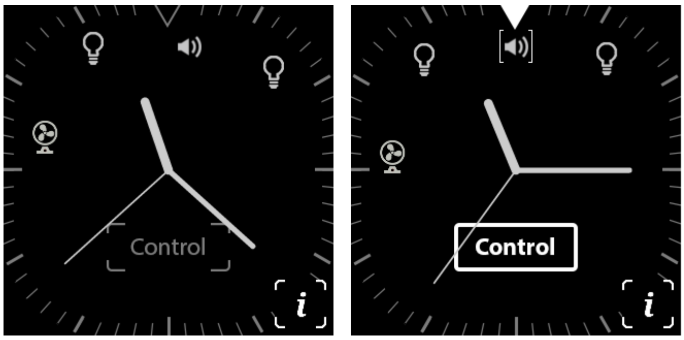

Figure 3.6: To the left: no device is in focus. To the right: the Sonos sound system is in focus.

The icons, shown in Figure 3.6 or 3.3 follow the same simplicity as the watchface in whole, stylish and minimalistic. They are monochrome as well with the thought to, at a possibly later state, make use of colors to show the devices’ active status. A lamp turned on could for example be illustrated by a yellow lamp. This feature however, is not yet implemented.

Control application

The general design in the control application follows the same style as the watchface - dark, simple, and clean. The used icons are similar to the ones used on the watchface and are chosen be as obvious as possible. The user should not be uncertain of what device that is chosen. One significant difference to the watchface, is the use of colours to provide feedback about the devices' current states.

The control application is started when a user hits the "Control"-button when a device is focused or if the user taps the "i"-button in the bottom right corner. This application adapts its user interface depending on the selected device. The icon in this view indicates the active state of the device e.g. it shows a yellow lamp if the lamp is on (Figure 3.8). In the same way, the fan icon changes to indicate that it is on (Figure 3.7).

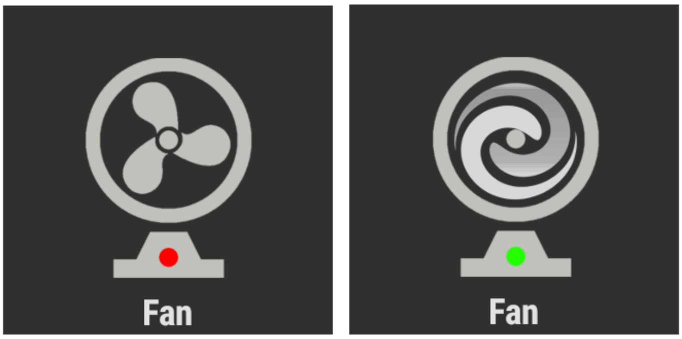

Figure 3.7: To the left: the fan is off. To the right: the fan is on.

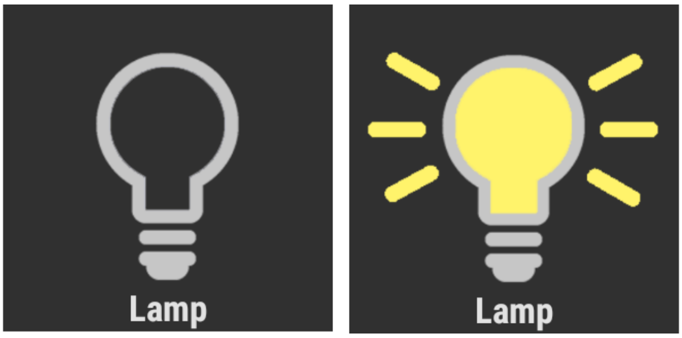

Figure 3.8: To the left: the lamp is off. To the right: the lamp is on.

For the adjustable devices, i.e the Sonos and the dimmable lamp, a scrolling text instruction is placed in the top of the screen (Figure 3.9 and 3.10). The Sonos view is static and does not change (Figure 3.10).

The room information view that is accessed through the "i"-button only shows the present room temperature and provides to interaction possibilities as seen in Figure 3.11.

3.3.4 Feedback

Graphical and *haptic* feedback through vibration are used in this prototype and described in detail below.

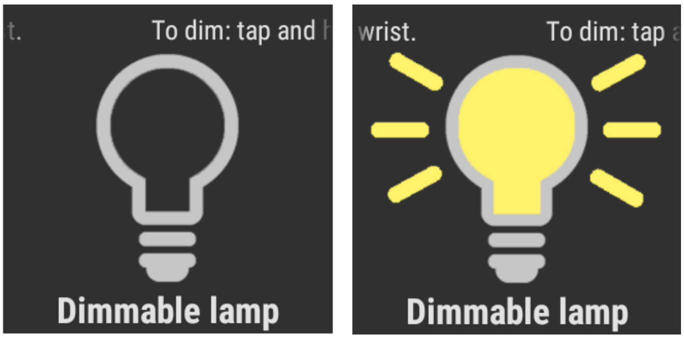

Figure 3.9: To the left: the dimmable lamp is off. To the right: the dimmable lamp is on. The scrolling text instruction in the top of the screen reads "To dim: tap and hold, then twist your wrist".

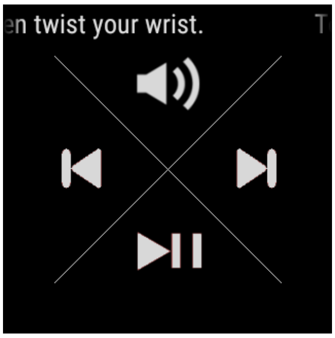

Figure 3.10: The Sonos control application. The scrolling text instruction in the top of the screen reads "To change volume: tap and hold, then twist your wrist".

Figure 3.11: The general information screen that is accessed via the "i"-button.

Watchface

On the watchface, feedback is provided when a device is in focus to emphasise the possibility to hit the control-button. As seen in Figure 3.6 and mentioned under "Watchface" in Chapter 3.3.3 Graphics, the white triangle in top of the screen turns solid white at the same as the "Control"-button contours turn white solid. The button text turns white and gets bolded. The device in focus also gets white brackets around itself.

Simultaneously, the user gets aware of that an object appears in focus by a subtile vibration pulse. To avoid unwanted and annoying remindings of focused devices, the feedbacks are only provided when the watch is "awake", i.e. not in ambient mode.

The procedure to leave ambient mode differs between different watches and can also be manually adjusted. Common ways to exit ambient mode is to touch the screen, press the side button or to make a "look-at-the-watch"-movement.

Control application

As seen in Figure 3.8, 3.9 and 3.7 graphical feedback is provided through changing the icon of the active device. To confirm a tap or a long-tap (used for e.g. dimming lights) a short vibration pulse is used. This helps the user to confirm that a control action has been performed and compensates for uncertainty due to system latency. Of course, this latency is minimized as much as possible since the most important feedback is the reaction of the controlled device.

3.4 Technical Design

This section regards technical design issues. An overview of the system is given as well as short summaries of the different prototype-specific Java classes used on each device. The descriptions are given on a high level so that readers with less programming experience should be able to understand the basic design. Some important general methods, classes and packages are mentioned though, to give the more programming experienced reader a deeper understanding and the possibility to further studies. This chapter begins with the section *System Overview*, and is followed by the sections *Mobile* and *Smartwatch*.

3.4.1 System Overview

One of the advantages with using the Z-Wave standard is to get a more flexible system where devices easily can be added or removed. Most device information is available through the Z-Wave controller's (Fibaro Home Center 2) web API but one important part is missing, the position of the device. For this prototype system, the device coordinates are predefined in the Z-Wave controller settings and the user's position is defined as origo. The coordinates can be programatically stored in the Z-Wave controller, but to simplify device position management throughout the project, they are now entered after the device's name e.g. "Lamp, 1.0, 2.0" (meaning the lamp is in the direction of 1 step north and 2 steps east of the user).

3.4.2 Mobile

The mobile application acts as a link between the wearable and the Z-Wave control unit. The purpose with this design is primary to provide a scalable solution if more wearable prototypes will be added or if the prototype, in the future, will support an extend-to-mobile feature for more advanced operations. Besides that, synchronization issues is more easily handled, especially if two or more wearable devices are used at the same time. A very simplified diagram of the classes are shown in Figure 3.12. This solution is, of course, not very dynamic, but functional for the context.

