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Exploration of Smartphone-based Ad-hoc Interaction Methods with Smart Devices

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Abstract

Observing our current environment reveals the insight that the number of smart devices increases rapidly. This reality can be summarized under the terms "Ubiquitous Computing", "Internet of Things" and "Pervasive Computing". In such an environment it is crucial to offer the users a pleasant and usable interaction possibility paired with a powerful user interface. However, the sad reality is that many of these devices lack a proper interface concerning the usability. The present thesis introduces two smartphone-based ad-hoc interaction methods utilizing NFC and QR code technology in order to couple a smartphone and smart device spontaneously and present a powerful UI. The suggested concepts are theoretically and practically evaluated in a performed usability study and compared to the direct interaction offered by a smart device's minimal user interface. The gained results show that a NFC-based approach performs better in nearly every aspect compared to the other two approaches.

Kurzfassung

Durch die Betrachtung unserer Umwelt stellt man fest, dass die Anzahl an intelligenten Geräten rasant zunimmt. Diese Einsicht kann unter den Begriffen „Ubiquitous Computing“, „Internet der Dinge“ und „Pervasive Computing“ zusammengefasst werden. In solch einer Umgebung ist es essentiell dem Anwender angenehme und verwendbare Interaktionsmöglichkeiten anzubieten, die am besten auch eine mächtige Benutzeroberfläche zur Verfügung stellen. Die enttäuschende Wahrheit ist jedoch, dass viele dieser Geräte unzureichende Bedienungsschnittstellen haben, besonders in Bezug auf die Benutzerfreundlichkeit. Die vorliegende Abschlussarbeit stellt deswegen zwei auf Smartphones basierende ad hoc Interaktionsmethoden vor, die es ermöglichen ein Smartphone und ein intelligentes Gerät spontan miteinander zu verbinden. Eine der Methoden arbeitet mit NFC und die andere basiert auf QR-Codes. Diese spontane Verbindung wird angestrebt, um dem Anwender auf dem Smartphone eine mächtige Benutzeroberfläche zur Verfügung stellen zu können. Die vorgestellten Konzepte werden theoretisch und praktisch in einem Usability Test evaluiert. Zusätzlich werden sie mit einer direkten Interaktion verglichen, welche durch die minimale Benutzeroberfläche eines intelligenten Geräts ermöglicht wird. Die gewonnenen Ergebnisse zeigen, dass das NFC basierte Konzept in fast jedem Aspekt besser abschneidet als die beiden anderen Methoden.

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1 Introduction

As technology evolves modern smart devices of all kind are getting more powerful and efficient in terms of computing power and energy-efficiency. Simultaneously their overall appearance and integration into our everyday life are perfected, thus leading to the term ubiquitous computing. Being closely related and lately getting a lot of attention, the new notion of “Internet of Things” came up. As a result, the number of devices integrating powerful functionalities with low-power communication modules are continuously introduced and released throughout the years [Nor]. For a long time many companies and authorities agreed on a number of 50 billion smart devices by the year 2020 [Eri]. This number was adapted by now from 20 to 30 billion devices by 2020 as you can see in Figure 1.1 [Eri15]. As getting omnipresent these

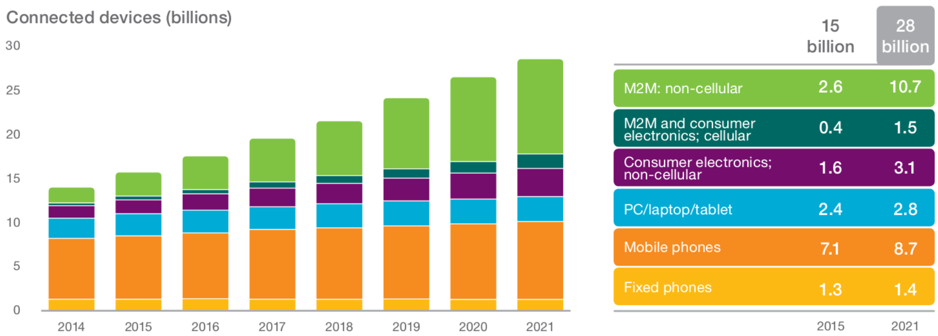


Figure 1.1: Estimation of connected devices done by Ericsson in their mobility report as of November 2015 [Eri15].

smart devices are interwoven into our everyday life and our personal and public environments so that users are getting compulsorily into contact with them on their daily basis. Due to reduced costs for hardware and production, these smart devices are getting more powerful thus offering more complex configuration and interaction possibilities. Summing up, one can say that these devices get more sophisticated but many of them lack a proper user interface to enable a pleasant human-machine interaction experience. As an example one could take the simple task of adjusting different appliances, e.g. microwave oven, oven and alarm clock at home from standard to daylight time or the other way around. Many people, especially the elderly, struggle in completing this simple task due to very minimal user interfaces and complex and inconsistent menus and designs. This is only one example for a very simple task. There are considerably more tasks and devices that are significantly more complicated and cumbersome to handle. Imagine modern solar systems that can be found in many private households. The configuration possibilities are endless especially if you include modules for using the solar thermal energy to warm the water for your home. Many owners of such devices are not using a great number of the offered adjustment possibilities due to very basic and complex user interfaces. Instead, users are looking for intuitive, ad-hoc, easy and pleasant interaction modalities.

The answer to the question why there are so many smart devices with minimal user interfaces that offer a poor usability, includes two main crucial factors which companies have to pursue. Reducing costs for used hardware components, development and implementation is the main focus. The majority of customers will avoid a solution which is too expensive compared to other products that fulfill the same or similar functionalities and offer the same quality standards. This aspect leads us to the second crucial factor, namely quality and reliability. Customers want to purchase products that last for a long time and include components that do not break down too fast. Manufacturers have to release something containing hardware that is reliable and offering all needed functionalities and at the same time they have to keep the final price as low as possible. As a result one receives a smart device that fulfills the need for quality but mostly not usability.

Arising from this reality and the steadily growing number of IoT devices finding their way into the real world, there is a need for better user interfaces and ad-hoc interaction concepts that empower the user to interact with these devices in a fast, intuitive and secure way. Interfaces that allow a pleasant human-machine interaction experience without the expectation of a broad knowledge in modern technology and concepts. One solution to avoid the mentioned problem is to utilize ubiquitous devices like smartphones or tablets. The advantages of this approach are that devices like smartphones are mostly on hand as investigated by Dey et al. [DWF+11]. Furthermore, they offer a dedicated, strong and multipurpose hardware, with a high resolution screen providing good contrast and many displayable colors as well as touch functionality. Moreover, these devices are mobile and compact and they contain a lot of different sensors and actuators. Most of our current smartphones include a camera and flashlight, a speaker and microphone, a WiFi, NFC/RFID and Bluetooth module and mobile internet access. Many users are familiar with smartphones and their design, layout and feedback given. That said one can outsource the whole or just some parts of the actual user interface from smart devices to smartphones. Thus, user interfaces can be kept consistent compared to already known designs and all sensors and actuators can be employed to give the user a meaningful feedback. Moreover, users can utilize ad-hoc interaction concepts to couple their smartphones to smart devices and transmit data wirelessly to stay mobile and do configurations in their own pace. Beside that, mobile devices like smartphones and tablets offer a broad platform of frameworks, high-level programming languages and concepts, resulting in a faster and maybe cheaper development and implementation process. All of these factors have a high potential in increasing the overall experience of interacting with smart devices offering minimal user interfaces.

The present master thesis is aiming at finding ways and concepts to simplify and improve the overall usability and user experience of networked and standalone smart devices with basic or minimal user interfaces. This is done by theoretically and practically exploring and evaluating possibilities to couple a smart device with a smartphone in an ad-hoc manner, transmit data by utilizing different connection and communication technologies and perform some simple and more complex configuration tasks on the user interfaces offered by the developed smartphone prototype. Exploration and evaluation are done in respect to effectiveness, intuitiveness, security, costs and ease of use. A prototype was developed consisting of an application deployed on a smartphone running Android and a Raspberry Pi, a single-board computer, acting as an actual standalone smart device with a minimal user interface. The mentioned prototype is evaluated in a study where technical experts and participants with no prior knowledge have to perform some configuration tasks on the Raspberry Pi, that is simulating a heating system as it is used for private homes. It offers many different parameters that can be modified, e.g. the temperature, a comfort- or eco-mode etc., on the smartphone-based user interface.

1.1 Structure of this Thesis

This thesis is structured as follows:

Chapter 2 – Related Work and Background: This chapter will give an overview of the already existant work in this area of research. Additionally some background information will be given concerning individual technologies and concepts that are relevant for this thesis.

Chapter 3 – Concept: Following the overview given in the second chapter our concepts of smartphone-based ad-hoc interaction methods will be presented and evaluated theoretically in the third chapter.

Chapter 4 – Implementation: In this chapter the implementation of our developed prototype consisting of an Android application and a hardware prototype based on a Raspberry Pi will be presented.

Chapter 5 – Evaluation: In the scope of this thesis a study was performed utilizing our developed prototype in order to compare the usability of two of our ad-hoc interaction methods with a direct interaction performed on a heating system's minimal user interface. The evaluation will be presented in this chapter.

Chapter 6 – Discussion: Chapter six will discuss insights gained during our performed usability study in order to give the results some meaning in context of our assumptions.

Chapter 7 – Conclusions: At the end a short conclusion of this thesis will be offered and the possibilities for some future work will be named.

2 Related Work and Background

The most important objective addressed in this thesis is to investigate on possibilities for ad-hoc interaction concepts between standalone or networked smart devices offering minimal user interfaces and current smartphones. For this task many different technologies, concepts and related studies have been already presented and have to be taken into account. The following chapter will give an overview of the most important basics for ad-hoc device coupling concepts, smartphones as outsourced smart device's user interfaces and related studies that have been conducted in this area of research.

2.1 Ubiquitous computing

Ubiquitous computing is a vision first introduced and shaped by Mark Weiser in 1987 [Wei]. He sees it as the next big development in computing after the epochs "Mainframe" and "Personal computer" as our technology evolved and our electronic devices got cheaper, smaller, more efficient and interwoven into our environment. The first era offered one computing device for n people. Next, every person was able to afford a personal computer for their personal use. Now we have come to an era that enables us to wander through an environment saturated with many different and mostly hidden smart devices. Figure 2.1 visualizes the described vision. Examples are information processing devices like smartphones, tablets and ebook readers, as

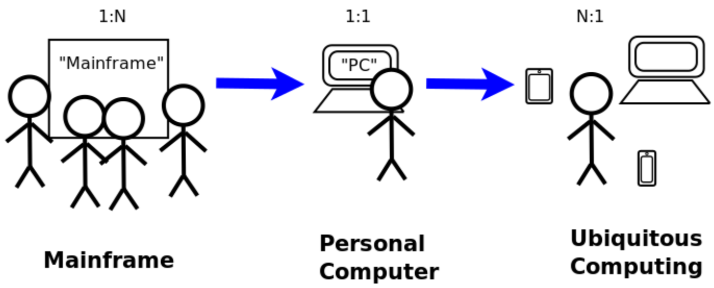


Figure 2.1: Visualization of the three different epochs of computing as described by Mark Weiser in 1987 [Wei]. "Mainframe" - One computing device utilized by many users; "Personal Computing" - Every user has its own computing device; "Ubiquitous Computing" - Every user is surrounded by many computing devices

well as computational enhanced devices like TVs, refrigerators and washing machines, as well as computational devices integrated into traditional objects like furniture or clothing. That means that smart devices should enhance the capabilities of humans and support them in everyday tasks without them even noticing as described by Posland Stefan [Pos09]. Next to ubiquitous computing there are several similar terms that are often mentioned simultaneously. *Pervasive Computing* stands for a concept that is often used synonymously to ubiquitous computing. The idea of ubiquitous computing is extended to the point, that these smart devices are interconnected and collect data for specific uses. *Internet of Things* is a term that is strongly connected to ubiquitous computing as well. It states that all smart devices should be electronically connected to each other.

As more smart and connected devices will appear in our everyday life, humans will come in contact with them by default. People are already interacting with these devices on a daily basis and in the near future, encounters will increase dramatically. Ubiquitous computing states that interactions with these devices should be seamless, easy and as intuitive as possible. Unfortunately many of these smart devices offer cumbersome interactions due to poor designs and user interfaces. Owed to their size and application they often only offer simple input and output modalities like buttons and LEDs. Consequently users have to first understand the interface before using the advantages of the particular device. If you expand this circumstance to the point that users have to interact with many different devices on a frequent basis, the core idea of ubiquitous computing is getting lost. Therefore it is essential to find standards and ways to create understandable and pleasant user interfaces for smart devices. Preferably interactions should be performed in an ad-hoc manner without the need of recalling passkeys and using old concepts as menus and lists to explicitly select a device to couple with.

2.2 Ad-hoc device coupling and data transmission

This thesis is addressing ad-hoc interaction concepts for smart devices that empower an user to couple their smartphone to them in a spontaneous manner and perform some actions or configurations. The whole configuration process is structured into the following three main tasks:

- Couple a smart device with a smartphone in an ad-hoc manner
- Transmit data between both devices
- Perform a configuration of smart devices utilizing a smartphone-based user interface

The process of ad-hoc coupling was already addressed in many studies. An overview summarizing different approaches and concepts was presented survey created by Chong et al. [CMG14]. Device pairing, binding and association are different synonyms for the term ad-hoc coupling that are frequently used in other publications. The process of device coupling involves two or more devices that connect in an one-way or bidirectional way over a common medium. This medium can be anything that enables a communication between at least two devices. A concept very well known to many people is a physical connection formed with a cable. This approach is very secure and reliable and it is very intuitive due to the actual physical connection created by an user. Other than that, it is quite cumbersome to have a cable handy that is also fitting the connection ports. That is one reason why wireless communication, e.g. WiFi or Bluetooth, is frequently used as a common medium to couple devices. The only requirement for a successful connection is the existence of a radio module integrated into both devices speaking the same protocol. Due to the dropping costs for radio modules and hardware in general, many smart devices already implement different sensors and actuators, only waiting to be utilized by the owner.

2.2.1 Security

The topic security for ad-hoc device associations is important and at the same time it is difficult to realize. As mentioned above, ubiquitous computing states that people will be in contact with many different smart devices located in their direct environment on a daily and frequent basis. Due to the fact that a big chunk of device coupling approaches uses wireless communication for convenience reasons, all transmissions can be listened to by strangers. As device interfaces will open up critical functionalities to connected and listening users, it is obvious that some kind of security mechanism has to be applied. The problem that arouses with the security aspect is that interactions will get more complicated and cumbersome. For most people it is not possible to recall dozens of different passkeys for all kinds of smart devices surrounding them. The interaction should be kept spontaneous, thus a prior common knowledge should not be assumed or even demanded. Moreover, in many cases people will interact with smart devices only once, thus creating a passkey or some other common secret is exaggerated.