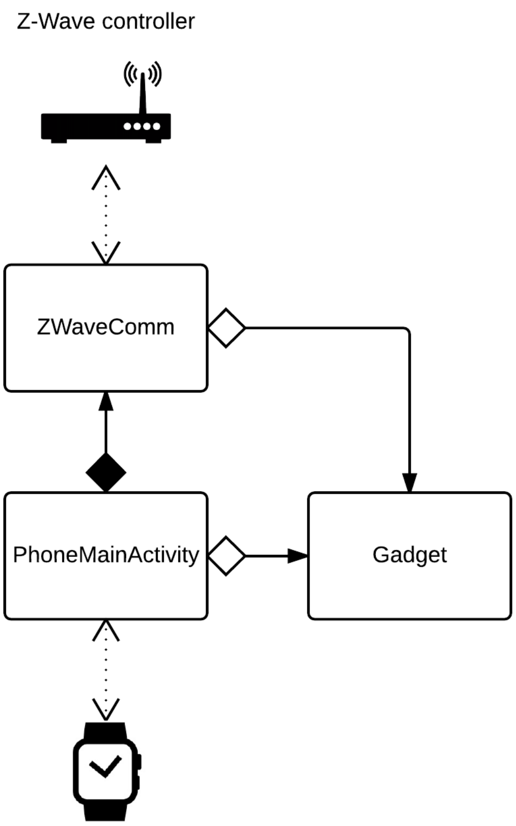

Figure 3.12: The `PhoneMainActivity` class instantiates `ZWaveComm` for communication with the Z-Wave controller. All devices are downloaded and a local list of `Gadgets` are generated and synchronized with the wearable.

PhoneMainActivity

To receive the available devices from the Z-wave controller, a `ZWaveComm` is instantiated and the `ZWaveComm` method `getGadgetsFromRouter` that returns a list of `Gadgets` (devices).

To synchronize this list with the wearable device the `GoogleApiClient` class, that provides simple synchronization of objects between devices, is used. When the list is changed, from either of the connected clients, i.e. the mobile or the watch, it is automatically synchronized between all clients. All `Gadgets` are passed as `DataMaps` in a `DataMapArrayList`.

When the mobile application receives an update from the wearable, the `updateGadgetStatus` method of the `ZWaveComm` object is called to execute the status change. The list is then once again synchronized with the controller via `getGadgetsFromRouter`.

ZWaveComm

In this class, the communication channel with the Z-Wave is setup and necessary credentials for this are provided here. All communication is made using `HTTP.GET` requests are sent to the controller which responses using `JSON` objects. The response is parsed and a list of `Gadgets` and their states are created and passed to the `PhoneMainActivity`.

To execute status changes received from the watch via `PhoneMainActivity`, different `GET`-requests are built depending on the device and the action.

Gadget

When the devices are parsed from the `JSON` response in `ZWaveComm`, a list of `Gadgets` are created. Mentionable attributes of a `Gadget` object are:

`Name` The name of the device

`PosX, PosY` The simulated position of the device relative the user (defined in origo). The values are configured in the Z-Wave controller interface.

`Angle` This is the angle in radians from north relative origo. It is calculated by using the `atan2` function with `PosX` and `PosY` followed by a subtraction $\pi/2$.

`Type` The type of the device e.g. a lamp. This is needed to select the correct icon and control interface for each device.

`Value` Answers to the current state of the device e.g. the fan is on.

The class also holds methods for object conversion to and from `Strings` and `DataMaps` to enable the possibility of transferring objects as local broadcasts and via the `GoogleAPIClient`.

3.4.3 Smartwatch

The smartwatch communicates indirectly with the Z-Wave system via the mobile software. The discoverability features are accessed directly from the watchface while the control features are accessed through an application, executed from the watchface.

WatchListenerService

This responsilibility of this service is solely to pass device information and updates to the `Watchface` class. It receives the gadgets from the mobile as `DataMaps` in a `DataMapArrayList` through `GoogleApiClient`, converts them to stringed `Gadgets` and passes them on to the `Watchface` via a `Broadcast`.

Watchface

The choice of implementing the main view directly on the watchface, i.e. not in a standalone application, has great impact on the development in whole. A watchface has several restrictions for the user e.g. the user should only be able to use short taps, since swipes and long taps are already reserved by the system. Besides, a watchface extends `CanvasWatchFaceService` which, due to restrictions in Java, makes it impossible to extend other classes.

The built in rotation sensor is here used as a compass to draw all gadgets on the face, based on their position relative to the user. When the watch is rotated, the devices keep their world coordinates, e.g. a lamp is always drawn to the north no matter the watch is heading north or south (Figure 3.3). The angle from true north is the `angle` attribute from `Gadget`. The drawing angle is calculated by subtracting `angle` from the watch's azimuth angle retrieved from the orientation sensor.

Device information and status updates are received indirectly from the Z-wave controller, via the mobile and the `WatchListenerService`. To pass relevant information to the `ControlActivity` application that is executed with the "Control"-button or the "i"-button, intents are used when executing the `ControlActivity`.

ControlActivity

The received intent from the `WatchFace` class decides the appearance of this application. From the intent, the activated `Gadget` and its status is read out. When status is changed, e.g. by tapping the lamp icon, proper feedback is given by changing the icon's appearance and the status update is sent to the mobile. This is performed by converting the `Gadget` object, including the updated value, to a `DataMap` and synchronized via `GoogleAPIClient`.

For the adjustment functions, i.e., the light dimming and volume change, the orientation of the watch needs to be tracked. The watch has a local coordinate system with first axis, x, at twelve o'clock, second coordinate axis, y, straight up from watchface and third coordinate axis, z, at three o'clock (Figure 3.13).

The `getRotationMatrixFromVector` function yields a 3x3 matrix, R, describing the watch orientation with respect to a global coordinate system. More precisely, the first column of R gives the current value of x in global coordinates, the second column gives the current value of y, etc.

To detect a rotation of the wrist, the motion of the x-vector is tracked. Let x_0 and x_t be the twelve o'clock vectors at time 0 and t respectively. It is the rotation about the wrist that should be measured. Hence, to eliminate rotation about the y_0-axis, x_t is projected into the x_0y_0-plane and the angle, θ, is measured between this projection and x_0. See Figure 3.13 for an illustration.

To make the adjustment function usable no matter the start position of the watch, the initial vectors are periodically updated and compared to the current vectors.

Gadget

The `Gadget` class is identical to the one described under Section 3.4.2 Gadget.

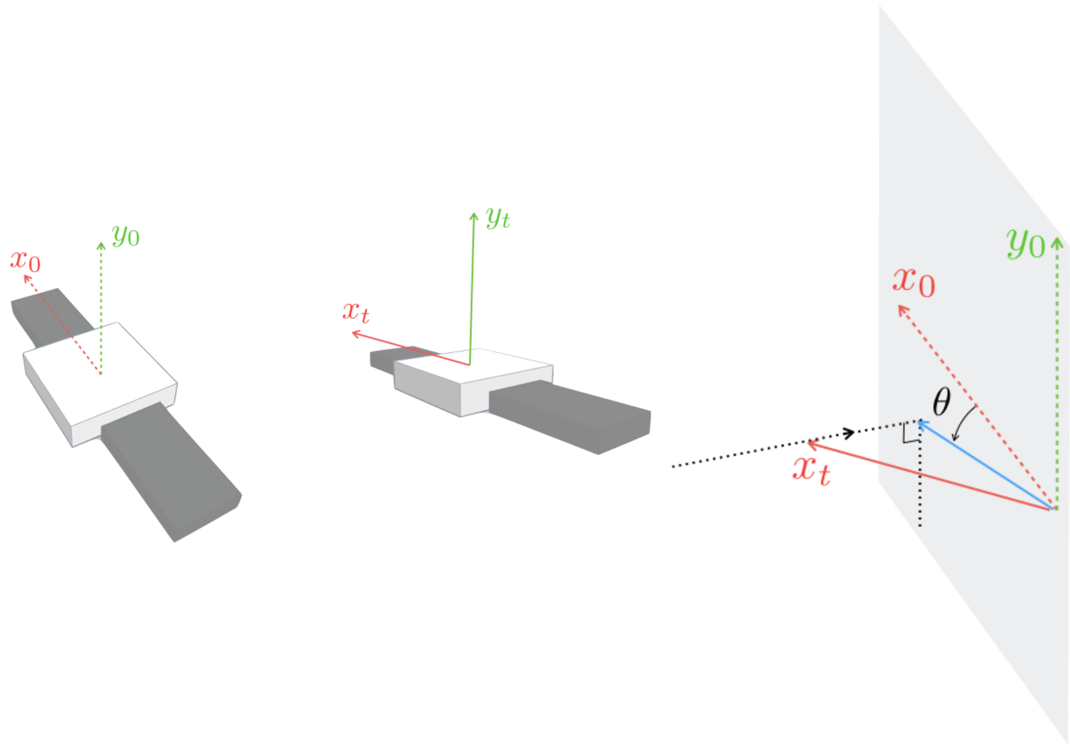

Figure 3.13: The left watch shows the vectors (x_0, y_0, z_0) at time 0 before rotation. The right watch the vectors (x_t, y_t, z_t) at time t after rotation. The x_t vector is projected into the x_0y_0-plane whereafter the angle, θ, gives the rotation about the z-axis.

Chapter 4

User Study

In this chapter the user study *Setup*, *Participants* and *Procedure* are described as well as the *Results* and a following *Discussion*.

4.1 Setup

The user study was performed in a usability laboratory; a controlled environment with audio and video recording fascilities. All test sessions were recorded. Five different devices were connected to the system according to Figure 4.1. The units used for controlling the devices were a Sony SmartWatch 3 with the UbiCompass watchface and a mobile phone running Android. More detailed information about the hardware is given under Section 3.2.1 Choice of Equipment.

The smart home controlling software on the phone is the official application from the Z-Wave controller's manufacturer Fibaro [36]. To control the Sonos system, a 3rd pard virtual device is used called Sonos Remote [37]. Screenshots of the application are shown in Figure 2.2.

4.2 Participants

32 test subjects participated in the user study and they were chosen with respect to *gender*, *age* and *background*. A complete list of the subjects is found under Appendix J and a short overview is given in Table 4.1.

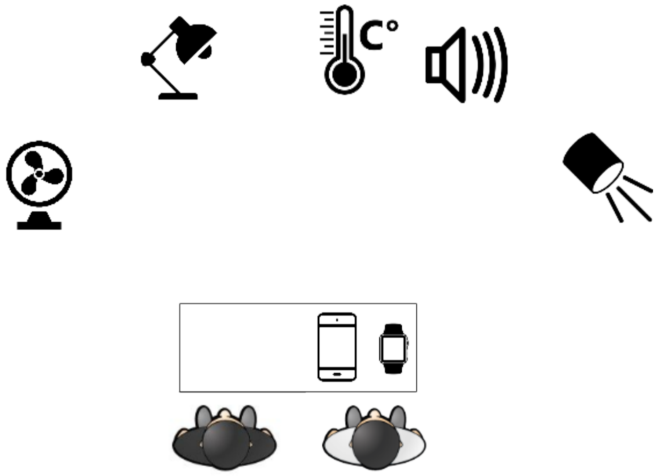

Figure 4.1: The setup in the user study. The person to left is the test leader and the person to the right is the test subject. The devices from left to right are: a fan, a desk lamp, a thermometer, a sound system and a dimmable spotlight.

Table 4.1: Participant data. The participants who chose one of the first three alternatives on the subject data form question regarding changing the phone system are here grouped as "less interested". Those who chose 4 or 5 are grouped as more interested.

Participants		
Attribute		
Gender	16 female	16 male
Background (based on education and occupation)	16 technical	16 non-technical
Smart home experience	9 have tried	23 have not tried (9 do not know about the concept)
Smartwatch or smartband experience	11 have tried	21 have not tried
Willing to change phone system	15 less interested	17 more interested

4.3 Procedure

To compensate for the test leader's behavioural variances over time, the tests were as evenly distributed as practically possible according to gender and the first tested device (i.e. mobile or smartwatch) respectively. Detailed test subject data can be found in Appendix J. Below is a summary of the user test procedure.

1. Some of the test subjects were a little anxious about what to come so they were assured that no technical experience etc. were required to participate. All participants were offered a cookie and students a cinema ticket as well.

2. The test subjects signed the ”Informed consent”, found in Appendix A.

3. They filled out the user details form, found in Appendix B.

4. They were read the general information of the introduction and the specific information referring to the device they were about to start with (Appendix C).

5. The practical testing session started and the test leader read out the scenario found in Appendix D.

6. After the tasks were finished, the test subjects filled out the Nasa Task Load Index (TLX) (Appendix F) and G) and the System Usability Scale forms (Appendix H). The test leader helped out with definitions etc. if needed.

   Nasa TLX is a subjective workload assessment tool and the purpose of using it in this study is to get an understanding of the contributing factors for the workload [38] [39]. The collected data is useful both when comparing the different concepts and when analyzing a single concept for future improvements.

   SUS is used to get a rapid usability evaluation of the interaction system [40]. Scores for individual items e.g. ”I thought the system was easy to use” can be studied and compared but the main intent is the combined rating (0 to 100) [41].

7. The subjects shared their initial thought about the concept and explained what went well and what did not.

8. The introduction part referring to the second tested device was read out by the test leader.

9. The practical testing session continued with the second device and the test leader read out the scenario again.

10. The Nasa TLX and the System Usability Scale forms were filled out.

11. The subjects shared their initial thought about the concept and explained what went well and what did not. The discussion continues and the subject were asked more specific questions regarding discoverability and the control ability (the questions are found in Appendix E). Finally, the test subjects were asked about what concept the liked most and why.

4.4 Results

In this section the results of the user study are presented and discussed. *Qualitative Data* as observations from the tests as well as notions from answers and discussions, are followed by *Quantitative Data* in form of diagrams based on the collected form data.

4.4.1 Qualitative Data

This collected data is split up between the different devices and grouped by occurrence.

Mobile

Very common

Inconsistency The interface was very inconsistent. E.g. Some icons are interactable, some not. Some devices need hierarchical navigation through layers to reach basic functions, some do not.

Low affordance Affordance is very low for most interactable areas. Some basic functions are very well hidden e.g. the scrollable room menu (to see all devices) or the layer based navigation reachable only by tapping the device name.

Well known form factor Most users are comfortable with the mobile form factor.

Device identification trouble Identification relies solely on device type and name.

Common

Within reach In practical use, the user must have the phone within reach for easy access.

Interaction steps At-a-glance interaction is not provided since there are too many steps before reaching the desired function (i.e. open application, navigate to the device, actual control).

Large screen A larger screen offers more possibilities for complex interaction. Visually impaired users might also benefit from the larger screen.

Less common

Overview The mobile application gives a good overview over the available devices.

Watch

Very common

Tappable icons Many subjects tried to take control of a device by tapping its icon instead of the ”Control”-button. If interacting with devices behind the user, an icon-tap function would be practical.

Discoverability Most subjects found that UbiCompass provided a fast and easy way to see all interactable devices.

Consistency The concept is very consistent.

Mapping The icons were very clear and logical.

General feedback The feedback was very clear both on the watchface and in the control application (except for the wrist-twist function).

Wrist-twist feedback Several subjects requested more feedback for the adjustment function, especially due to system delay.

Within reach The form-factor is suitable since the user always have the watch within reach.

Common

Wrist-twist function Some were really fond of the wrist adjustment function while some would have preferred a touch-screen solution.

Wrist-twist direction About half of the subjects found the twist direction right.

Many devices If too many devices are available in the room, the discoverability and the device selection might get ambiguous.

Physical activation The physical ingredient of the interaction was intuitive and inspiring.

Less common

Physical demanding The device selection was too physical demanding.

Room information A few found the temperature information under the ”i”-button illogical.

Icon size The size of the icons on the watchface were too small.

General

Very common observations

Complementary The interaction methods complement each other. The watch is good for simple at-a-glance interaction while the mobile application is more suited for more complex functions.

Common observations

Watch advantage The watch is superior due to its coolness and its at-a-glance interaction capabilities.

Less common observations

Unnecessary There is no need for a smartwatch interaction method if you already have a mobile.

4.4.2 Quantitative Data

The box-plotted results from the Nasa TLX analysis are shown in Figure 4.2, 4.3 and 4.4. To get a clear overview and an understanding of the answers distribution, the results are represented in percentiles (25th, 50th, 75th). The plots are based only on the first Nasa TLX form (Appendix F) and no consideration has been taken into the weightings (Appendix G).

The result box-plots for the System Usability Scale form (Appendix H) are shown in Figure 4.5 and 4.6, and a comparing diagram in Figure 4.7. Comparing diagrams gender-wise are shown in Figure 4.9 and 4.10, and ”willing to change phone system”-wise in Figure 4.11 and 4.12. The latter is based on the last question of the subject data form (Appendix B where the subjects who have answered 1-3 represent the group less willing to change phone system (15 persons) while those who answered 4-5 represents the group more willing to change phone system (17 persons). The SUS-score is calculated as described in Appendix I.