A broad overview covering the mentioned security aspect of ad-hoc interaction concepts can be found in the Habilitation Thesis created by Mayrhofer in the year 2008 [May08]. Mostly security for ad-hoc coupling between devices can be achieved by using an “out-of-band channel” (OOB channel), also called auxiliary channel. It is the second, secure and trusted channel of a mostly wireless communication. There is always a primary (in-band) channel, that is used as the main communication channel. In order to be able to use encryption to protect the main channel from attackers the OOB channel is utilized to share a common secret. An example that uses an OOB channel to secure an ad-hoc interaction was presented by Seewoonauth et al. [SRHH09]. They introduced a concept called “Touch & Connect”. It uses a NFC tag as the OOB channel attached to a laptop and containing coupling information for the Bluetooth connection that is used as the main channel as shown in Figure 2.2.

An interaction can be human-initiated or device-initiated. In other terms, manually or autonomously created as described by Meshkova et al. [MRPM08]. The concept of integrating the human into the whole coupling process is a commonly used approach. The user can act as the verifying instance to ensure that the correct devices are establishing a connection. It is also possible to let the user authenticate himself to his personal device once and use it later on to secure an ad-hoc interaction. The most dangerous attack scenarios that can be named in combination with ad-hoc interaction concepts using wireless communication are the following.

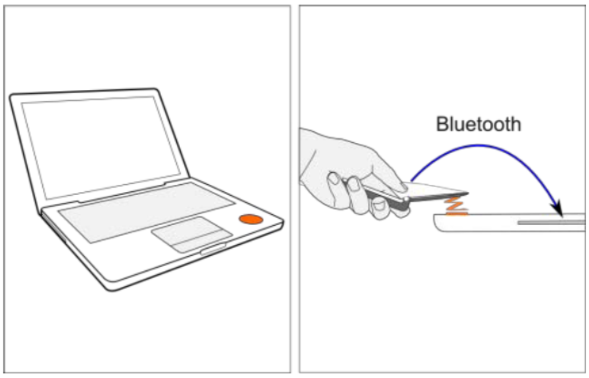


Figure 2.2: "Touch & Connect" presented by [SRHH09]. A system using a NFC tag as the OOB channel to store coupling information for the bluetooth-based main channel.

Eavesdrop The common medium used by wireless transmissions can be accessed by anybody that is in range. Thus every package exchanged between devices can be listened to. A commonly used countermeasure is to encrypt the wireless communication.

Man-In-The-Middle This scenario is a result of the possibilities enabled by eavesdrop attacks. An intruder can block, inject and modify sent packages so that the communicating parties do not notice that they are not talking to each other but rather to the attacker.

Denial-of-Service Services that are offered over an open channel can be inquired in an intensive manner so that the instance offering the specific service stops handling requests, even if they were initiated by an authorized user.

2.2.2 Taxonomies

Due to the incredible amount of different ad-hoc interaction concepts and technologies it is a difficult task to establish a general taxonomy that is applicable to all approaches. Chong et al. [CMG14] gave an extensive overview of different spontaneous device association concepts that have been explored in the research community. They created a taxonomy based on the required user actions.

User action required

Next to the taxonomies classifying different coupling approaches by the *hardware* that is required for the interaction or by the *physical communication channel* Chong et al. [CMG14] classified interactions by the required *user actions*. Therefore the whole coupling process is viewed from the user's perspective rather than from the technical. In their work they created four distinguishable user action classes, namely *guidance-based*, *input-based*, *enrollment-based* and *matching-based* that will be explained in the following part of this work.

Guidance-based The first ad-hoc coupling approach is using the environmental, real-world context of devices that should be coupled. That means that users employ actions in the real-world that are external to the involved devices, e.g. contact, alignment and proximity.

Varshavsky et al. [VSLL07] presented a system named “Amigo” that offers a secure device coupling approach relying on physical proximity. WiFi is utilized as the main communication channel and the secondary OOB channel is completely left out. Additionally no user is required for verifying the validity of the authentication process. Their idea is to use information that can be obtained from the shared radio environment based on WiFi signals, in order to authenticate the co-location of devices that are supposed to couple. Both devices share their signature of the radio environment and compare them. If both signatures are similar enough both devices couple to each other.

“Network-in-a-box” is a concept presented by Balfanz et al. [BDG+04] in 2004 and can be viewed in figure 2.3. Their solution for secure ad-hoc device coupling is making use of proximity and gestures. In their experiment an access point, typically a router, and laptop are placed

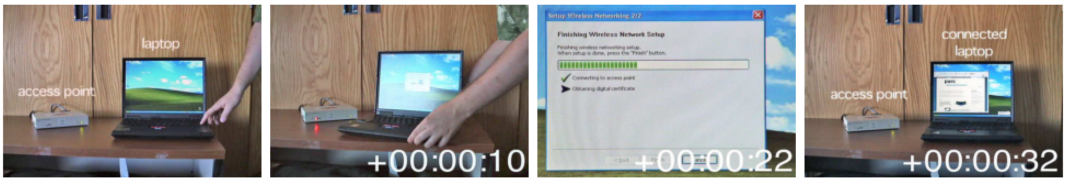


Figure 2.3: Ad-hoc coupling process as described by Balfanz et al. in their concept “Network-in-a-Box”[BDG+04]. Two devices are placed next to each other so that their infrared emitters and sensors are aligned in a close proximity.

next to each other so that their infrared sensors and emitters are in close proximity and have a direct line of sight. In order to start the coupling process, the laptop’s enter button has to be pressed. After the initialization both devices share some information via the infrared-based communication channel. Their presented approach is very similar to the standard called “WiFi Protected Setup” used by many routers and modems to enable a fast connection possibility via WiFi. Placing both devices next to each other symbolizes a gesture of coupling two devices by aligning them and bringing them physically together. It is comparable to a pointing gesture with a laser pointer.

Input-based The next element of the taxonomy created accordingly to required user actions, are input-based ad-hoc device coupling interaction concepts. In contrast to guidance-based techniques they do not rely on the environmental context of the devices that are supposed to connect to each other. Instead, the devices simply offer a physical input possibility like keys, buttons or touchscreens to the user.

An example for an input-based device coupling approach was presented by Chong et al. [CMG10]. Their system is called “GesturePIN” and it utilizes gestures as an actual passphrase. Characters are directly replaced by gestures captured by accelerometers integrated into the smart devices. An user that wants to couple his device to another has to initially define a passphrase by performing several gestures. This can be done by moving the device up, down, right, left, etc. The other device has to mimic the defined gesture sequence in order to authenticate and establish a secure connection. This approach aims at coupling devices that do not offer buttons or other elements of a basic user interface. Instead an integrated accelerometer is sufficient. Their team conducted a quantitative study that showed that entering an actual PIN is superior in terms of accuracy and speed, although the differences and drawbacks were still acceptable. The big advantage of this solution is the fact that gestures can be sensed by any sensor. Thus enabling device coupling between devices that offer a very minimal user interface.

Another input-based solution is called “Synctap” and was presented by Rekimoto [RJ04] in 2004. Figure 2.4 illustrates the overall coupling process of two laptops. A button is pressed

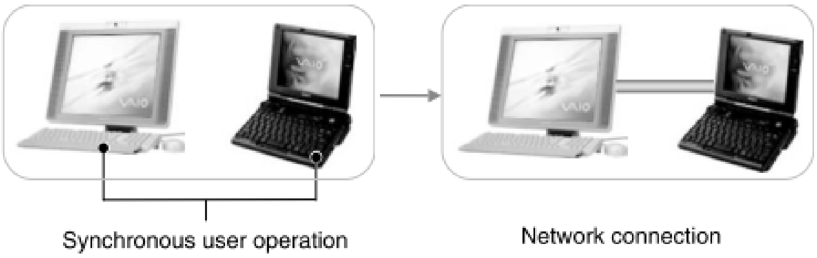


Figure 2.4: Overview of the device coupling approach introduced by Rekimoto et al. [RJ04]. Two devices are connected by comparing button-pressed and -released events on both devices.

and released in a synchronous manner on both devices and the time for the different actions is captured. Both devices share these measurements and compare them to each other. If they are similar enough the coupling is successful.

Enrollment-based Other ad-hoc device coupling approaches can be categorized as “enrollment-based”. For this approach a prior knowledge in form of an unique secret has to be prestored on the different devices. Any secret can be used that is storable by a machine and also reproducible by a user, e.g. fingerprints and rhythms.

One solution was presented by Buhan et al. [BBD+09] that uses prestored face and handgrip patterns of users. In general, humans offer a broad variety of biometric patterns, e.g. iris, gait, voice and speech, that can be used for enrollment-based approaches. Additionally a combination of different biometric patterns can be utilized. For a successful connection the stored and entered pattern have to be equal. This approach is not truly an ad-hoc interaction due to the prestored secret that has to be created before the actual connection can be established.

Matching-based Another element of the presented taxonomy is based on matching. In this case humans have to verify outputs done by the devices that want to connect to each other. In order to successfully couple two devices both outputs given by them have to match. Therefore, the user is acting as the verifying instance.

"HAPADEP" (human assisted pure audio device pairing) is a system created by Soriente et al. [STU08]. As the name already states this system involves the human to authenticate a connection by only using sound. The notion is that the audio channel is used as an OOB channel and simultaneously as the actual primary data transmission channel. Initially both devices that are supposed to couple exchange some system related information by sending audio signals similar to the early dial-up modem sounds. The second step performed by both devices is to play a specific tune that is encoded to sound like a rhythm. The user has then to compare and verify both tunes and authenticate the coupling process in a successful case.

Likewise, Goodrich et al. [GSS+06] utilized the audio channel for their approach called "Loud-and-clear". The verification data is encrypted into syntactically correct sentences in English and the user's task is to compare both created sentences and authenticate the coupling process.

A more complicated matching-based approach presented by Mayrhofer et al. [MGH07] is to employ sound to determine spatial information of other devices. In order to determine the spatial information, the time of flight (TOF) values of the sound signals are utilized. The user then gets a visualization of the captured spatial relationships between devices displayed on a map and it is his task to select the correct device he intends to couple to.

As shown in the previous paragraphs there is an enormous amount of different ad-hoc device coupling approaches that have been presented in the research community. Many of these concepts are used simultaneously and mixed together to accomplish secure and spontaneous device interaction paradigms. Chong et al. [CG11] conducted a broad study in the year 2011 in order to evaluate which of these concepts are the most preferred by users. They created low-fidelity plastic devices as shown in figure 2.5 in oder to not influence their participants by using existent devices and their user interfaces. Users received different combinations of

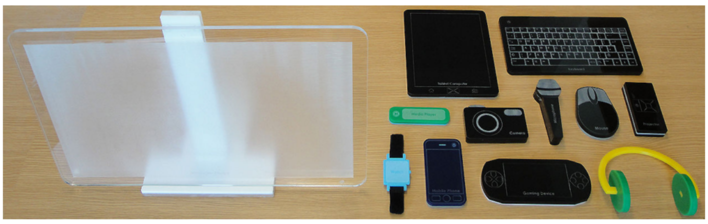


Figure 2.5: Low-fidelity plastic devices created by Chong et al. [CG11] to evaluate how users prefer to spontaneously couple different devices in an ad-hoc manner.

plastic devices so that they could perform an ad-hoc coupling process by their own notion. It was possible to collect more than 700 user-defined actions for 37 different device combinations. An example for devices that had to be associated by participants is a mobile phone coupled with a handheld projector and wireless headphones. The results of their study shown in figure 2.6 point out that users preferred "search & select" actions before any other concept. The top five techniques "search & select", "proximity", "button event", "device touch" and "gestures" made up more than 80% of all captured user actions. Another interesting outcome was the fact that users tend to re-adopt already known concepts they made use of recently.

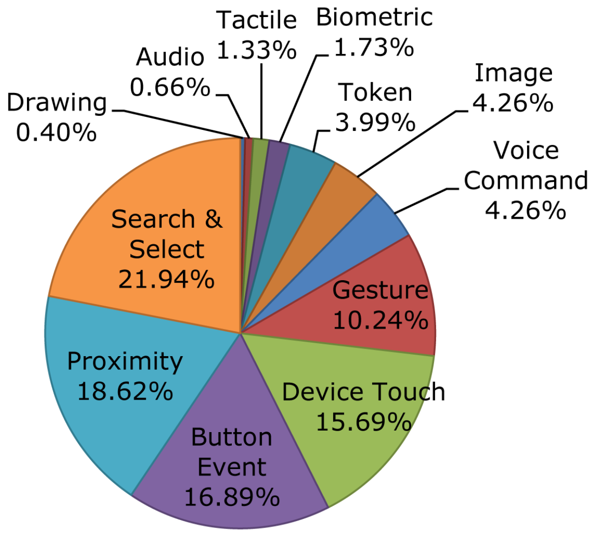


Figure 2.6: Results of a study conducted by Chong et al. [CG11]. Users were given low-fidelity plastic devices so that they could perform ad-hoc coupling actions by their own notion.

Used physical communication channel

Creating a taxonomy structured by performed user actions is one possibility. Two alternative classifications can be achieved by observing what hardware is needed for the coupling process or by the used physical communication channel the connection is based on. Both are very similar due to the fact that an used physical communication channel enforces some necessary hardware being integrated into both devices. Our work sets its focus on only two different physical communication technologies and their implications onto the user actions required for a successful coupling process. Therefore the whole process involving ad-hoc coupling and data transmission is based on only one communication technology in order to avoid the necessity for additional hardware modules. Physical communication channels can be classified into the groups *optical*, *acoustic*, *electromagnetic* and *tangible*.

Optical Most existing optical ad-hoc device coupling approaches use a camera in combination with a LED. Both, sensor and emitter, can work with light that is sensible for humans and also with imperceptible wavelengths of light. The light itself is a medium that is vulnerable to eavesdropping and man-in-the-middle attacks. Although it is a wireless medium, it still offers a basic security mechanism due to the fact that connections established by light require a free line of sight (LoS) between sender and receiver. It is a directed signal transmission, thus the interaction implicitly uses a very well known gesture to humans, namely pointing. In general, connections based on light can reach very high bandwidths and transmission rates. They offer many different light spectrum frequencies that can be utilized and the medium itself is actively used by only one device. Except of some noise created by our natural light sources the channel can be used solely. Therefore security is implicitly given but can be bypassed if an attacker can sense the active beam of light without the sender and receiver noticing it.

LED As mentioned above many approaches are utilizing LEDs in combination with a camera to enable a device coupling. A bidirectional ad-hoc device coupling system called “Flashlight” was presented by Hesselmann et al. [HHB10]. Their setup is supposed to establish a connection between a vision-based interactive tabletop and smartphone. The process of coupling happens by placing the phone on top of the tabletop. Hereby the phone’s camera serves as the “data-in” channel and the flashlight acts as the “data-out” channel. Both elements have to face the screen of the tabletop so that it can push data via its screen or read data via its integrated camera.

As a side note Saxena and Uddin [SU09] did some research on “rushing” users that just “skip” the coupling verification step they are supposed to do properly and carefully. Therefore they used an optical OOB communication channel to avoid the “rushing user behavior”.

Barcodes For this approach a camera is crucial to sense input and a screen is needed to produce output. Figure 2.7 displays the two widely known barcode types, namely *linear barcodes* as often seen from shopping as well as *matrix barcodes* as known from QR codes.