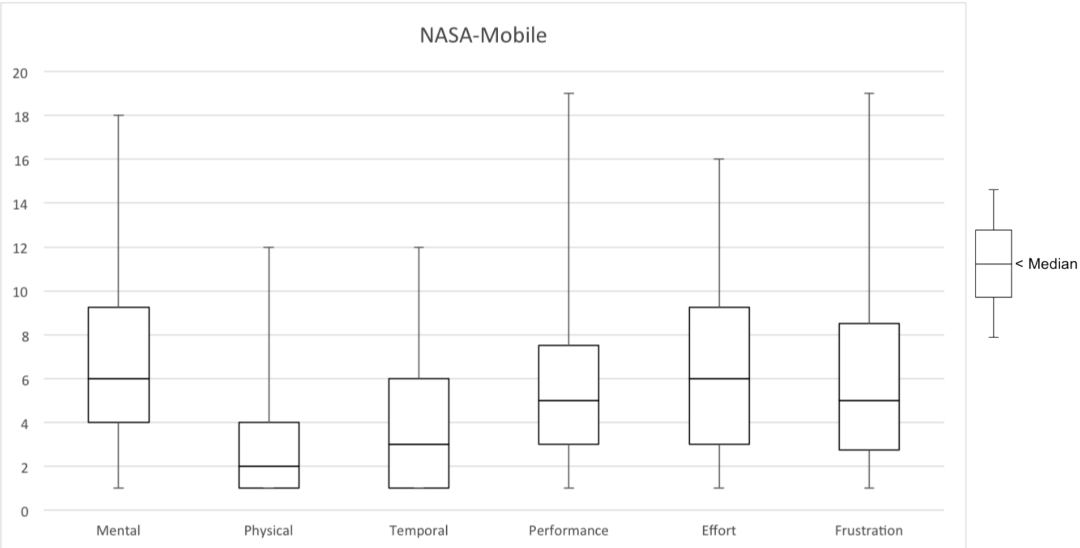

Figure 4.2: The box-plots show the Nasa TLX results in percentiles for the mobile concept.

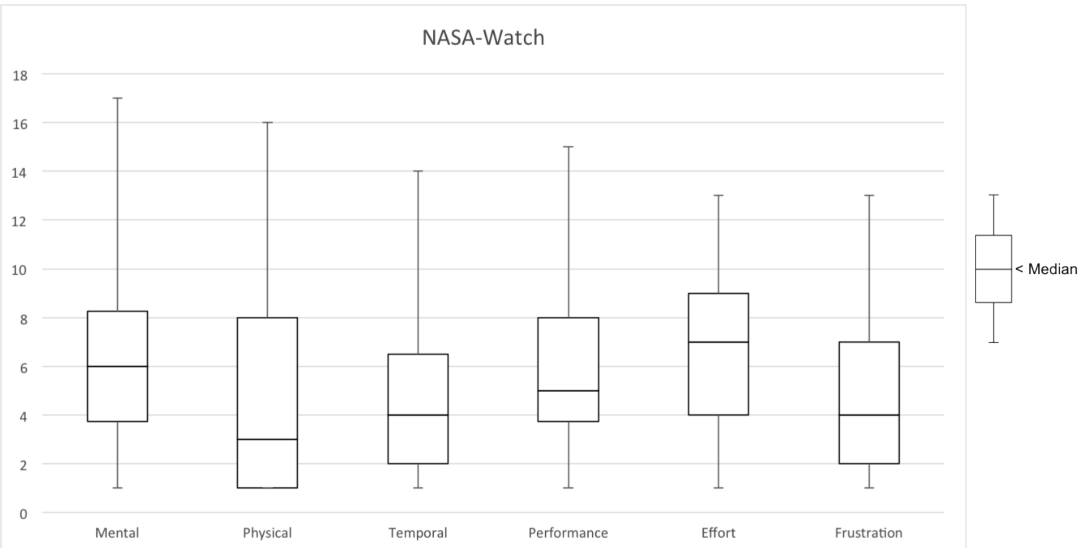

Figure 4.3: The box-plots show the Nasa TLX results in percentiles for the watch concept.

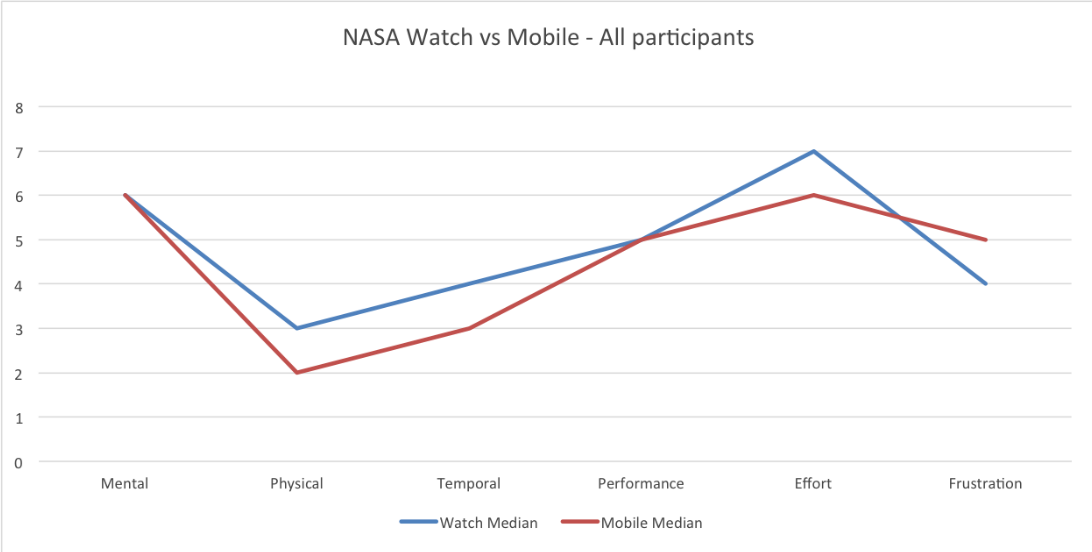

Figure 4.4: The diagram shows a comparison of median Nasa TLX results for the mobile and the watch respectively.

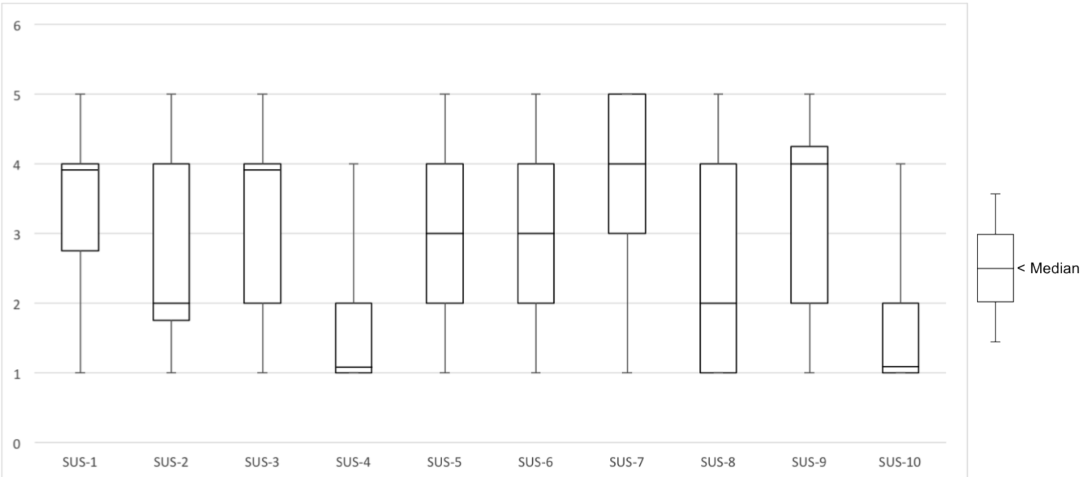

Figure 4.5: The box-plots show the SUS results in percentiles for the mobile concept. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

4.5 Discussion

Below are discussions based on Observations and Interviews, the System Usability Scale results and the Nasa TLX results respectively.

4.5.1 Observations and Interviews

Overall, the test subjects were very positive to the UbiCompass concept. The at-a-glance interaction was ”something new” and the simplicity of interacting with non-complex de-

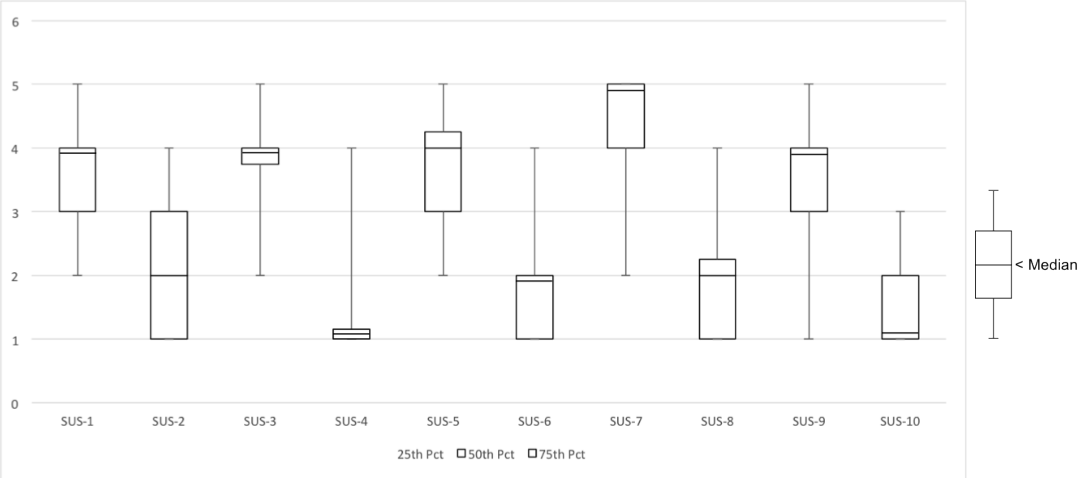

Figure 4.6: The box-plots show the SUS results in percentiles for the watch concept. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

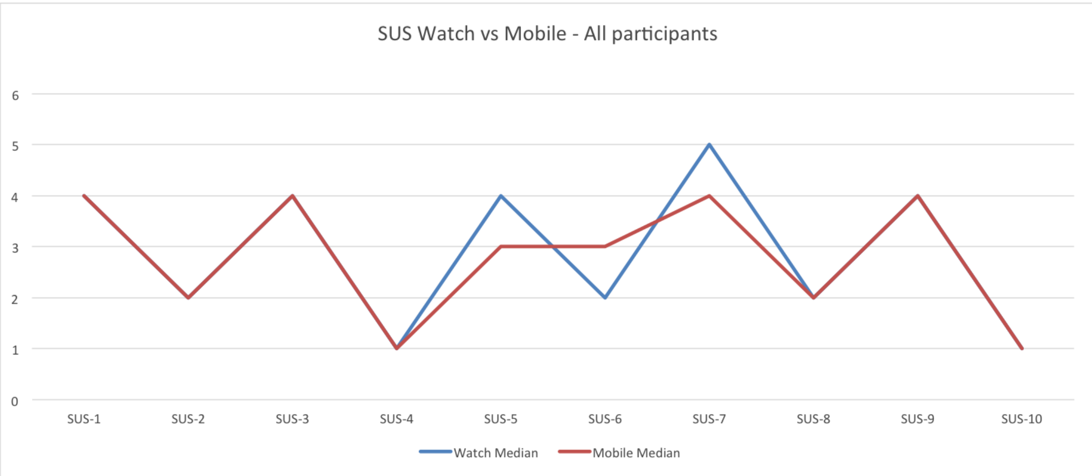

Figure 4.7: The diagram shows a comparison of median SUS results for the mobile and the watch respectively. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

vices made the concept applicable on situations where mobile solutions would be practically unusable. E.g. when turning on the lights, it is often easier to get up and flip the switch instead of fiddling with the mobile. Some noticed how this method possibly could facilitate interactions for motion disabled users. The form-factor is also appealing since it is always within reach. It is remarkable though, that most people does not own a smartwatch today and there are some resistance to get "yet another device" just to control smart home devices. The consistency of the interface was much appreciated and the graphical layout and icons were clear and well designed.

Many test subjects first tried to take control of a device by tapping its icon instead of the "Control"-button. Some also found it difficult and unnecessarily physical to target a

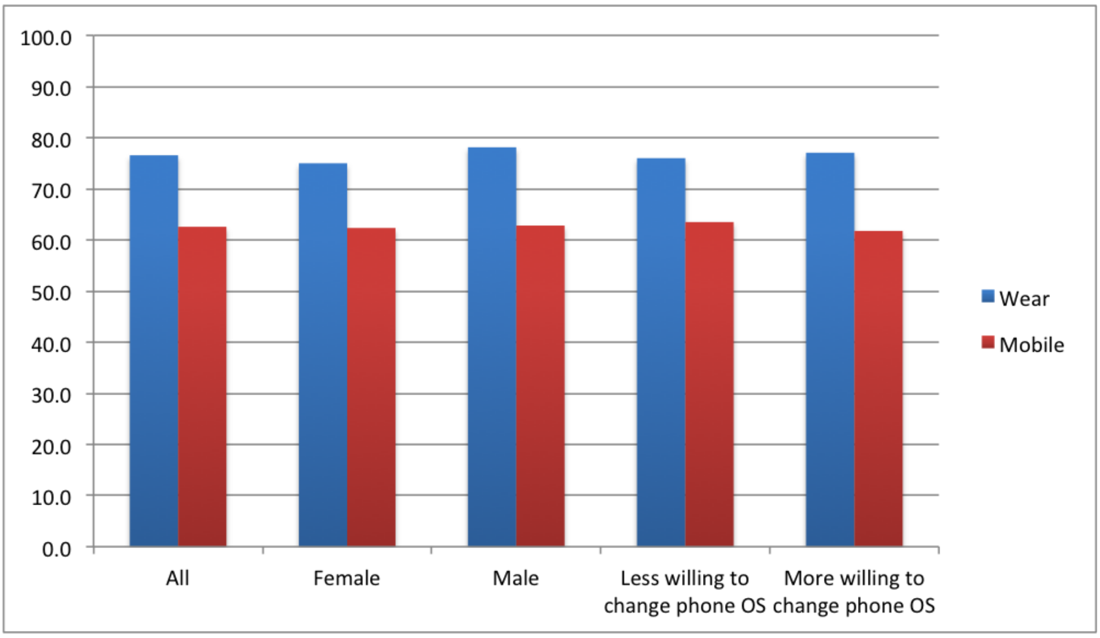

Figure 4.8: The diagram shows the average SUS scores for the mobile and the watch respectively. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

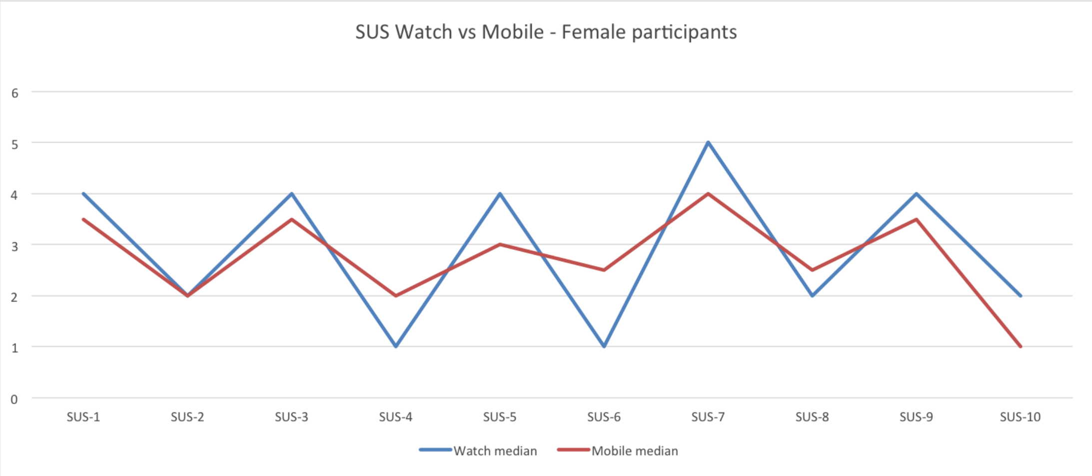

Figure 4.9: The diagram shows a comparison of median SUS results for the female participants. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

device on the watchface. The adjustment (twist the wrist) function would have required more feedback to compensate for the latency in the system. The preferred rotation direction of the adjustment function were very evenly divided between those who preferred clockwise and those who preferred anti-clockwise, though all participants agreed on that the ”right” direction was adaptable; the preferred direction was a quite vague feeling.