Figure 2.7: This is an example for a linear and matrix barcode.

McCune et al. [MPR05] developed “Seeing-is-believing”, a system that uses a camera, screen and barcodes to establish a secure ad-hoc connection between two phones. The created and displayed barcode contains some authentication information for the main Bluetooth-based communication channel. Figure 2.8 shows two mobile phones sharing a barcode.

Laser Laser-based ad-hoc coupling concepts use a directed signal to transmit data and therefore a line of sight is necessary. Furthermore, a laser beam emitting module and a light sensor are required as additional hardware.

A solution utilizing an OOB channel working with a laser in order to successfully establish a secure connection was presented by Mayrhofer and Welch [MW07]. Their general approach is to point a laser beam at a receiver and transmit all necessary data for a coupling attempt. They consciously chose visible laser light to counteract against possible man-in-the-middle attacks. A very similar system was presented by Kindberg and Zhang in 2003 [KZ03].

Figure 2.8: "Seeing-is-Believing", a system using barcodes to establish a secure ad-hoc Bluetooth connection between two mobile phones as presented by McCune et al. [MPR05].

Acoustic Another possibility to enable a communication between two devices is by using acoustic signals. These signals can be audible or inaudible for humans, as sound can rely on a broad band of different frequencies. Mostly, there is also no need for additional hardware due to the fact that acoustic signals are already often utilized for user interfaces. One system using sound for ad-hoc device coupling is "Loud and clear" presented by Goodrich et al. [GSS^{+}06]. The acoustic channel serves as an OOB channel to present the user syntactically correct sentences for matching purposes. A very similar system named "HAPADEP", introduced by Soriente et al. [STU08], was already mentioned above.

Kukka and Marjakangas [KM14] based their ad-hoc coupling concept for smart devices on inaudible and directed acoustic signals. In their approach static devices in smart environments are emitting inaudible signals for other smart devices to discover as displayed in figure 2.9. The receiving device proactively proposes a coupling opportunity for the user to verify and

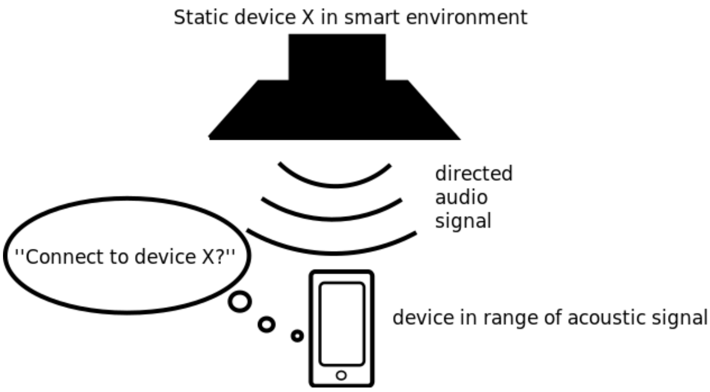


Figure 2.9: Concept of "SONDI" presented by Kukka et al. in 2014 [KM14]. Static devices in smart environments emit inaudible acoustic signals for other devices to sense and propose coupling.

decide. Another already introduced system presented by Mayrhofer et al. [MGH07] creates spatial references of smart devices in close proximity.

Radio waves Next to optical and acoustic approaches imperceptible radio waves like WiFi or Bluetooth can be used to enable ad-hoc interactions.

NFC/RFID NFC (near field communication) and RFID (radio-frequency identification) are both working with electromagnetic fields whereas NFC is based on the RFID technology. Mainly two different approaches are used for this communication technology. Firstly there are tags that store static information that can be read and secondly a peer-to-peer communication between two devices is possible. The range for a successful transmission is very limited and has to be less than 10 cm in the case of NFC thus offering an implicit security aspect. The bandwidth of these technologies are rather limited and can reach up to 424 kbit/s in the case of NFC.

One approach for ad-hoc device coupling utilizing NFC tags as an OOB channel was introduced by Seewoonauth et al. [SRHH09]. A NFC tag is placed on a laptop and contains coupling information for the main Bluetooth-based communication channel.

Another system called "GroupTAP" utilizing NFC and the concept of co-location was presented by Chong et al. [CKG11]. It extends ad-hoc coupling interactions so that more than just two devices can be connected with each other. People that are in close proximity and desire to connect their devices have to touch a reference point, e.g. a table, in order to transmit some information via NFC and eventually couple.

WiFi WiFi (wireless fidelity) is the standard 802.11x defined by IEEE [IEE] that uses electromagnetic waves, mostly the two frequencies 2.4 GHz and 5 GHz, in order to enable a communication between two devices. WiFi is capable of working within a very high range of up to 100 m and it can provide very high data rates of up to 250 Mbps in the case of the "WiFi Direct" standard. Signals can pass through solid objects, e.g. walls, and they are also reflected by obstacles. Combined with the fact that signals can be sensed in a wide range this poses a potential security risk. WiFi is widely used in the real-world for connecting devices and enabling a communication between them. Examples are laptops, TVs, smartphones, routers, etc.

A concept presented by Sheth et al. [SSW09] utilizing WiFi for ad-hoc device coupling purposes, addresses the security issue of WiFi technology by using a geo-fencing approach. Their idea is to work with several directed WiFi antennas in order to create overlapping signal areas in which WiFi frames are split between the different senders as shown in figure 2.10. These WiFi frame segments are then sent by different emitters so that a successful communication is only possible in the area where all signal sources are overlapping. This approach can be used for, e.g. coffee shops, who want to offer their WiFi to only people inside of their facility.

There are already existent standards included into the WiFi and Bluetooth technologies that can be used to establish an easy ad-hoc connection between devices. In the case of WiFi, the standard is called *WPS ("WiFi Protected Setup")* and in the case of Bluetooth *"Bluetooth Simple Pairing"*. Both were analyzed in the work of Kuo et al. [KWP07].

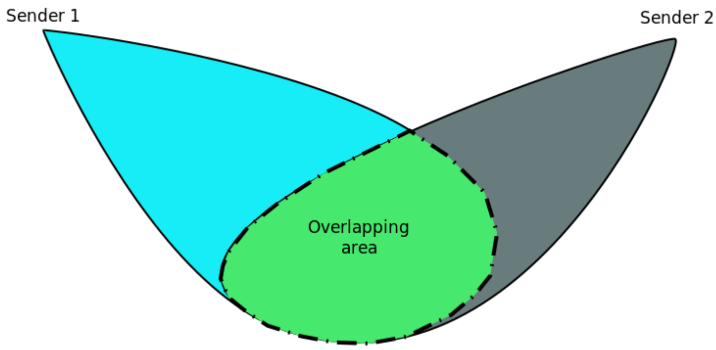


Figure 2.10: Geo-fencing approach introduced by Sheth et al. [SSW09]. A successful WiFi connection can only be established in the overlapping area of sender 1 and sender 2 due to the fact that WiFi frames are split between all involved senders.

WiFi Protected Setup There are three different approaches defined in the "WiFi Protected Setup" standard that enable a secure coupling of devices.

1. *PBC ("Push Button Configuration")*: A button on both devices has to be pushed in order to couple two devices. For this concept no attacker in close proximity is assumed.
2. *PIN*: For a successful connection a passkey has to be entered.
3. *Additional OOB channel*: An extra OOB channel is used to share secrets. As an example a NFC tag can be used that stores the WiFi network's SSID and passkey.

Bluetooth Simple Pairing The following four different secure coupling approaches can be named for the Bluetooth technology.

1. *Numeric Comparison* Two devices that want to couple display a 6 digit number that the user has to compare on both and accept the connection or dismiss it.
2. *"Just works"* This approach offers no security at all thus is mostly used for devices like a wireless headset.
3. *Additional OOB channel* This case is identical to the one explained for WPS.
4. *Passkey entry* For this concept one device has to implement a keypad and the other one a screen. In order to couple two devices the one with a screen has to show a 6 digit number and the user has to enter it into the second device.

In a study conducted by Jewell et al. [JCKD15] in 2015 an evaluation of different WiFi ad-hoc coupling approaches between smart devices with minimal user interfaces was done. In their analysis three different WiFi coupling approaches were performed. The first one makes use of a cable that connects two devices in order to exchange the WiFi's SSID and passkey. The second one utilizes flashing. For this case the smartphone has to be placed with its screen on top of the other device in order to transmit all necessary data by flashing its screen. In the third one, the smart device with a minimal user interface acts as a WiFi access point. The smartphone has to connect to the AP in order to get the web-based login interface presented. There the user has to enter the WiFi's SSID and passkey. This concept is well known from, e.g. airports, and is called "captive portal".

Bluetooth Bluetooth is another technology that shows many similarities to WiFi and enables ad-hoc device interactions. The range for a Bluetooth communication is limited from 5 to 30 m and the bandwidth is also limited to up to 25 MBits/s in case of the Bluetooth 4.0 standard. One reason for the shorter range and smaller bandwidth is the very low power consumption of Bluetooth radio modules. That is especially true for the "Bluetooth Low Energy" standard included into the Bluetooth 4.0 specification. Smart devices with the focus set to low power consumption can work for several years with only one battery offering around 1000 mAh. Thus, this technology is implemented into many devices, e.g. smartphones, activity trackers, wireless mouses, keyboards and headsets. Similar to WiFi, Bluetooth is frequently used as a primary communication channel combined with additional security realized by an OOB channel based on, e.g. NFC. Furthermore, the standards are maintained and introduced by the "Special Interest Group", shortened "SIG" [SIG13]. An example is the whitepaper for the "Bluetooth Simple Pairing" standard that was defined by Bourk et al. [BFH+06].

Infrared Infrared shows many similarities compared to the optical laser approach used for ad-hoc interaction concepts, since active communications between a sender and receiver are relying on a direct line of sight. In contrast to the laser technology, the optimal range for infrared connections is limited to up to 1 m. Nevertheless transmission rates of up to 10 GBit/s were already reached with the Li-Fi technology [LiF] based on infrared and near-ultraviolet spectra. Standards are defined and maintained by the "Infrared Data Association (IrDA) [IrD]. Next to ad-hoc interactions, another field of application are "personal infrared networks" (PANs). Devices that implement infrared modules are older smartphones, tablets and many different remote controls. This technology offers an implicit security aspect due to the necessary line of sight that is required for a communication. In addition infrared has a very low energy consumption thus enabling long operating times of devices.

A system presented by Balfanz et al. [BDG+04] utilizes infrared technology in oder to couple devices that are placed in such a manner so that both, emitter and sensor, are next to each other.

Another approach combining gestures, WiFi and infrared in order to enable ad-hoc device coupling was evaluated by Swindells et al. [Swi02] in 2002. Their system uses an infrared-based device called "GesturePen" that is utilized for pointing at devices the user wishes to couple with. The device notices that it was selected by the pen and sends information about itself back to "GesturePen". Then, the pen forwards this information to the smartphone and the actual primary communication channel is realized via WiFi. Therefore the pen is only used to select the device for coupling. The whole coupling process is visualized in figure 2.11. Due to the fact that users are very familiar with the pointing gesture, since they are utilizing it frequently in their everyday life, pointing-for-coupling is a very natural and intuitive way to enable coupling.

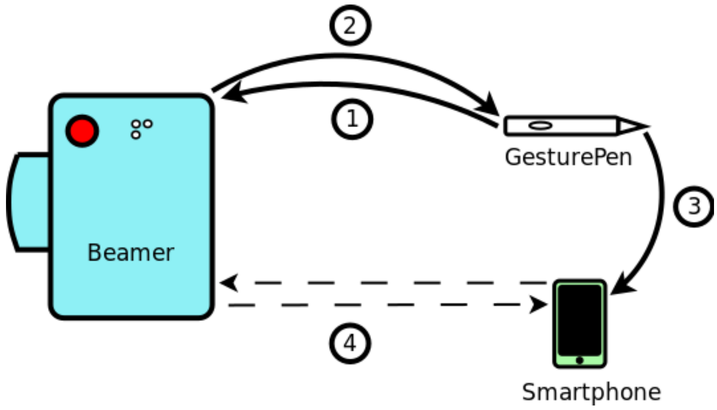


Figure 2.11: An example for the concept of "GesturePen" introduced by Swindells et al. [Swi02].

Tangible Several approaches have been investigated that employ the concept of tangible ad-hoc interactions. For an attempt to couple devices the user has to physically touch them or their parts. Buttons, accelerometers, touchscreens, cables and intrabody communication can be utilized for this purpose.

Mayrhofer et al. [MG07] introduced a new method for ad-hoc device coupling that utilizes accelerometers. In order to connect two devices they have to be placed together and the user has to shake them. For authentication and coupling the shaking patterns on both devices are compared and verified.

A very simple protocol only requiring one button per device to enable coupling was presented by Soriente et al. [STU07]. The system called "BEDA" (Button-enabled Device Association) requires the user to synchronously push a button in order to enter data that is needed for the coupling process. One button push equals a binary bit.

Another technique called "GesturePIN" that uses tactical operations was already referenced above [CMG10]. The idea is that each gesture represents a character of the passphrase.

Another button-based system called "Synctap" [RJ04] requires synchronous button press and release events on both devices in oder to enable coupling.

Next to utilizing buttons the possibility exists to use a cable in order to physically connect two devices. As already mentioned it is a simple and understandable concept but requires the user to carry the fitting cable with him.

Another very similar approach that utilizes the human body as a communication channel is called intrabody communication. "TAP" (Touch-And-Play) is one example presented by Park et al. [PPK+06] that requires the user to simply tap onto a device in order to perform a context-aware interaction. An user can, for example, hold a smartphone and tap onto a TV to start a slideshow.

As seen in the above section there is an enormous amount of different concepts for ad-hoc interactions based on a variety of physical communication channels. They can be used as solitary solutions or multiple technologies combined to one concept. An example is a fusion of NFC joined with WiFi or Bluetooth and accelerometers combined with buttons.

2.3 Smartphone-based user interfaces

Due to the fact that we are employing a smartphone-based approach for ad-hoc device interaction concepts, it is worth to look at user interfaces for smart devices created on smartphones. Since several years smartphones are experiencing a very high demand [Cha]. The total number of actively used mobile devices is still growing and it will continue to grow in the near future. Currently, there are more than one billion smartphone users [Cha]. Additionally, these mobile devices are mostly in close proximity to their operators as investigated by studies. One of them was a data collection field study conducted by Dey et al. [DWF+11] monitoring 28 smartphone users over the period of four weeks. The results show that users keep their devices within arm's reach for nearly 50% of the time throughout the whole day. However, for almost 90% of the time they have their smart phone within arm's reach or the same room. Another outcome of the conducted study showed that the numbers are mostly independent of the environment people are located in, e.g. office, home, store, etc. The overall study results show that people tend to keep their smartphone very close to them throughout the whole day. Following the insights given by research, user interfaces realized on smartphones could be a real and feasible alternative to the minimal user interfaces offered by some smart devices. Additionally one can state that modern smartphones implement a powerful hardware and many different sensors and actuators that can be utilized for user interactions. Moreover, they established an enormously huge platform of frameworks, high-level programming languages and concepts as well.

The question if smartphone-based approaches used for coupling and controlling smart devices are feasible, was addressed by Roduner et al. [RLF07] in a study. The idea was to control many different devices with only one universal interaction device based on a smartphone. They split interactions into four categories.

- **Control task** The user has to configure a specific device setting.
- **Problem solving task** The smart device displays an error and the user has to solve this issue by utilizing the smartphone-based user interface. The smartphone can give hints and tips concerning the specific issue.
- **Everyday task** This category contains the most typical daily tasks performed on devices. E.g. brewing a coffee.
- **Repeated control task** A control task that an user performed recently.

As visible in figure 2.12 quantitative results showed that the mean time required for completing a task dropped drastically for control and problem solving tasks by using a smartphone-based user interface. The other two tasks showed only minimal differences, in fact, the approach using mobile phones performed only slightly worse than the standard device interaction. In general the smartphone-based user interface performed well for rare and more complex tasks

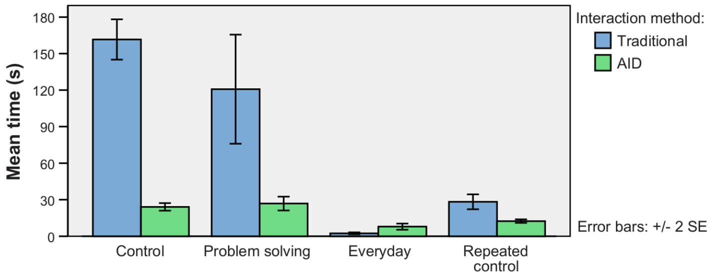


Figure 2.12: Results of a study conducted by Roduner et al. [RLF07] showing the mean times required for completing different categories of tasks on devices, by utilizing a smartphone-based user interface or traditional direct interaction.

because of a clear, structured, intuitive, appealing and understandable appearance due to a bigger screen and more input and output possibilities.

Derthick et al. [DSVW] introduced a system called “SAWUI”, a smartphone-based dynamically created user interface for devices like coffee machines. These devices were offering a WiFi access point for the smartphone to connect to and dynamically load the actual user interface as a web page. Again, this concept is called a “captive portal”. In their work they also conducted a study in which designers were given the task of redesigning the user interface of devices, by distributing it onto the device itself and the smartphone. The overall goal was to optimize the usability of appliances. They gained similar insights as received by Roduner et al. [RLF07], namely that designers preferred the smartphone-based interface for more complex and not everyday tasks.

Another very early approach for a “personal universal controller” (PUC) used for operating different complex appliances was introduced by Nichols et al. [NMHR02] in 2002. The idea is to store a high-level description of the user interface’s functionality and structure inside the appliance itself. The actual interface is then dynamically and automatically created by the “PUC” after establishing a successful connection.

A year later a study was conducted by Nichols et al. [NM03] comparing the performance of users completing some configuration tasks on the device’s integrated user interface in contrast to the dynamically created UI on PUCs. The outcome showed that users completed the same tasks in half of the time utilizing a PUC’s interface. The concept of dynamically and automatically created user interfaces presented by Nichols et al. [NMHR02] was improved in the following work done by the same team [NMRN06] in the year 2006. They introduced a technique called “UNIFORM” that creates UIs by trying to take into account which designs the user is familiar with and used previously. The main focus here lies on consistency and interfaces with a similar visual appearance.

3 Concept

The focus of this thesis is set on smartphone-based ad-hoc interaction techniques with smart devices offering minimal user interfaces. The number of smart devices available in our environment is increasingly rising thus leading to the concept of ubiquitous computing. Nowadays and in the near future users will get in contact with these devices on a daily basis, forcing them to interact with many different interfaces and concepts. Arising from this reality there is a need to offer users an easy, fast and intuitive way to connect to these devices in an ad-hoc manner and enable completing simple, repeating and also more complex tasks and configurations on these devices. Simple tasks are for example brewing a coffee daily and an example for a complex task is to set or change the water hardness on your washing machine. Humans should not be forced to recall complex passkeys and to known different concepts and designs of user interfaces, due to the huge amount of devices one needs to work with. Currently, many configuration possibilities and features of smart devices are not used because of inconsistent and hard to understand user interfaces. The question why these devices offer cumbersome interfaces can be answered with the lack of powerful hardware, sufficient sensors and actuators that are integrated into them and the fact that each manufacturer has its own way to build solutions.

Therefore, we are focusing on solutions utilizing smartphones in oder to create an user interface for smart devices. They offer a powerful and dedicated hardware with an enormous number of sensors and actuators. Additionally, smartphones support a broad base of frameworks, programming languages and concepts.

We tried to address all these requirements and issues with our concept of a smartphone-based ad-hoc interaction solution, used to configure smart devices. The next section will present the procedure of our concept that is necessary in order to interact with a smart device and perform changes to its configuration.

3.1 Configuration process

In this thesis smart devices are targeted that offer simple and also very complex configuration possibilities. The specific "smart device" used as a baseline for our evaluation is a heating system that offers simple adjustments, e.g. changing the overall temperature of the warm water as well as settings that normally are only changed by technicians, e.g. at what rate the installed pump has to work. Figure 3.1 shows such a heating system and its user interface. The developed prototype simulating a "heating system" that was compared to the baseline

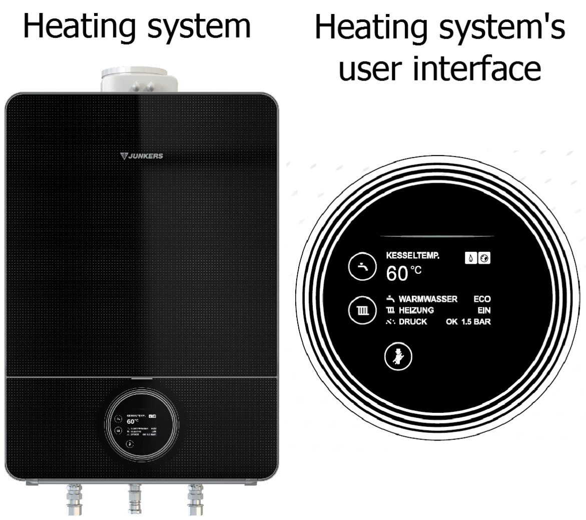


Figure 3.1: This is an example of a heating system and its user interface.

during the conducted study is shown in figure 3.2. The prototype's front is designed to look like an actual smart device with a minimal user interface and in the background all necessary hardware modules were implemented. It offers a screen, button, camera and NFC module and is controlled by a Raspberry Pi.

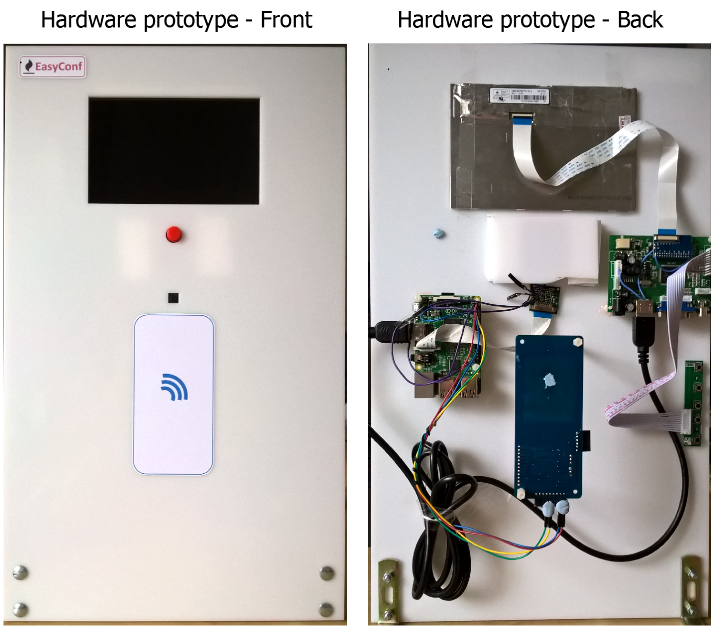


Figure 3.2: The developed prototype's front and back. It was simulating a heating system as displayed in figure 3.1.

For a successful configuration process performed with the developed prototype utilizing a smartphone and our concept the following steps are required. In addition it is to mention that only ad-hoc interaction techniques were utilized without tight connections, e.g. WiFi or Bluetooth.

1. **Ad-hoc device coupling**
   The user has to couple his smartphone to a smart device located in his environment.
2. **Data transmission (smart device → smartphone)**
   Applying changes to the configuration of a smart device requires its current state to be accessible on the smartphone.
3. **Perform configuration on smartphone**
   Use the smartphone-based user interface to apply changes to the current configuration.
4. **Data transmission (smartphone → smart device)**
   Retransmit the performed changes to the smart device in order to adopt them.

The following sections will look at each configuration step in detail and explain the used concepts and technologies. The first section that discusses our chosen ad-hoc device coupling techniques will examine each of them under the aspects *proximity*, *intuitiveness*, *playfulness*, *security*, *required hardware*, *privacy*, *robustness* and *costs*.

3.1.1 Ad-hoc device coupling

Ad-hoc device coupling between a smartphone and a smart device can be enabled by many different communication technologies and concepts as explained in the last chapter. Due to restrictions on the available hardware and the expected overall usability, our decision fell onto the following shortlist of concepts and technologies. Two of them, namely the optical and NFC approach were implemented in our study prototype and two of them are evaluated and compared on a theoretical level.

Optical approach (Using barcodes) For the optical approach an user has to scan one or multiple barcodes displayed by the smart device in order to couple his smartphone in an ad-hoc manner.

This concept requires the user to move close to the smart device in order to establish a connection, thus using *proximity*. Consequently, the user can see and touch the device as it is always done with current devices and their physical user interfaces. Thus an old and very well known concept is utilized in this approach. Furthermore, barcodes are also a very well known concept for many people and it is frequently used in our environment, e.g. in stores attached to products or QR codes containing URLs. Both facts can lead to an *intuitive* interaction experience. The optical approach also involves *playfulness* due to the fact that users can see the environment through a camera and have to aim at a specific position to capture the displayed barcode. After successfully capturing a code a sense of achievement occurs and the user can move on to the configuration step. Concerning the *security* aspect an optical approach involves some basic security features. Due to the required proximity and direct line of sight this concept is perfectly fitted for smart devices located in private locations. In public areas an attacker standing next to the actual user can also intercept the data contained in the barcode. For this case an additional security layer can be included, e.g. the displayed barcode can be protected by a visual cover to avoid a direct line of sight for potential attackers. Speaking of *required hardware* this solution demands a camera, screen and some advanced computing power for processing barcodes. For the future it is very likely that both components, camera and screen, will not disappear, since users will always need a camera for their personal use and a screen is essential to display information and feedback. Another aspect that is problematic in this approach is the question about *privacy*. If a camera is included in many different smart devices the surroundings can constantly be monitored and filmed. This problem can be overcome by using the camera-based solution only on the smartphone's side and utilize another communication technology on the smart device's side. Furthermore, this approach enables only one smartphone to be coupled with the smart device. For more phones and parties that want to perform a configuration, the consistency of changes has to be guaranteed. Addressing the *robustness* of such a concept one can say that it is very robust against user errors and technical difficulties. No error-prone wireless connections are involved in the coupling process and current smartphone cameras offer very high resolutions and frame rates. For current devices more than 12 MP are common. Finally, this approach requires no additional hardware on the smartphone's side thus keeping the *costs* for a consumer at zero. In contrast smart devices currently offer a screen but mostly a camera would be additionally required.

Near Field Communication For an approach utilizing NFC an user has to move to the smart device and nearly touch it with the smartphone in order to establish an ad-hoc connection.

Thus this interaction concept requires the user to bring both devices in a very close *proximity*. The distance has to be less than 10 cm in order for NFC to work properly. Additionally the user has to perform a gesture, namely touching the smart device with the smartphone as known from the concept of contactless payments. As shown in the study results found out by Chong et al. [CG11] humans prefer user actions involving proximity, device touch and gestures. These three made up nearly 45% of all user actions personally chosen by users in the conducted study. A NFC approach involves all three of them, thus one can say it could be perceived as *intuitive*. Speaking of *playfulness* the presented concept can offer some sort of fun factor due to the utilized "touch to connect" technique. However this is only valid if a proper feedback is given for a successfully established ad-hoc connection. Other than that the approach using near field communication offers a basic but very reliable *security* aspect. Due to the required proximity no one further away than 10 cm can attack the common wireless communication. Additionally, an user can authenticate himself to his smartphone once and use it as a token in order to connect to a smart device that has the mentioned token stored. Talking in terms of *additional hardware*, this concept only requires a NFC radio module integrated into both devices. Including a separate module into a smart device will not require much additional costs due to the fact that nowadays they are cheaper than 5 $ [Ali] and most of the modern smartphones already integrate such a module. Thanks to the required close distance this approach is perfectly fit to offer a high *privacy* standard. Additionally, no other sensors are required for the interaction thus no unnecessary data can be collected about the user. Answering the question of *how many devices* can be coupled using this interaction concept, one can say that it is intended to only couple two devices with each other. Still, it is possible to connect more than two devices to each other if they are all in close proximity. Talking about the *robustness* of this concept one has to mention that some basic requirements have to be fulfilled in order to establish and keep a connection between two devices. First of all there is an optimal distance the smartphone and the smart device have to keep. Secondly, a connection and data transmission can be aborted if the user moves his phone away from the NFC module integrated into the smart device. One possibility to overcome these shortcomings is to simply integrate and display a flat area where the user can just put down his smartphone. This approach would guarantee an optimal distance between both devices. At last the *costs* for such a concept have to be considered as well. As stated above, most smartphones already include a NFC module. Plus, extra modules that have to be integrated into a smart device are quite cheap.

WiFi - Access point Utilizing WiFi to establish an ad-hoc connection between a smartphone and smart device that provides an access point (AP) requires the user to select the proper AP from a list displayed on his phone. Thus he has to know the SSID and preferably also a passkey. A big advantage of a WiFi-based communication is the fact that a connection has to be established once. After that the user can move freely in the range of the WiFi signal.