The majority of those who preferred the mobile interaction method relied on more

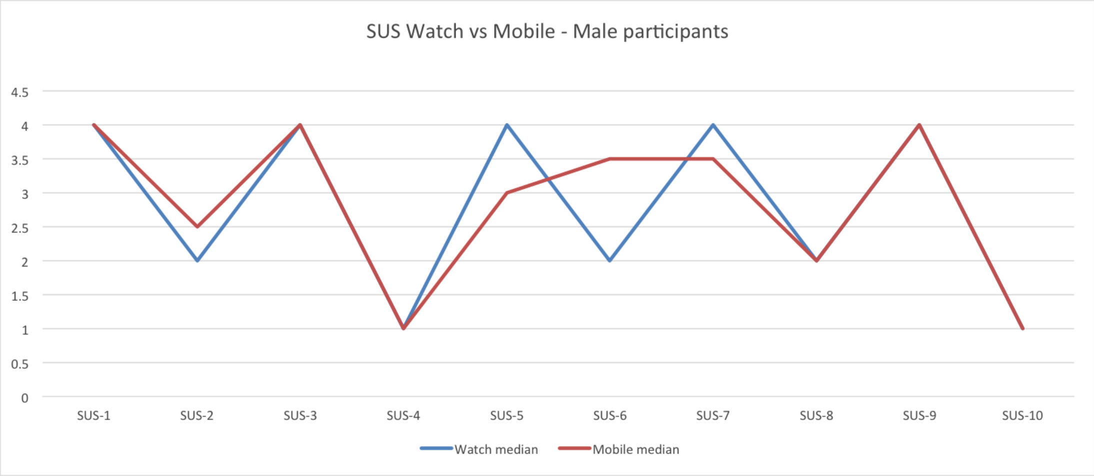

Figure 4.10: The diagram shows a comparison of median SUS results for the male participants. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

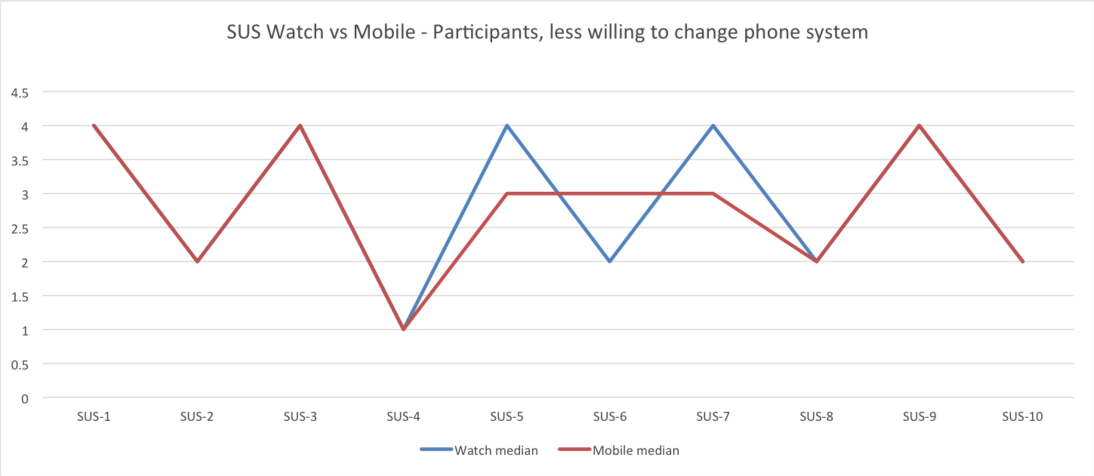

Figure 4.11: The diagram shows a comparison of median SUS results for the participants less willing to change mobile OS. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

practical arguments, i.e. "everybody has a phone" or "I do not want or need yet another technical device to carry around", than conceptual thoughts. Two of the test subjects did not find any use at all for the smartwatch method and thought of the mobile phone superior overall; there is no need for at-the glance interaction.

The common opinion of the mobile interface was that it was inconsistent and cumbersome. They also found the mobile interface unnecessary complex to deal with simple interactions.

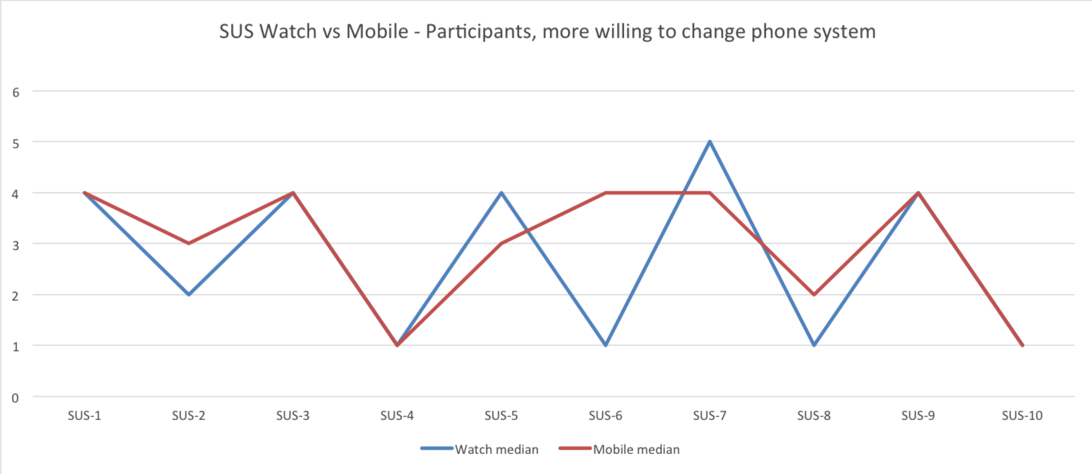

Figure 4.12: The diagram shows a comparison of median SUS results for the participants more willing to change mobile OS. The items on the horizontal axis represents the different statements in the SUS questionnaire (H).

4.5.2 Nasa TLX Analysis

Below each result for the first Nasa TLX form are described and possible explanations and motivations are given with the observations and discussions in mind.

Mental Demand

The both concepts were mentally low demanding and very similarly estimated. The mobile phone values might be explained of the inconsistency and lack of affordance found in interface. The smartwatch values are probably explained by the initial mental model understanding (compass) and the wrist adjustment function.

Physical Demand

Due to obvious reasons, the watch is more physical demanding than the mobile. 75 % of the subjects estimated it 8 or lower and 50 % 3 or lower (on a 20 graded scale). The corresponding values for the mobile application is 4 and 2 respectively. Since the analysis has been made without weightings, the importance of these values are obscure.

Observations from the tests and the discussions indicates that most subjects did not find the physical demand problematic. There were two users though, that had some problems with moving their arm in certain positions, that found it problematically physical demanding.

Temporal Demand

These values are almost identically low for both devices but slightly higher on the smartwatch. One explanation can be the wrist adjustment function that in a few tests lead to unwanted high music volume due to system latency.

Performance Level

The participants valued the performance level almost identical. Most subjects found themselves very successful in accomplishing the tasks.

Effort

The diagrams are very similar but a slight more effort was needed for the watch. This is possibly explained by the physical ingredient.

Frustration Level

The frustration level is somewhat lower on the smartwatch, probably due to higher consistency in the system.

Summary

The Nasa TLX form results were very identical for the both devices. The physical and temporal demand answers as well as the effort answers give the mobile a slight advantage though. These answers can most probably be explained by the physical interaction needed while interacting with the watch. Since the analysis has not taken the weightings into considerations, it is hard interpret the overall relevance of these results.

4.5.3 SUS Analysis

Under each statement, the results of the System Usability Scale form (Appendix H) are shown as well as, if possible, probable explanations to the results. After the statements, the SUS-score is explained.

1. I think that I would like to use this system frequently

The answers for all subjects are almost identical for the mobile and the watch (around 4). Female subjects rated this slightly higher for the watch.

2. I found the system unnecessarily complex

For all test subjects the answers are very identical and low (2). Male participants and participants more likely to change phone found the phone more complex. Perhaps subjects that are more willing to change phone system already have tried out different systems and are more observable or dependent of affordance and clarity in the UI.

3. I thought the system was easy to use

All participants found the systems easy to use (around 4) and female participants found the mobile slightly less easier than other groups.

4. I think that I would need the support of a technical person to be able to use this system

All participants gave both devices low values (1), but the female participants rated the mobile higher (2).

5. I found the various functions in this system were very well integrated

All participants rated the watch higher than the mobile (4 against 3). An explanation can be the less hierarchical navigation on the watch; the control function is always one tap away. It is possibly correlated with the next statement.

6. I thought there was too much inconsistency in this system

All participants found the mobile concept more inconsistent (3 against 2). Female subjects found both systems less inconsistent (2.5 against 1) and male slightly more inconsistent for the mobile (3.5 against 2). The subjects more likely to change phone finds the mobile very inconsistent and the watch very consistent (4 against 1). As for statement 2, this group might be more observable or dependent of affordance and clarity in the UI.

7. I would imagine that most people would learn to use this system very quickly

All subjects rated this almost identical in favor for the watch (5 against 4). The answers might be correlated with statement 6 and 7.

8. I found the system very cumbersome to use

The answers are low for all participants (2 for both devices). Female participants and he group more willing to change phone found the mobile more cumbersome. A possible explanation for the latter can be the same as for statement 2 and 6.

9 I felt very confident using the system

Most subjects were confident using both systems (4). By studying the box-plots it is shown that the watch answers are more concentrated around 3-4 while the mobile answers are more spread.

10. I needed to learn a lot of things before I could get going with this system

All answers are very low (1) but female participants gave the watch a slightly higher grade (2). This is interesting when studying the other female divergent answers that all were in favor of the watch. According to statement 7, they found the system very easy to learn, so the need to learn new things can be interpreted as a positive experience.