There is no real *proximity* involved in this concept except the limiting range of WiFi signals. This can be a distance of up to 100 m outdoors and depending on walls and other obstacles 10*x meters indoors. That means that an user can access the interface provided by a smart device from a more or less far distance without being physically in front of it. Due to the very well known concept of WiFi networks and how to use them, one can assume that many users, but surely not all, would perceive this approach as *intuitive*. In terms of easy to use concepts, connecting to a WiFi AP requires some cumbersome steps. First of all an user has to recall the SSID of the AP in order to select it from a list of many other APs. Furthermore a passkey has to be recalled to enable a basic security in form of encryption. Additionally the user is not physically in front of the smart device, thus the user preferred concepts proximity, gestures, devices touch and physical button touches are not applied. Instead, a "search and select" interaction is used as presented in [CG11]. For an experienced smartphone user this approach will be very intuitive, other users will perceive it as a complicated concept. Using a WiFi AP to enable an ad-hoc interaction can involve some level of *playfulness*. However, this aspect strongly relies on the preferences of a specific user. Does he appreciate it to virtually select an AP, e.g. go through menus and make a selection from a list, or would he conceive more fun being physically active? Thus, no proper statement can be done. In addition, WiFi without any *security* layer can be attacked and listened to by any person within the WiFi's signal range, due to the used common wireless communication. Even in your private home a possible attacker from outside can sense the signal. Thus a passkey and encryption have to be included by all means. The passkey can be also replaced by a NFC tag or QR code attached to a smart device, that stores a private secret. For a pure WiFi-based solution only a radio module is needed as *additional required hardware*. Nearly all smartphones include such a module and already many smart devices are offering it as well. One problem with such a module is the relatively high power consumption. Furthermore one can say that as long as the wireless communication is secured and the required configuration application is not collecting or leaking data no *privacy* issues arise. For this approach *more than two devices* can be coupled as long as all changes and the data stored on the smart device are kept consistent. Additionally, it can be stated that using WiFi in order to establish an ad-hoc connection may lead to some possible *robustness* issues. One issue is the fact that the signal can be interrupted due to interferences and obstacles. Another could be caused by the user himself if he moves out of the WiFi's signal range. At last talking about *costs*, most modern smartphones already include a WiFi module. Besides that, the price for WiFi radio modules is constantly decreasing.

WiFi - Cloud-based Extending the concept of a WiFi-based ad-hoc coupling solution by utilizing a cloud can simplify some steps and tasks of a configuration process for smart devices. First of all, an Internet connection is required so that the smart device and smartphone can both connect to the router at home. Benefits could be that templates of optimal configurations for smart devices can be offered for download, dynamic help can be requested if necessary and personal configurations can be stored online and reused if needed. Additionally, a connection has to be established only once. After that the user can perform configurations from anywhere in the world if he can access the Internet. This is a valuable fact for professionals offering support via remote control.

For the aspects *proximity* , *playfulness*, *required hardware* and *how many devices* are able to couple, the statements of the pure WiFi approach stay the same. However by connecting a smart device to the Internet some critical *security* issues can arise. The device has to be made safe against viruses, Trojans and also active attacks from outside. The whole configuration process will also get more complicated, thus some *intuitiveness* gets lost. Users will have to know many modern concepts of the Internet and computer science in general. Additionally *privacy* can be at risk, due to the active Internet connection and the fact that all data is stored online in a cloud. If data gets leaked in some way, an identification of a specific user is possible. This approach also involves some risks concerning the *robustness* of the whole system. In the case of issues with the Internet connection, configurations can not be loaded and help topics will not be displayed. Other than that the WiFi connection is also relying on an additional bridge - the router - thus increasing the risk for a connection abort due to malfunctioning hardware. Speaking about *costs* one can say that the actual hardware costs on the side of the smart device will stay the same. However, the user has to provide an active Internet connection and a router.

3.1.2 Data transmission

After a successful coupling attempt an user desires to accomplish some tasks by using the smart device and its features or perform a configuration of the said device. Therefore, it is necessary to enable data transmission between the smartphone and a smart device. The following sections will discuss our different approaches and their strengths and weaknesses under the aspects of *bandwidth*, *usability* and *security*.

Optical approach (Using barcodes) Currently barcodes are mostly used to store some static data that never changes. An example are linar barcodes used on products in stores in order to save their article number. However, barcodes can also be utilized to transmit some encrypted data between devices implementing a camera and screen. For our prototype QR codes were utilized. Following the standardization a code with the maximum size (177x177 elements) can store up to 2.953 bytes of binary data with the lowest error correction setting. The capacity, thus the *bandwidth*, is strongly connected to the size of a code, therefore can be increased and decreased. Other approaches utilized to increase the capacity are using different colors for encoding and animated sequences of QR codes. Current smartphones implement very powerful cameras that can easily scan very complex and dense QR codes. This data transmission approach requires the user to be physically in front of the smart device, thus restricting the *usability* to only direct interactions. Other than that the communication is also unidirectional. Therefore a user has to scan a displayed code in order to get data to the smartphone and flip it in order to transmit data back to the smart device. The presented way of communication is very *secure* since a direct line of sight and close proximity are required.

Near Field Communication Compared to the barcode approach NFC offers the possibility to establish a bidirectional connection with a *bandwidth* of up to 424 kBit/s. Other than that the *usability* is restricted to only direct and physical interactions due to the range NFC is working in. An user who wants to interact with a specific smart device has to move close to it and hold his smartphone next to the NFC module. Speaking of *security* this data transmission technology can not be attacked from a distance bigger than 10 cm.

WiFi - Access point WiFi seen as a data transmission technology is commonly used due to its convenient *usability* aspect. One can move freely within the possible range without loosing the connection. The *bandwidth* is also extraordinary high, therefore much data can be transmitted in a short period of time. Other than the advantages, WiFi also entails several *security* risks due to the wide range in which signals can be perceived. Data transmissions can be attacked by the commonly known attacking scenarios for wireless communications.

WiFi - Cloud-based This approach is identical to the WiFi - Access Point case.

Decision making For our prototype and study we chose two of the presented ad-hoc interaction techniques. The reasons for that decision are the following.

- **Optical approach**
  Our decision to utilize an optical approach including barcodes is based on the fact that much research for ad-hoc interaction concepts is relying on acoustic signals, radio waves and tangible actions. Furthermore, most smartphones will probably still include a camera

and screen in the future, since screens are the main and also one of the strongest output mediums. In addition users will always feel the urge to capture moments of their life by taking pictures. Another goal was to utilize a concept that offers a basic security without the need of a priorly shared knowledge as it is necessary for most interactions that are based on wireless communication, e.g. WiFi or Bluetooth. The presented concept also involves gestures and a direct contact with devices, which humans are very familiar with. Users have to “point” their camera at a displayed barcode in order to scan it. Additionally many steps of a configuration process are directly perceptible by the user, thus they are providing several small steps that lead to multiple occurrences of a sense of achievement. As a comparison many steps are happening seamlessly in the background in the case of the WiFi concept. Thus they are not noticed by the user. Despite all differences, the optical approach still enables all necessary actions that are required for an ad-hoc configuration process.

- **Near Field Communication**
  Similar to the optical approach an ad-hoc interaction based on NFC requires several very easy to understand and familiar concepts, namely proximity, device touch and gestures. Therefore, the user gets in a direct physical contact with the smart device. Additionally NFC is a very robust and reliable communication technology that only involves few hardware components and still enables a bidirectional communication.

3.1.3 Configuring smart devices utilizing smartphone-based user interfaces

After discussing the different approaches for ad-hoc coupling and data transmission this section will talk about our used concepts to enable a smartphone-based user interface. Additionally benefits and drawbacks will be mentioned.

Current smartphones offer a very powerful hardware including a high-resolution multi-touch screen, much computing power and mostly an Internet connection. In the case that an Internet connection exists user interfaces for specific smart devices can be dynamically loaded. This fact enables a centralized distribution and maintenance by the manufacturer. If no connection to the Internet is favored the user interface can also be stored and loaded from the smart device itself. Other than that smartphones are mostly in close proximity to the user throughout the day and also in different locations. Due to the powerful hardware smartphones are feasible for displaying web-based user interfaces as well. The conclusion of an user interface created by utilizing web-technologies is that they will mostly look and feel the same on smartphones with different operating systems.

In order to design an user interface that provides a pleasant user experience Shneiderman’s “Eight Golden Rules of Interface Design” [Ben] have to be followed. In the following section the different rules will be discussed with respect to smartphone-based user interfaces.

Shneiderman's eight golden rules of interface design

1. **Strive for consistency**
   By utilizing smartphones in order to design and provide user interfaces consistency is much simpler to sustain. Many users are already accustomed to interfaces created for smartphones and the web. Developers and designers are working on the same platforms and also with the same frameworks thus resulting in a common layout for prompts, menus and help screens. Performing the same actions on user interfaces developed for different smart devices will therefore feel and look very similar. Thus users will struggle less in performing specific actions. The importance gets obvious if we are looking at smartphones with different operating systems and the users having troubles switching between them.

2. **Enable frequent users to use shortcuts**
   Offering shortcuts on smartphone- and web-based user interfaces is much simpler due to the bigger screens and possibilities to integrate them.

3. **Offer informative feedback**
   Current smartphones are offering an enormous number of different sensors and actuators. Optical, acoustic and tactical feedbacks can be provided easily due to an available screen, speaker and vibrating motor. Thus even disabled users can be addressed through different ways.

4. **Design dialog to yield closure**
   Concerning this topic smartphones are not dominant. One could argue that the ad-hoc coupling and data transmission steps lead to more actions that are complete, thus giving the user a satisfaction of accomplishment more often.

5. **Offer simple error handling**
   Error handling on a platform offering much computing power, storage and maybe an Internet connection is much simpler than on standalone smart devices with very limited capabilities. Most offer an extra manual whereas smartphones can display context-aware hints and prompts helping the user to resolve issues. Even unknown and complex errors can be directly forwarded to the support of a specific manufacturer.

6. **Permit easy reversal of actions**
   Enabling the user to reverse actions is again much easier to realize on a smartphone. Previous states of the system have to be saved somewhere, thus requiring storage. Comparing smartphones with smart devices in terms of storage capacities the dominant alternative is obvious.

7. **Support internal locus of control**
   This topic is not directly related to the choice on which device the user interface is realized.

8. **Reduce short-term memory load**
   Most modern appliances are working with menus composed of many different sub-menus the user has to navigate through. Smartphone- and web-based user interfaces offer, e.g. tabs, expandable sub-menus, etc., thus reducing the short-term memory load for users.

In general one can say that an user interface that is based on smartphone and web concepts can strongly improve the overall usability and likeability. Web-based interfaces can build upon a huge number of different existent languages and concepts particularly developed to create appealing and usable user interfaces. Examples are CSS, JavaScript, HTML, etc. Additionally, one can utilize an enormous number of frameworks that reduce the time and costs for development, e.g. Semantic UI[1], ChartJS[2] (creating appealing charts, graphs, etc. in JavaScript and HTML), ZXing[3] (proprietary barcode encoding, decoding library of Android), Android Beam[4] (NFC p2p communication).

[1]http://semantic-ui.com/
[2]http://www.chartjs.org/
[3]https://github.com/zxing
[4]https://developer.android.com/guide/topics/connectivity/nfc/nfc.html

4 Implementation

This chapter will firstly give a rough overview of the developed prototype including a general description and its system architecture with all involved modules and components. Secondly, there will be a detailed description of both used ad-hoc interaction concepts, namely their procedure and actual implementation. Thirdly, a closer look will be taken at the utilized Raspberry Pi that is simulating a smart device with a basic user interface. In addition it offers very simple and also complex configuration possibilities. At the end the application developed for an Android smartphone will be presented.

4.1 System architecture

The developed prototype is meant to enable ad-hoc coupling between the hardware prototype running on a Raspberry Pi and a smartphone. Additionally it should be possible to make changes to its current configuration by utilizing the web-based user interface implemented on the smartphone.

4.1.1 General description

Figure 4.1 gives an overview of the whole prototype consisting of a Nexus 5X [LG] running Android 6.0 Marshmallow and implementing a 1,8-GHz-Hexa-Core-CPU, 5,2 inch multi-touch display, 12,3 MP camera, NFC module and much more. The smartphone can be coupled to the Raspberry Pi system in two ways, namely by utilizing an optical approach using QR codes and by making use of NFC communication. These technologies are not only used for coupling purposes but also to enable a bidirectional communication between the smartphone and the Raspberry Pi. Additionally, it has to be mentioned that NFC is working with a peer-to-peer approach using the Android Beam protocol that offers a real bidirectional communication. In contrast, the optical approach is in fact unidirectional. However, data can be sent both ways due to the fact that both devices implement a screen in order to display QR codes and also a camera for scanning QR codes. Being more detailed there are several external modules implemented into the Raspberry Pi system, namely a 7.0 inch HannStar screen (1280x800 pixels), a Raspberry Pi camera with 5 MP, an Adafruit PN532 NFC/RFID v1.6 breakout board and a simple button. Additionally, the Raspberry Pi system is intended to serve as an intermediary component that can be connected to the serial BUS of a heating system, thus making it possible to actually configure existent devices.

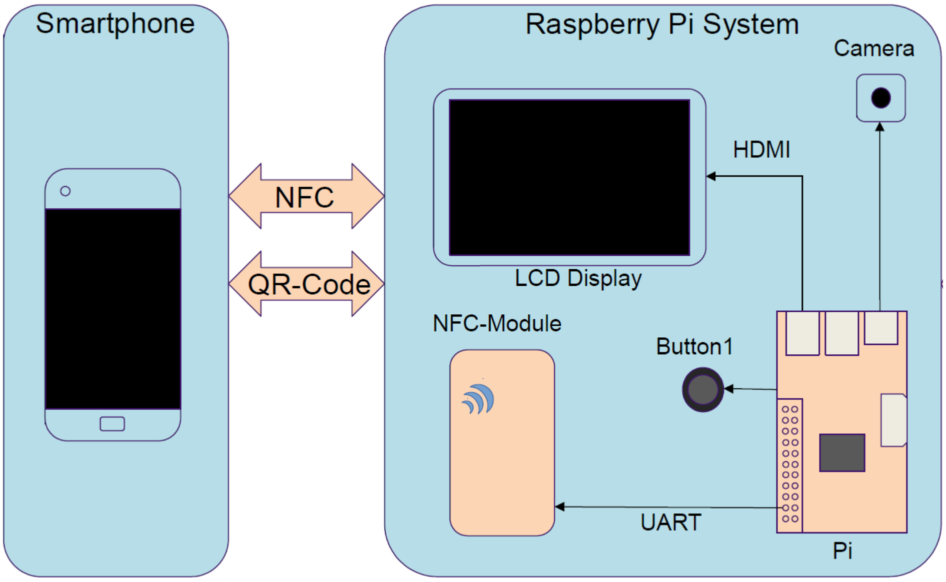


Figure 4.1: System architecture of the developed prototype. In order to enable a NFC- and optical-based communication, the Raspberry Pi system implements a camera, screen, button and NFC module.

The next two sections will give a detailed description of how the configuration process is working in case of the QR code and NFC concept. Afterwards, there will be an in depth description of how the Raspberry Pi and smartphone implementations were realized.

4.2 Procedure for the configuration process - optical approach

As figure 4.2 indicates the procedure used to apply changes to a smart device is split into four essential steps. In the following they will be described individually. Additionally, it is important to mention that prior to the actual configuration process the user has to install the required smartphone application.

1. **Scan one or multiple QR codes (ad-hoc coupling & data transmission from smart device to smartphone)**
   The first step of each interaction involves an ad-hoc device coupling and in the same time a transmission of the smart device's current configuration state to the smartphone. Therefore, the user has to move to the device and wake it by pressing any button, so that it can display one or multiple animated QR codes containing its current state. The user has then to scan the displayed QR code with his phone, receiving a feedback for a successful coupling and data transmission attempt.

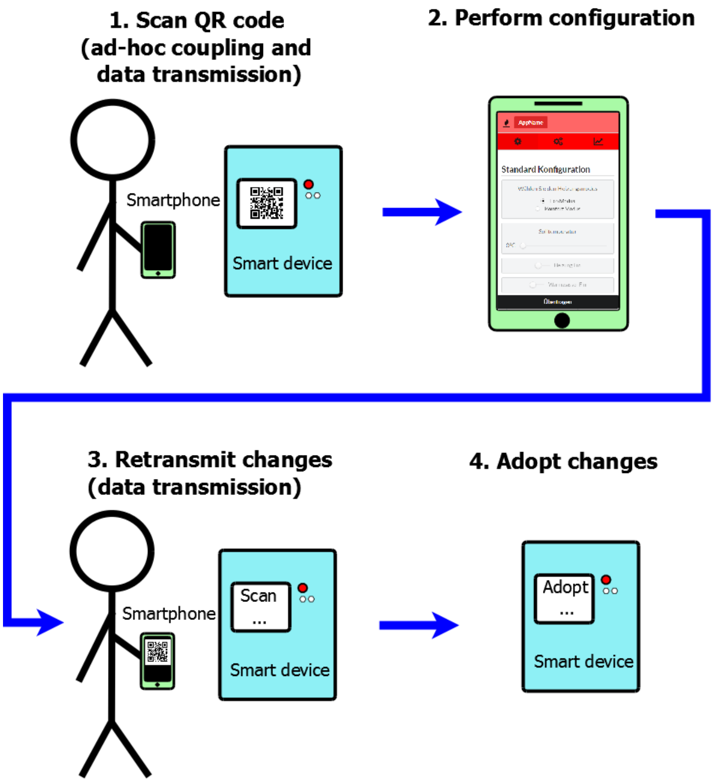


Figure 4.2: Visualization of a configuration process utilizing the optical approach. 1. Start smartphone application and scan the QR code. 2. Perform configuration. 3. Hold smartphone's screen into smart device's camera. 4. Smart device adopts changes.

2. **Perform configuration**
   The second step requires the user to perform the actual changes to the configuration on his smartphone utilizing the displayed web-based user interface.
3. **Retransmit changes (data transmission from smartphone to smart device)**
   After the user performed all desired changes he has to confirm them. The smartphone then starts to display one or several animated QR codes on its screen. Following that, the user has to move to the smart device and again push a button in order to indicate that he is ready to retransmit the made changes. Afterwards, the user has to rotate his smartphone so that the device's camera can scan the displayed QR codes.
4. **Adopt changes**
   At the time all required QR codes were scanned the smart device indicates that the data transmission was successful. Simultaneously, the new configuration is adopted to its system in the background.

4.3 Procedure for the configuration process - NFC approach

Similar to the configuration process described in the prior optical approach the NFC concept involves four essential steps as well. Again, they will be described in detail in the following part and can be viewed in figure 4.3.

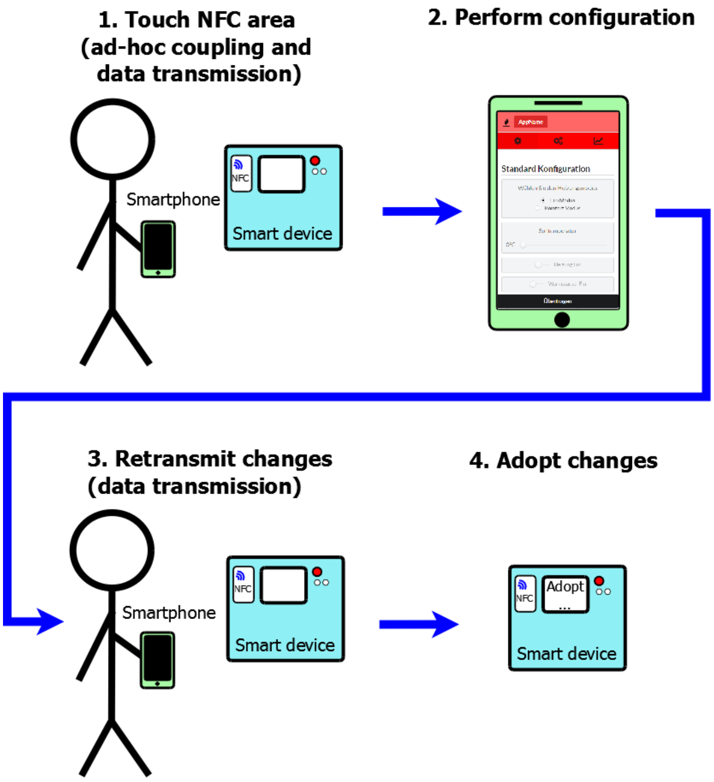


Figure 4.3: Visualization of a configuration process utilizing the NFC approach. 1. Start smartphone application and touch the NFC area. 2. Perform configuration. 3. Touch the NFC area again. 4. Smart device adopts changes.

1. **Touch the NFC area on the smart device (ad-hoc coupling & data transmission from smart device to smartphone)**
   In order to initiate the configuration process the user has to take his smartphone and touch the NFC area on the smart device. The device will sense that there is an appropriate communication partner that wants to interact with it. Therefore it couples to the smartphone and immediately transmits all data that is representing its current state.
2. **Perform configuration**
   Afterwards, the user can perform his desired changes by utilizing the web-based user interface displayed on his smartphone.
3. **Retransmit changes (data transmission from smartphone to smart device)**
   Immediately after the first step the smart device is waiting for the data that is containing

the performed changes. The user has to confirm his alterations and move his phone to the NFC area on the smart device. During this step all necessary data will be transmitted by utilizing NFC technology.

4. **Adopt changes**
   After a successful transmission the smart device will give the user an appropriate feedback and adopt all made changes to its current state.

4.4 Implementation - Detailed description

After a broad overview of the whole system architecture and each configuration process, this section will talk about the prototype's detailed implementation. Firstly, the Raspberry Pi system will be described and afterwards the application developed for an Android smartphone will be looked at. Figure 3.2 shows the prototype's front and back side.

4.4.1 Raspberry Pi

The Raspberry Pi is functioning as a smart device with some included modules that enable a basic interaction. Thus the user interface is intentionally kept minimal. A Raspberry Pi, a single-board computer, was chosen for our developed prototype due to fact that it is a fully functional computer running Linux Debian. Therefore, it supports most known programming languages and web-based frameworks. Additionally many drivers for the utilized modules are available and can be simply used.

Hardware

The following hardware is required in order to realize the QR code- and NFC-based ad-hoc interaction concepts.

Camera A Raspberry Pi camera v1.3 with 5 MP was included so that QR codes displayed by the smartphone can be scanned and decrypted. The relatively low resolution and the absence of a physical autofocus were consciously selected in order to test how reliably QR codes can be scanned by smart devices with comparatively cheap hardware. For this case the latency and bandwidth of the data transmission are depending on the camera resolution and frame rate. On the Raspberry Pi system the "raspistill" command line tool is running in a loop and taking frequent pictures in order to scan if QR codes are available.

NFC Breakout board An Adafruit PN532 NFC/RFID controller breakout board v1.6 was used to enable a basic NFC communication between the smartphone and the Raspberry Pi system. It was connected via UART and is controlled by the Python-based library “Nfcpy”[1] that offers the actual driver as well as some essential tools in order to enable basic reading/writing operations to tags as well as the Android Beam technology that is used for a peer-to-peer communication.

Screen The implemented screen has a size of 7.0 inch and is used to display QR codes that are scanned by the smartphone. Additionally it is used to give feedback for the user. It has a resolution of 1280x800 pixels and is not touch-capable. This property was also intentionally selected to have a very basic visual output possibility.

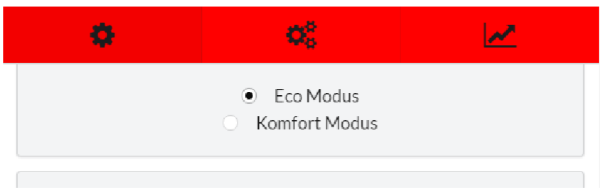
Button The only input possibility next to the camera and the NFC module is a simple button used to wake the Raspberry Pi system and to signalize the wish to continue the configuration process.

Wizard

The idea behind the configuration process is to keep the whole ad-hoc interaction simple, easy to understand and as fast as possible. Therefore, a wizard-like procedure was implemented leading the user through the whole procedure. It is based on and controlled by NodeJS[2] that offers many standardized libraries and functionalities that speed up the whole development process. Many libraries and tools are distributed in a centralized manner by the “Node Package Manager”[3], thus can easily be downloaded and installed. Additionally, the whole wizard is implemented by utilizing web-based technologies, namely CSS, JavaScript and HTML displayed in a browser window maximized to full screen. In order to accelerate the whole development process Semantic UI [Sem] was utilized to create appealing, simple and modern web pages. This is realized by using components defined by natural language. Due to utilizing Semantic UI it is possible to create UI elements by only using keywords. These elements are already formatted properly with CSS and equipped with JavaScript without the need to implement it manually. Figure 4.4 shows a menu produced with Semantic UI. The contained code snippet creates an element that is always attached to the top and itself contains a menu with three items that are displayed as tabs, only using icons as labels. The icons are already predefined and can be used out of the box. Additionally, formatting can be done by using keywords, e.g. “small, big, large”.

[1] https://nfcpy.readthedocs.io/en/latest/
[2] https://nodejs.org/en/
[3] https://www.npmjs.com/

Menu created with Semantic UI



HTML code snippet for menu

```
<div class="ui fixed top sticky">
        <div class="ui icon three item attached menu">
                <div class="active item" onClick="">
                        <i class="big setting icon"></i>
                </div>
                <div class="item" onClick="">
                        <i class="big settings icon"></i>
                </div>
                <div class="item" onClick="">
                        <i class="big line chart icon"></i>
                </div>
        </div>
</div>
```

Figure 4.4: On the left side the menu is visible that is a visual representation of the code snippet displayed on the right side. It shows a menu consisting of three tabs using icons as labels. Additionally it is always attached to the top of the view.

4.4.2 Smartphone

For the developed prototype a smartphone application was implemented that includes a wizard-like configuration process that is similar to the one used in the Raspberry Pi system. For the optical approach a camera with 12,3 MP was utilized that performs very well with QR codes, even with very complex and dense ones. Therefore, the initial configuration contained in the QR code displayed by the Raspberry Pi system can be scanned in less then a second, even from distances of more than 1 m. Encoding and decoding of QR codes is done with the ZXing library that offers fast and reliable detection algorithms. Furthermore, a QR code can be scanned from various angles and orientations making it easy to interact with the smart device. The whole application was developed for Android thus Android Beam was utilized for the NFC communication enabling a bidirectional data transmission. The actual data representation is encoded into a float array in which each index is standing for a specific parameter. This was done in order to minimize the overall size of a single transmission. Additionally, the whole array is always minimized in order to only contain the data that is necessary for a specific step.

Configuration wizard

Identical to the Raspberry Pi system the whole configuration process is performed by utilizing a wizard-like procedure in order to lead the user step by step. Thus, he is not required to have a prior knowledge of specific technologies and how they function, instead he is always explicitly told what to do. The aim was also to base the whole user interface only on web technologies, namely CSS, JavaScript, HTML and all of it was abstracted by utilizing Semantic UI. In order to achieve this approach, it was necessary to implement the whole wizard and user interface by using a concept called “WebView”. It is supported by Android as well as the other commonly known mobile operation systems. The mentioned concept is a simple browser embedded into the whole application running all necessary web-based technologies and communicating with the actual application through a defined interface. Figure 4.5 represents

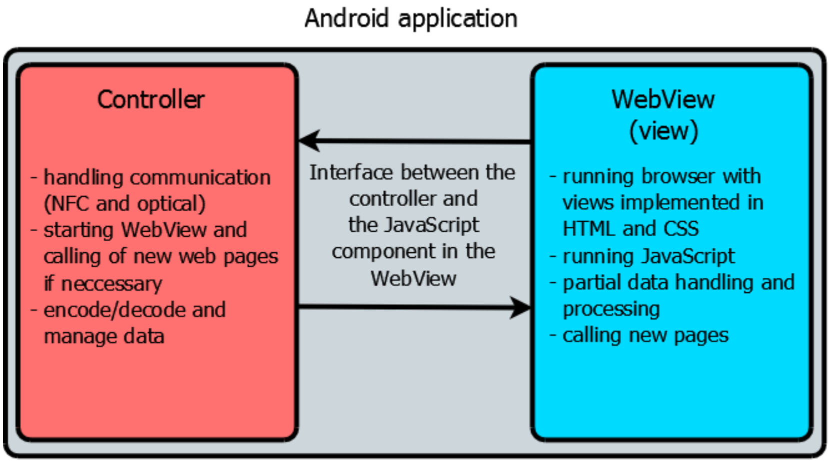


Figure 4.5: The displayed architecture of the developed Android application consists of a controller and a view.

the application architecture and how the controller and view are working together. Data can be sent back and forth between them as required. This whole approach makes it easy to develop user interfaces for different platforms due to the commonly supported technology.

Web-based user interface

At the time data is received from the controller representing the current state of the smart device, a view is called where the user can perform his desired changes. In this user interface all current parameters and their values are set so that the user is informed prior to applying his wished changes. Other than that the menu is fixed to the top part of the view at any time so that the user can always access it easily. This is shown in figure 4.6. Additionally, a signal color is used for the menu so that it is highlighted. Moreover, the values that can be changed are embedded into boxes in order to make it easier to distinguish the different parameters. The menu is also split into three tabs of which two are particularly important. The first one denotes the "simple" configuration possibilities and the second one stands for the more "advanced" ones. Simple means that no real harm can be done to the smart device by changing them and the quantity is limited to only six parameters.