SUS-score

As shown in Figure 4.8, the SUS-score results are very similar for the different groups. The scores for the watch are around 75-78 which is well above the scores for the mobile that shows 62-63. It is difficult to draw any detailed conclusions about this difference other that the watch performed better. It is mentionable that the average SUS-score for tested systems in general is 68 [42]. This very general comparison should be handled with care, but it is still notable that the mobile performed below average while the watch performed above. One conclusion that can be drawn though, is that both designs are examples of including design regarding both gender and whether the users are willing to change phone system.

Summary

The divergent answers were almost exclusively in the favor of the watch, which also is confirmed by the SUS-scores. The group more willingly to change their phone system found the mobile less favorable on several statements, even if the SUS-scores shows that the group evaluated the mobile concept similarly as the other groups. Maybe this group is be more observable or dependent of affordance and clarity in the UI. The female group rated the watch slightly more beneficial on several points but found that they needed to learn more new things before they could get going, which probably is a positive, not very demanding, experience.

Chapter 5

Conclusions

The goal with this thesis was to find out whether wearables can be used to provide clear and accurate discoverability in combination with fast and simple controllability to provide at-a-glance interaction. The results from the user study indicate that this is possible. Most of the participants found UbiCompass to fill a gap where the mobile application was too advanced and cumbersome for simple interactions. The requested discoverability was achieved implicitly by showing all the interactable devices directly on the watchface while the controllability was explicit. Most test subjects found the watch very consistent, fun and intuitive to use and experienced at-a-glance interaction with smart home devices for the first time.

The main issue that needs to be solved for turning this concept into a practically usable interaction solution, regards in-door positioning. There is no necessary need for dynamic positioning of the smart home devices, but the controlling device, i.e. the smartwatch, needs to be correctly tracked.

Chapter 6
Future Work

Possible areas of further studies or concept development are listed below.

Further user study results analysis More extensive analysis of the user study results can be performed. The Nasa TLX weightings should give more substance to the according results. Result comparisons with isolated subject data factors (e.g. the results for the participants that have used a smartwatch or a smart band before) can also lead to more or other conclusions.

Latency The UbiCompass concept on a smartwatch can be improved by lowering the system latency, especially for the wrist adjustment function. The latency is hardware related and can possibly be solved by using another Z-wave control unit or another communication protocol with the existing control unit.

Visual feedback Visual feedback for the wrist adjustment function can be implemented.

Icon control Many participants tried to take control of a device by tapping its icon instead of the ”Control”-button. A feature supporting this could be implemented.

Crowded watchface This potential issue can be targeted with a function where only favorite devices are shown on the watchface. Too select favorite devices, the mobile could be used.

Watchface device status The icons on the watchface could change regarding to its status. E.g. a turned on lamp could be yellow with light beams.

Extend on phone For more advanced operation, e.g. selection of music playlists, an extend-to-phone feature could be implemented. This way, the user till benefits of the watch’s discoverability function.

On-boarding A framework for device interaction permissions could be implemented. Some devices can be public, some private and sharable.

In-door positioning Some interesting in-door position solutions emerge, e.g. Chronos [19]. Integration of a in-door positioning system would make UbiCompass much more usable in practice. There is no actual need for dynamic tracking of all connected device. If the smartwatch supported in-door positioning, its functionality could be used to ”place” the smart home devices.

Bibliography

[1] D. Norman, *The Design of Everyday Things: Revised and Expanded Edition*. Basic Books, 2013.

[2] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Computer networks*, vol. 54, no. 15, pp. 2787–2805, 2010.

[3] S. Poslad, *Ubiquitous Computing: Smart Devices, Environments and Interactions*. Wiley, 2009.

[4] M. Weiser, "The Computer for the 21st Century," *Scientific American*, vol. 265, no. 3, pp. p. 66–75, 1991.

[5] Y. Rogers, *The changing face of human-computer interaction in the age of ubiquitous computing*. Springer, 2009.

[6] S. Mann, "Wearable computing as means for personal empowerment," in *Proc. 3rd Int. Conf. on Wearable Computing (ICWC)*, pp. 51–59, 1998.

[7] D. Ledo, S. Greenberg, N. Marquardt, and S. Boring, "Proxemic-aware controls: Designing remote controls for ubiquitous computing ecologies," in *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pp. 187–198, ACM, 2015.

[8] Y.-H. Chen, B. Zhang, C. Tuna, Y. Li, E. A. Lee, and B. Hartmann, "A context menu for the real world: Controlling physical appliances through head-worn infrared targeting," tech. rep., DTIC Document, 2013.

[9] T. S. S. of ITU, "Recommendation itu-t y.2060: Overview of the internet of things."

[10] Global Standards Initiative on Internet of Things (IoT-GSI), "Internet of Things Global Standards Initiative." http://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx, 2015. Accessed: 2016-03-11.

[11] Nexa, "Trådlöst och säkert." http://www.nexa.se.

[12] Sigma Designs, Inc., “Z-wave smart home.” http://www.z-wave.com.

[13] The ZigBee Alliance, “Control your world.” http://www.zigbee.org.

[14] SmartThings, Inc., “Smart home. intelligent living..” https://www.smartthings.com.

[15] Apple Inc., “ios 9 - homekit.” http://www.apple.com/ios/homekit.

[16] Microsoft, “Alljoyn - windows iot.” https://developer.microsoft.com/en-us/windows/iot/win10/alljoyn.

[17] Google Inc., “weave - google developers.” https://developers.google.com/weave/.

[18] Jean-Marie André, “Bespoon.” http://spoonphone.com/en.

[19] Mark Harris, “Mit turns wi-fi into indoor gps.” http://spectrum.ieee.org/tech-talk/telecom/wireless/mit-turns-wifi-into-indoor-gps.

[20] K. Tehrani and M. Andrew, “Wearable Technology and Wearable Devices: Everything You Need to Know,” *Wearable Devices Magazine, WearableDevices.com, March 2014. Web*, vol. March 2014, 2014. http://www.wearabledevices.com/what-is-a-wearable-device/.

[21] Fibaro Group, “Fibaro motion sensor.” http://www.fibaro.com/us.

[22] Y. Rogers and H. Sharp, *Beyond Human-Computer Interaction*. Wiley, 2002.

[23] Sony, “Sony smartwatch 3 swr50.” http://www.sonymobile.com/global-en/products/smartwear/smartwatch-3-swr50.

[24] SAMSUNG ELECTRONICS CO., LTD, “Samsung galaxy s6 edge.” http://www.samsung.com/global/galaxy/galaxys6/galaxy-s6-edge.

[25] Sonos, “Play:1 wireless speaker- compact & powerful.” http://www.sonos.com/en-gb/shop/play1.

[26] Zipato, “Zipato rgbw bulb.” https://www.zipato.com/product/zipato-rgbw-bulb.

[27] Aeotec, “Z-wave led bulb with rgbw.” http://aeotec.com/z-wave-led-lightbulb.

[28] Aeotec, “Wall plug switch indoor.” http://www.popp.eu/products/actuators/wall-plug-switch/.

[29] Fibaro Group, “Wall plug switch indoor.” http://www.fibaro.com/en/the-fibaro-system/motion-sensor.

[30] Lund University, “Ease - embedded applications software engineering.” http://ease.cs.lth.se/.

[31] Lund University, “Design sciences, lund university.” http://www.design.lth.se/.

[32] Lund University, “Mapci - mpbile and pervasive computing institute lund university.” http://mapci.lu.se/.

[33] Axis Communications, "Axis communications." http://www.axis.com/.

[34] Sony, "Sony mobile." http://www.sonymobile.com/.

[35] Google Inc., "Google glass." https://www.google.com/glass/start/.

[36] Fibaro Group, "Google play - fibaro." https://play.google.com/store/apps/details?id=com.fibaro&hl=

[37] Jean-Christophe Vermandé, "Gdomotique fibaro - sonos remote v1.0.0 beta pour fibaro hc2." http://www.domotique-fibaro.fr/index.php/topic/616-fibaro-hc2-vd-sonos-remote-t%C3%A9l%C3%A9commande-pour-diffuseur-sonos/.

[38] Nasa, "Nasa tlx homepage." http://humansystems.arc.nasa.gov/groups/tlx/.

[39] S. G. Hart, "Nasa-task load index (nasa-tlx); 20 years later," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 50, pp. 904–908, oct 2006.

[40] J. Brooke, "Sus-a quick and dirty usability scale," *Usability evaluation in industry*, vol. 189, pp. 4–7, sep 1996.

[41] T. Tullis and W. Albert, *Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics (Interactive Technologies)*. Morgan Kaufmann, 2008.

[42] Jeff Sauro, "Measuring usability with the system usability scale (sus)." http://www.userfocus.co.uk/articles/measuring-usability-with-the-SUS.html.