The complex option offers 26 different values that can be manipulated thus it is necessary to structure them somehow and make them easy and fast to access. Therefore, an accordion concept was used as shown in figure 4.6. It empowers the user to select specific sub-menus and their contained parameters and still be able to close the dropdown and easily move to another sub-menu. As shown in figure 4.6 the layout of all user interface elements is centralized thus making them easily accessible on a smartphone by only utilizing the user's thumb. Additionally sliders were used to configure specific ranges of a value, e.g. the temperature. Thus it is not required to pop up a keyboard on the screen that would be used to type in the desired value. At the end when all changes were made by the user he can confirm the changes by pressing the

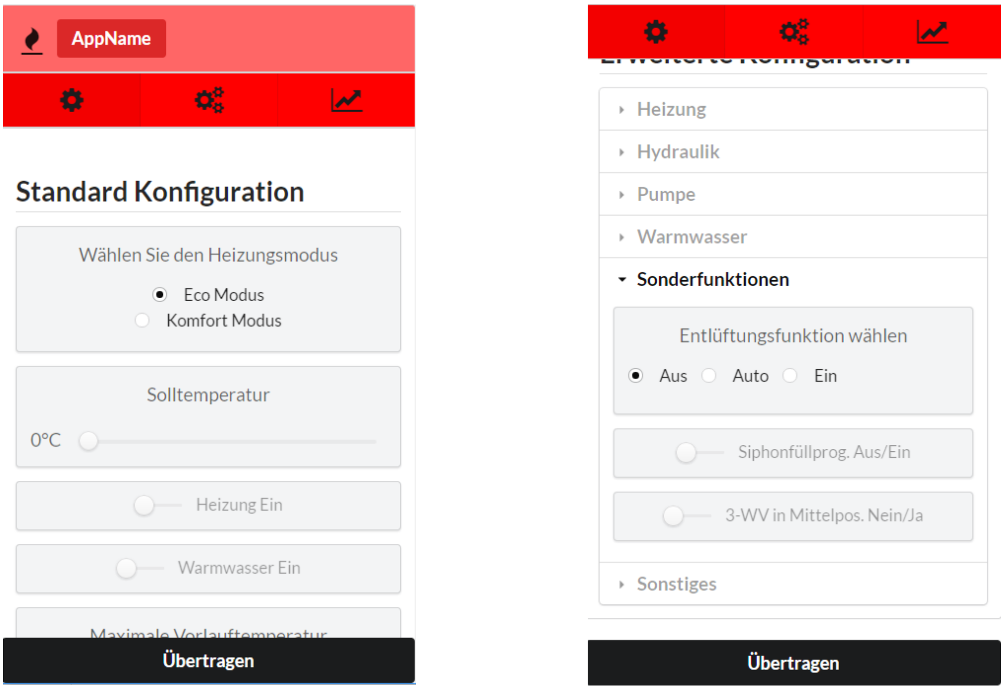


Figure 4.6: This is the smartphone-based user interface. In both images a fixed menu and "Transmit" ("Uebertragen") button can be seen. On the left side the simple sub-menu is displayed and on the right side the complex one. An "accordion" principle was used in order to group the 26 different parameters.

dark confirm button at the bottom. Similar to the menu it is always attached to the bottom part of the user interface.

5 Evaluation

This chapter describes the evaluation of the suggested ad-hoc interaction concepts and the developed prototype. A study was conducted by utilizing an user interface that is currently used for many heating systems manufactured by Bosch Thermotechnik GmbH and the developed prototype described in chapter 4. In the first section the hypothesis will be stated. Following that, a description of the experiment's design and apparatus will be given and a characterization of the participants will be depicted. The procedure used to conduct the experiment will be shown in the next section and the last one will describe and analyze the obtained results.

5.1 Hypothesis

A smartphone-based ad-hoc interaction concept and user interface utilized to configure a complex smart device, provide the same or better performance and usability compared to a direct interaction utilizing a physical user interface provided by the smart device itself.

5.2 Design and Apparatus

The objective of the performed study was to give users configuration tasks that they had to perform on the following two systems.

- A physical user interface as it is used for many heating systems developed by Bosch Thermotechnik GmbH. That system was utilized as the baseline in order to a direct interaction.
- A smartphone-based user interface communicating with a developed hardware prototype that is simulating a heating system. Three essential steps were required in oder to perform a specific configuration.
    1. Getting the current configuration to the smartphone in an ad-hoc manner.
    2. Performing the desired configuration changes on a smartphone-based user interface.
    3. Transmitting the made changes to the "smart device" in an ad-hoc manner.

  Additionally it is to mention that the ad-hoc interactions were enabled by an optical and NFC approach.

The purpose of the developed prototype was to simulate an actual heating system offering simple and complex configuration optionalities and empower the user to utilize a smartphone to change them. The performance and likability of the baseline and the developed prototype with two different ad-hoc interaction approaches were compared to each other. Figure 5.1

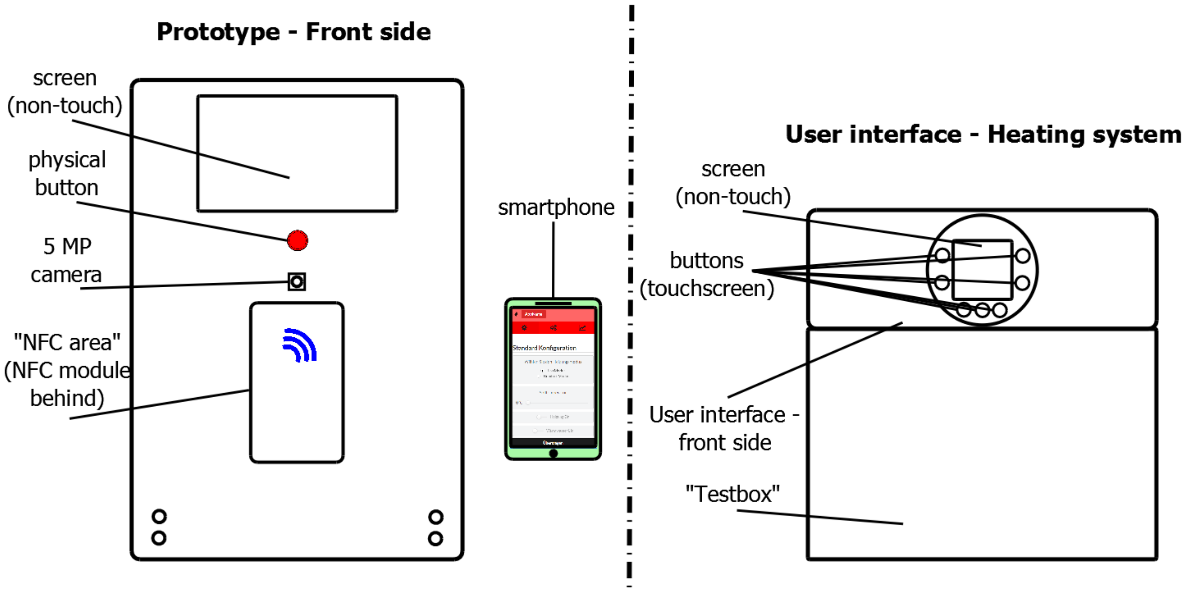


Figure 5.1: This is the sketch of the utilized apparatus. On the left side the developed prototype is displayed. On the right side the user interface used for a direct interaction is shown.

displays the sketch of the whole study setup with all contained physical elements. On the left side the actual prototype is shown that inherits all electronic parts in order to enable a NFC and optical communication with the smartphone carried by the user. The optical communication is exclusively based on QR codes displayed either on the prototype's screen and scanned with the smartphone or the other way around. Thus, the hardware prototype implements a non-touch screen and a 5 MP camera. In addition the participants required a smartphone offering a camera and screen. NFC communication is enabled by an implemented NFC module attached to the back of the prototype. For a successful communication the participants had to place the smartphone approximately at the displayed NFC area, that was visualized by a printed sticker with a blue NFC symbol.

On the right side the current user interface as it is produced by Bosch Thermotechnik GmbH for many different of their appliances was placed on top of a "testbox" so that users were able to interact with it accordingly. Such an user interface can be seen in figure 5.2. The "testbox" was necessary in order to simulate actual sensor data for the user interface, thus enabling a real configuration of specific values.

Other than that the smartphone that was utilized by the participants was running the developed Android application, leading them through the whole configuration process, handling the communication with the hardware prototype and managing all data. The participants in- and

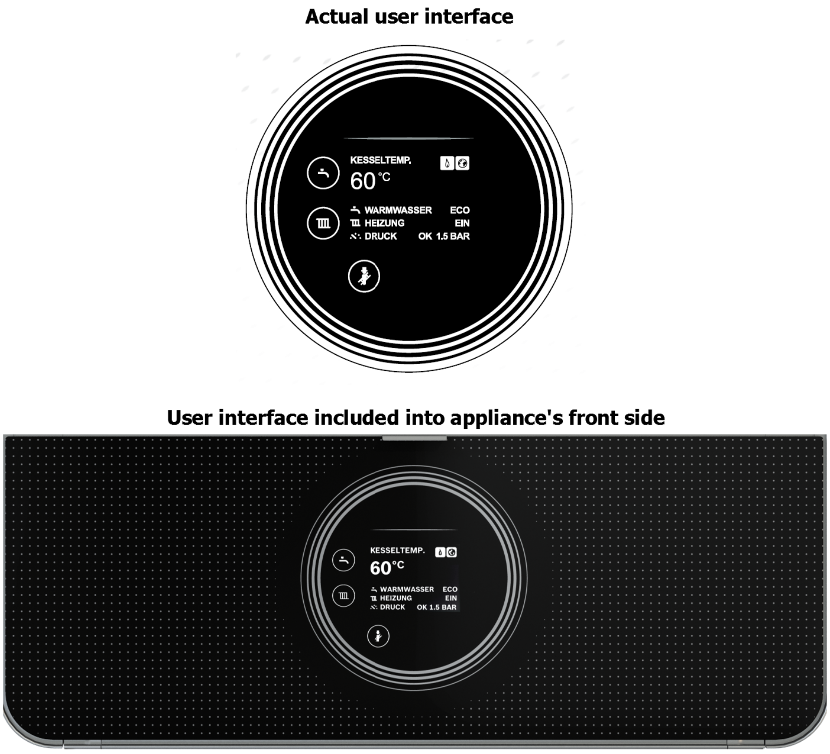


Figure 5.2: At the top the actual heating system's minimal user interface can be seen with a non-touch screen and several buttons. The picture at the bottom shows how the user interface is embedded in a panel used for many heating systems produced by Bosch Thermotechnik GmbH, e.g. the Cerapur9000i.

output interactions were handled by the hardware prototype in a server-client manner between the maximized browser view and the controller. Therefore, a NodeJS server was utilized.

5.3 Participants

In order to recruit participants for the performed study, employees of Bosch Thermotechnik GmbH were asked and invited personally to attend. Altogether 14 participants agreed to participate in the experiment, of which 11 were male and 3 female. Their age ranged from 21 to 60 years with the properties mean = 38,5 and standard deviation = 11,65. Figure 5.3 visualizes the participants' ages in a diagram. The handed out task was to perform several different configuration actions on the two mentioned systems. Therefore, we tried to recruit participants from two different groups, namely novice, a person who is not familiar with the menu structure, parameters that can be changed and the present Bosch user interface and experts/technicians. The second group of people was working with the named characteristics on a regular basis or at least had deeper insights on them. At the end 6 of 14 participants were classified as novices and 8 as experts or technicians.

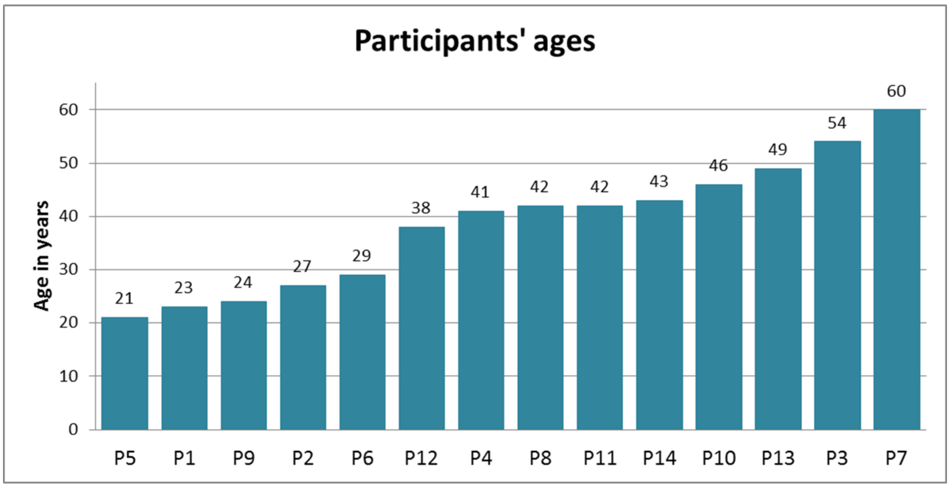


Figure 5.3: This diagram displays the distribution of the participants' ages.

Additionally all participants were asked three major questions that were referring to their background knowledge about QR codes, NFC technology and the purposes they used their smartphone for. Six gave the answer that they already had scanned QR codes with their smartphone and 8 negated this question. Furthermore, only one person stated that he already used NFC technology in his life but did not give an example. The third question that asked for what purposes they use their smartphones was divided into the following four categories.

- Voice and message services
- Internet/browsing
- Various applications
- Controlling other devices (e.g. remote control)

Here it is important to mention that only one person stated that he is not using a smartphone on a daily basis. Other than that, 12 participants are utilizing their smartphone for voice and message services and the same number indicated that they are browsing the Internet. 10 are using various applications on their smartphones and the number of 7 participants are utilizing their smartphone to control other devices, e.g. as a remote control.

5.4 Procedure

The whole study took place in a laboratory. Both systems were placed on a table so that the participants were able to interact with them in a standing position as visible in figure 5.4. That position was chosen due to the fact that heating systems are placed in the cellar without any possibility to sit down, therefore creating a situation that is close to the reality. The participants had appointments and were tested individually. The experiment was conducted in a controlled environment due to the fact that in reality these heating systems are located

Figure 5.4: This picture shows the actual study setup. On the left side the developed prototype is displayed and on the right side one can see the user interface utilized for the direct interaction condition.

in private locations without the possibility to access them and monitor interactions. The duration that was required to perform the study with one participant was approximately 40 to 50 minutes long. As a motivation and reward for the participants, bakeries were promised and handed out at the end of each iteration.

The aim of the study was to do a qualitative and quantitative comparison between smartphone-based user interfaces combined with ad-hoc interaction concepts and a direct interaction performed on the user interface offered by a heating system. Three conditions were tested, namely NFC-based vs. optical-based vs. a direct interaction of which the first two were realized by utilizing the developed prototype.

At the beginning each participant received a consent form to sign and a pre-questionnaire to fill out. The questionnaire asked demographic questions and in addition the participant's background experience and knowledge concerning the utilized hardware, concepts and technologies were inquired. Before the participant was able to start with the study a small oral introduction was given informing him about special characteristics of both systems, namely the developed prototype and the actual heating system. Additional background information was necessary due to the fact that the later given configuration tasks required the participant to known about sub-menus that are not obviously to reach and only accessible by pressing a specific button combination. Furthermore, the hardware elements of the developed prototype had individual characteristics that needed a small hint. In detail the following introductions were given to each participant.

- What is the general idea of the study. - Configuring a heating system.
- The systems can not crash and you should simply try to accomplish the given tasks. - This information was given in order to avoid the participant trying to rely on feedback given by the study attendant.
- Please do not try to give feedback during the actual procedure. - The information that there will be an open interview in the end was given.
- It is possible to reach an expert configuration menu by pressing those two specific buttons on the heating system's user interface. - Without this additional information the participants would not be able to reach the expert sub-menu.
- If the prototype asks you to place your phone on the specified NFC area you should place your phone directly on top of the surface without an additional space between them. - The used NFC breakout board had an optimal working range and sometimes had difficulties to sustain a proper bidirectional communication. This is only a characteristic of the used hardware.
- The prototype's camera is located at this position. - The camera was integrated into the prototype's surface and was not easily distinguishable as such.
- Try to push the prototype's button now and do not be afraid if it bends slightly. - Sometimes users were afraid to push the button since it offered a high resistance and the prototypes surface was slightly bendable.