Appendices

Appendix A
User Study - Informed Consent

Informed consent

I hereby affirm that I have been given the following information:

- I understand that all participation is voluntary and that I have the right to withdraw from the experiment at any time.
- I know that I can regret my participation and get all data destroyed as long as it has not yet been used in a presentation and or publication.
- I approve that the team can use data recorded, in presentation, publications and in other academic contexts.
- I have taken part in information about the study and have gotten satisfying answers to my questions.
- I know that all data will be anonymized and will be treated confidentially.

Name:____

Signature:_____________________________________

Date & place:__________________________________

Signature of the person who explained this document to the participant

_________________________________ _________________________________

Dennis Samuelsson Günter Alce

If you regret your consent or have any further questions,
send an email to Dennis Samuelsson via dennis.samuelsson@gmail.com

Appendix B
User Study - Subject Data

Personal details

Name (optional):____

Gender: Female ▢ Male ▢

Age:____

Phone number (optional):________________________________

E-mail (optional):______________________________________

Background information

Education/Major

____

Work

____

How familiar are you with smart home products?

▢	▢	▢	▢	▢
Not familiar at all	I know the concept	I have tried it	I have a smart home device	I have my own smart home

How do you use your telephone?

▢	▢	▢	▢	▢
Only phone calls and messages	I use a few simple apps	My phone functions makes my everyday life easier	I am highly dependent of my phone functions.	I do everything,

How familiar are you with smartwatches or smartbands?

▢	▢	▢	▢	▢
Not familiar at all	I know the concept	I have tried one and it is not for me.	I have tried one and want one	I own or used to own one

How willing are you to change your current phone to another one with a different system (e.g. Android to iPhone)?

▢	▢	▢	▢	▢
Not at all	Only if i get paid	If it doesn’t cost me anything	Maybe later	Much

Appendix C

User Study - Introduction

Introduction in english

More and more products we use on daily basis get connected to the Internet. Many newer televisions and audio equipment are connected and many new smart home devices hit the market. Alarm systems, lamps, white goods and power outlets get thereby new possibilities of interaction. These units are 'traditionally' controlled through a web page or with mobile apps but we want to examine how interaction can be done with the help of a smart watch.

- The connected units in this room are:
- A lamp that can be switched on or off (it is a little slow)
- A Sonos sound system playing music
- A dimmable lamp
- A fan connected to a smart switch
- A temperature sensor

All units are connected to a control unit that acts as a communication hub.

SmartWatch

This is a Sony SmartWatch 3 running Android 6. It has built-in sensors recognizing your wrist movements at in what direction you hold the watch. It also has a touchscreen that you use to interact with the watch. From the watch's home screen (the watch face), you can use short taps as well as swiping in different directions to use the watch's different functions. The home screen swipe functions will not be used in this test. Though you will need to swipe right to get back to the home screen from the app controlling the different units. In this app, you will need to use short taps as well as long taps i ń combination with twisting your wrist.

The UbiCompass concept relies on that you can see all units for possible interactions on the home screen. You point at the unit you want to control and tap the 'Control'-button. An app starts where you can control the desired unit and to get back to the home screen you swipe right. General information about the room can be achieved by tapping the 'i'-button in the bottom corner.

Mobile app

We use a mobile app from Fibaro where all units connected to the control unit are displayed in several ways. To get a simpler overview over the units you will control, tap 'Rooms' and select 'TestRoom'.

Scenario

This study is scenario-based and we will give you short instructions of what to do next. If you get stuck, we are glad to help you out, but you should complete the tasks with as little help as possible. Feel free to think out loud during the test.

Appendix D

User Study - Scenario

Startup states

Desk lamp: OFF
Music: ON, LOW VOLUME
Dimmable spotlight: ON, MAX
Fan: OFF

Scenario in english

1. You arrive at home and it is a little dark, you decide to turn on the desk lamp.

2. You decide to pause the music.

3. You press the home button on your phone to check some new messages and notice that it needs charging. You connect the charger.

4. You check the temperature.

5. It is quite warm, you turn on the fan.

6. It is time to relax and you dim the spotlight and put the phone away.

7. To get into the right mood you turn on the music again and increase the volume.

Appendix E

User Study - Questions

Questions

After each tested prototype:

- What is your initial thought about this concept?
- What went well?
- What did not went well?
- Your own thoughts?

After both prototypes tested

About discoverablility

(a brief introduction to the discoverability concept is given if needed)

- Can you see any specific situations where it would be preferable to use a smartwatch for discoverability?
- Can you see any specific situations where it would be preferable to use a mobile for discoverability?

About controlling

- Can you see any specific situations where it would be preferred to use a smartwatch for control?
- Can you see any specific situations where it would be prefered to use a mobile for control?

Final question

- What concept did you like and why?

Appendix F

User Study - Nasa Task Load Index (TLX)

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix G

User Study - Nasa TLX Weightings

Mark the factor that represents the more important contributor to workload for the task

Mental Demand vs Physical Demand	Temporal Demand vs Mental Demand	Performance vs Temporal Demand	Physical Demand vs Temporal Demand	Frustration vs Mental Demand
Performance vs Frustration	Mental Demand vs Effort	Frustration vs Effort	Effort vs Performance	Temporal Demand vs Frustration
ffort Vs Physical Demand	Physical Demand vs Frustration	Performance vs Mental Demand	Physical Demand vs Performance	Temporal Demand vs Effort

Appendix H

User Study - System Usability Scale (SUS)

System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Appendix I

User Study - SUS-score Calculation

SUS-score

The SUS-score for a filled out SUS-form is calculated as follows:

- *For odd items (statements #1, #3, #5, #7, #9): subtract 1 from the user response.*
  These are the positive points.

- *For even-numbered items (statements #2, #4, #6, #8, #10): subtract the user responses from 5.*
  These are the negative ones.

This way, all responses are scaled to 0-4, where 0 is the most negative and 4 is the most positive response.

- *Add up the converted responses for each user and multiply that total by 2.5.*

The result is a number between 0 and 100

Appendix J
User Study - Participants

	Gender	Age	Education/ Major	Occupation	Technical Background (based on education and occupation)	How familiar are you with smarthome products?	How do you use your telephone?	How familiar are you with smart-watches or smartbands?	How willing are you to change the OS of your phone?
Pilot 1	Male		Phd Biomedical engineering	Interaction Design Research	-	2	1	1	1
TP1	Male	25	M.Sc.	Student	Yes	2	3	3	4
TP2	Male	26	M.Sc.	Student	Yes	4	4	4	4
TP3	Male	26	M.Sc.	Student	Yes	3	5	5	4
TP4	Male	23	M.Sc.	Student	Yes	2	5	5	4
TP5	Male	24	Computer Engineering	Developer Program Engineer	Yes	4	4	5	1
TP6	Female	42	M.Arts.	Communicator	No	4	5	2	1
TP7	Male	46	Engineering	IT-engineer	Yes	3	4	5	1
TP8	Female	43	Environmental Science	University employee	No	1	2	1	3
TP9	Female	26	Bachelor Chemistry	PhD student	No	1	2	1	4
TP10	Female	25	M.Sc.	PhD student	No	2	3	2	4
TP11	Female	25	M.Sc.	Student	Yes	1	3	1	3
TP12	Female	25	Technical design	Student	Yes	1	3	5	2
TP13	Male	32	Business Adminsistration	Business Controller	No	2	3	5	2
TP14	Male	40	M.Sc.	Software company	Yes	5	5	2	4
TP15	Female	39	PhD. medicine	Communicator	No	2	3	2	5
TP16	Female	24	Economy	County employee	No	2	2	2	3
TP17	Female	24	M.Sc.	Student	Yes	2	4	2	3
TP18	Female	31	Theology	Student	No	1	2	1	4
TP19	Male	43	PhD psychology student	Student	No	1	3	2	5
TP20	Male	47	Technical	Workshop LTH	Yes	4	5	2	4
TP21	Male	51	Fil Lic Statistics	Data analysist	No	3	5	5	2
TP 22	Female	26	M.Sc.	Student	Yes	2	5	2	1
TP 23	Female	27	M.Sc.	Student	Yes	2	5	2	2
TP 24	Female	22	Pedagogy	Student	No	1	2	1	4
TP 25	Male	21	High school	Employer	No	1	4	2	1
TP 26	Female	38	PhD technology	Researcher	Yes	2	3	2	4
TP 27	Male	18	Electrics	Student	Yes	2	4	2	4
TP 28	Male	24	Economy	Restaurant	No	3	4	2	4
TP 29	Female	19	High school	Undertaker/Restaurant	No	2	4	1	3
TP 30	Female	25	Theology	Student	No	1	3	2	1
TP 31	Male	25	Pedagogy	Student	No	2	5	5	5
TP 32	Male	34	M.Sc.	Softare Engineer	Yes	2	5	4	5