After the introduction the participants were able to start with the actual configuration process. Figure 5.5 shows the study procedure performed with one participant. Three different concepts were tested with each of them, therefore the study was structured according to a within-subject or repeated-measure design. In order to overcome the learning effect of such a design a 3x3 balanced square algorithm was applied that is shown in figure 5.6. Learning effects of within-subject study designs occur due to the fact that after each condition the users get to know specific characteristics of the procedure and the individual systems. Examples are the menu structure, how to use the physical interaction possibilities, etc. As a result, within three consecutive participants each started with a different condition and was also facing another ordering. That led to a counterbalanced structure. Additionally, for each condition each participant received two different task sheets named T_{sim} and T_{comp} as shown in figure 5.5. T_{sim} involved two simple tasks that could be easily performed in the "simple" configuration menu. An example is to set one temperature to a given value or switch the heating system on or off. T_{comp} involved three more complex tasks that were hidden in the expert menu. An example is to select a specific pump that is installed in the heating system. Additionally, the third task of the complex task sheet involved a searching process in a given sub-menu due to the fact that the name did not give any hint at were to find the specific configuration possibility. For each task sheet the participant had to start the configuration process from the

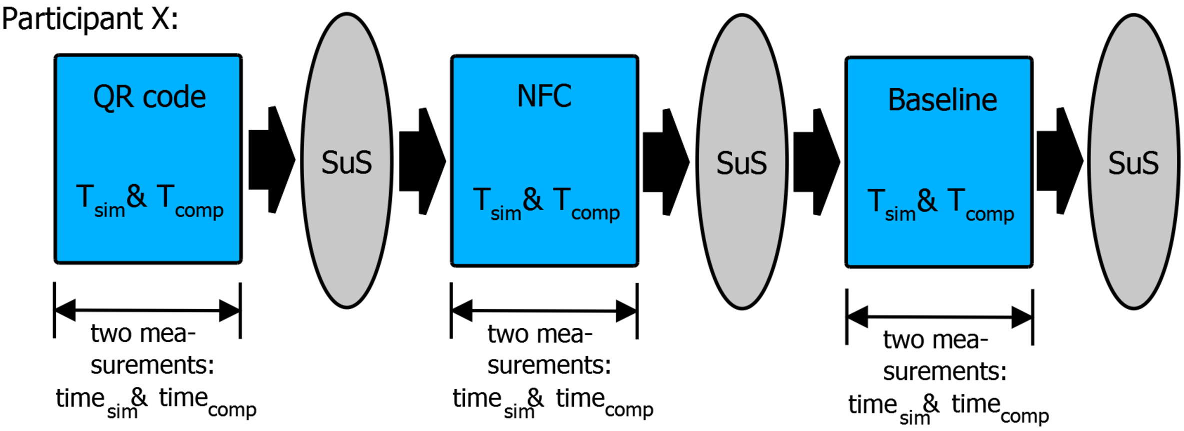


Figure 5.5: The study procedure. The order of the different conditions was changed after each participant. For each condition two iterations were made, one with a simple and one with a complex task sheet.

A	B	C
B	C	A
C	A	B

Figure 5.6: The displayed 3x3 balanced square algorithm was used in order to change the order of the different conditions.

beginning. That means that data was collected two times per condition and six times in total. The reason to conduct two runs per condition was to observe how fast users can adapt to a technology and concept that they never or rarely used before.

On the one hand the direct interaction was started by giving the participant the task sheet and observe the whole process. On the other hand the NFC- and optical-based configuration process required the user to couple the smartphone to the hardware prototype, perform the asked configuration changes and transmit the new state back to the hardware prototype. Thus, the participant initially received the smartphone that led him through the whole process that was designed like a setup wizard known from software installations. At the beginning the hardware prototype was in a standby mode waiting for the user to start the configuration process on his smartphone and perform the asked steps. At the time the participant reached the point that he successfully connected to the hardware prototype, he was given the task sheet that he had to accomplish by utilizing the user interface displayed on the smartphone.

When the user finished the whole process by retransmitting the made changes to the hardware prototype all data logging was stopped.

The following quantitative and qualitative data were collected during the study for each participant.

5.4.1 Quantitative data

For each condition and both task sheets the overall completion time was respectively measured. Thus, six measurements were taken per participant in total. Additionally, it is worth mentioning that timekeeping of important steps during the configuration processes of the NFC- and optical-based conditions was also written down, e.g. after successfully coupling the smartphone with the hardware prototype.

Next to the completion time all observed issues were written down during each configuration process.

Furthermore, each participant had to fill out a System Usability Scale questionnaire for each condition, resulting in three of them per participant.

5.4.2 Qualitative data

Other than the quantitative data, qualitative data was collected in form of a semistructured interview held at the end of the whole study. The participant was asked to express his impressions on the different conditions and which of them he liked the most or disliked and why. More detailed questions were asked evaluating the two different user interfaces and the additional steps required in order to couple the smartphone and the hardware prototype and perform a data transmission.

5.5 Results

This section will give insights about the gained results of the performed study. It is divided into two parts, namely the presentation of the quantitative and the qualitative results. The first one will present the gained insights about the system usability scales filled out by each participant for every tested condition. In addition, the mean completion times of each condition will be discussed. In order to gain some deeper insights on the two more complex procedures of the NFC- and optical-based approaches the mean completion times of each of their phases will be analyzed. Moreover, at the end of the quantitative data analysis the observed issues will be discussed. The second part that presents the qualitative results will talk about the performed semistructured interviews and the impressions the participants made during the study.

5.5.1 Quantitative Results

Two systems were tested in the conducted study of which the developed prototype contained two different approaches utilizing the same user interface. In oder to evaluate the usability, an aspect that is hard to measure in terms of absolute values, a system usability scale (SuS) was performed after each condition. The SuS is a simple and easy questionnaire consisting of ten items asking the participant about their subjective impressions about a specific system after using it. This results in a score that ranges from 0 to 100. That value can be used to compare different systems and their usability. The user has to answer questions based on scales with the range from one to five by indicating his level of agreement for a specific statement, e.g. "I think that I would like to use this system frequently.". This kind of scale is called "Likert scale". Figure 5.7 shows a diagram with the insights gained from the performed SuS questionnaires.

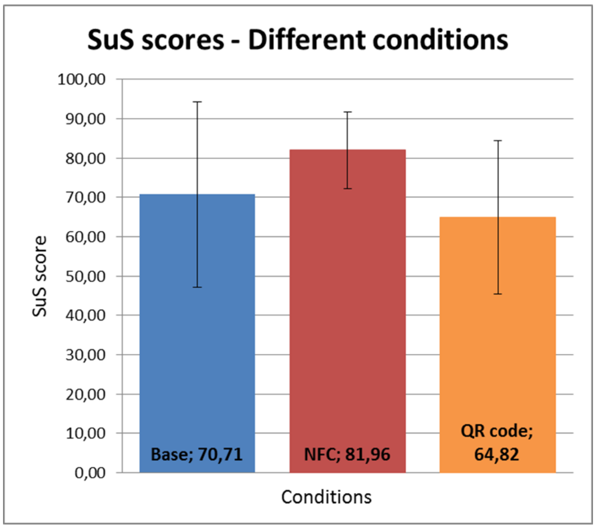


Figure 5.7: Here the mean SuS scores are displayed. Base is the baseline utilizing a direct interaction. Additionally, the standard deviation of each condition is displayed.

From left to right the baseline, NFC and QR code condition's mean value of all SuS scores received from the participant are displayed. They ranged from the minimum of 64,8 scored by the QR code condition to the maximum of nearly 82 in the case of the NFC condition. Additionally, the standard deviations are displayed in order to make a statement about the different impressions made by the participants. In the case of the baseline condition the worst score was 10 and the best score that was reached was 100. In the case of the NFC condition the worst score was 65 and the best score was 100. The QR code condition had it's minimal score of 37,5 and the maximal of 95.

Figure 5.8 displays the mean completion times of each condition measured in seconds in a respective diagram. Six different times were measured during the study due to the fact that each of the three cases involved two iterations, namely one with a simple task sheet and one with a more complex task sheet. Again, from left to right the baseline, NFC and QR code conditions are displayed in three different colors. The completion times ranged from the lowest

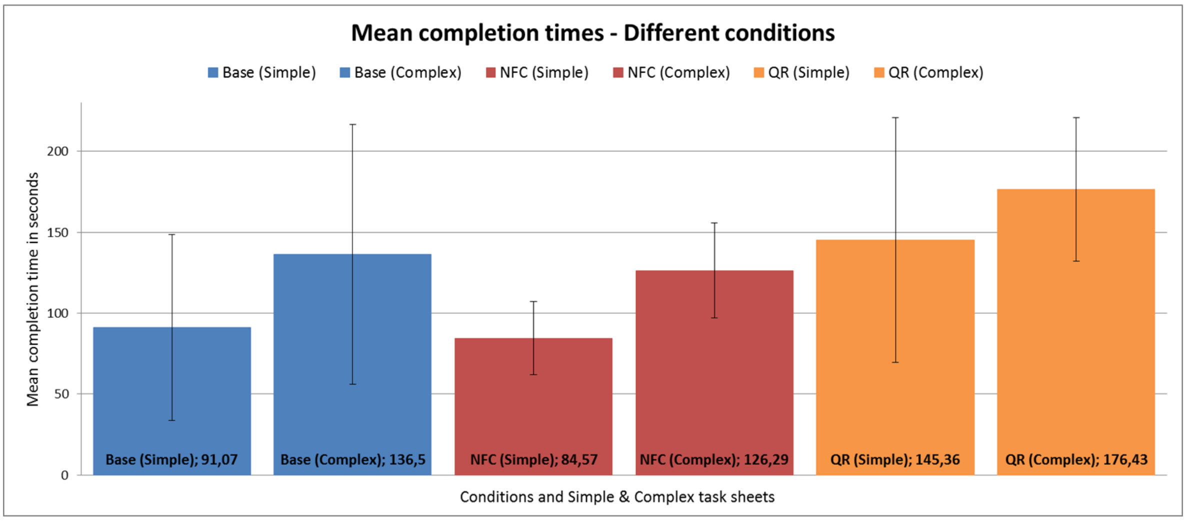


Figure 5.8: A visualization of the mean completion times of each condition. Per condition two iterations were performed, one with a simple and one with a complex task sheet. Additionally the standard deviations are included.

value of 84,6 sec in the case of a simple task sheet performed with the NFC approach, to the highest value of 176,4 sec utilizing a complex task sheet performed with the QR code condition. The worst completion time of 343 seconds was reached with a simple task sheet utilizing the QR code approach. The best time of 28 seconds was measured using a simple task sheet and working with the baseline condition. Once more the standard deviations are included in the diagram in order to give an impression for the differences between the participants. The biggest standard deviation of 80,2 sec was measured during the baseline condition and working with a complex task sheet. The smallest of 22,6 sec resulted from the NFC approach and a simple task sheet.

In order to gain deeper insights on the developed NFC- and QR code-based concepts utilizing the prototype, additional mean completion times were measured for each phase of the two conditions. This was necessary due to the fact that three phases were required in order to perform a configuration on the "smart device", namely ***Phase1****:"Ad-hoc coupling and data transmission between the smartphone and the smart device"*, ***Phase2****:"Actually changing the configuration utilizing the smartphone-based user interface"* and ***Phase3****:"Retransmitting the new configuration back to the smart device"*. The baseline condition involved only one phase, namely performing the configuration by utilizing the direct interaction. Figure 5.9 displays two different graphs, namely one for the NFC condition and one for the QR code condition and their individual mean completion times of each phase and task sheet. This resulted in six measurements per condition.

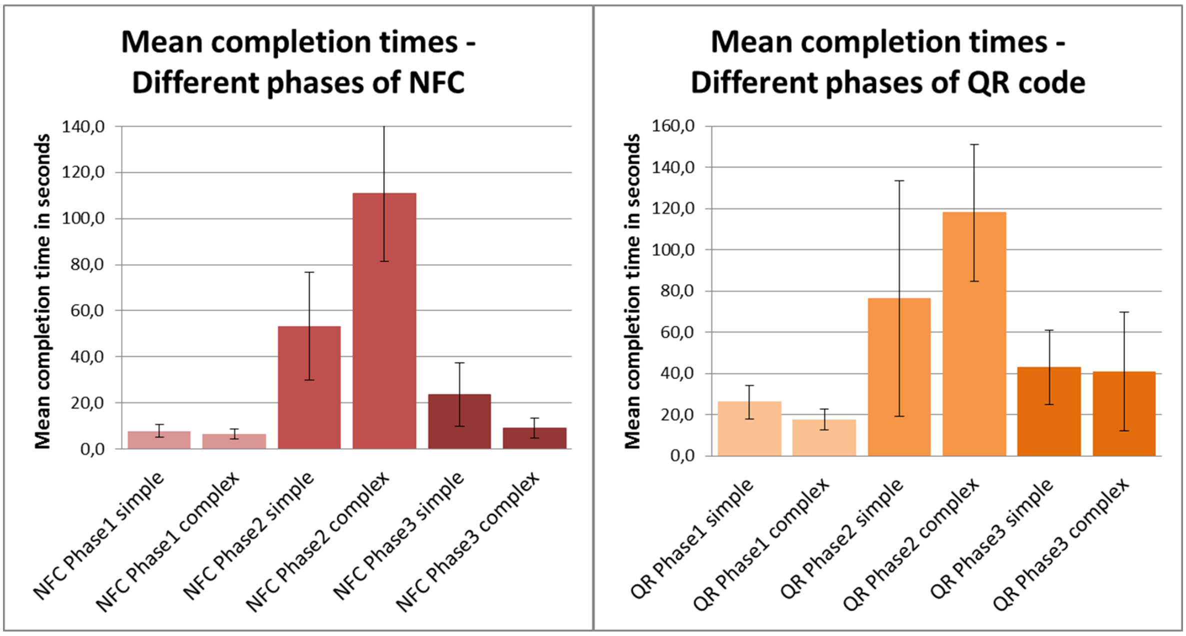


Figure 5.9: In this two diagrams the mean completion times of the NFC and QR code conditions are displayed and broken down into three different phases that were required in order to perform a configuration.

NFC condition

In the case of the NFC condition the phase with the minimal mean completion time of 6,4 seconds was reached during the first phase using a complex task sheet. The longest completion time of approximately 110 seconds was measured during the second phase and with a complex task sheet.

QR code condition

In the case of the QR code approach the phase with the minimal mean completion time was 17,6 seconds and was accomplished during the first phase with a complex task sheet. Other than that the maximal mean completion time of 118 seconds was reached during the second phase solving a complex task sheet.

Next to the mean SuS scores and completion times all occurred issues were also monitored during the whole study. In contrast to the other quantitative measurement no diagram was created for the observed issues, instead the following listing will give an overview.

Firstly, the issues that appeared during the NFC condition will be listed.

Issue 1 Accidentally change another value during scrolling. This issue appeared *6 times* during the *second phase*.

Issue 2 Difficulties with the slider's precision. Users had issues setting a precise value. This issue was monitored *5 times* during the *second phase*.

Issue 3 Wrong parameter changed due to similar naming. This issue was observed *twice* during the *second phase*.

Issue 4 A complete task was left out *once* during the *second phase*.

Issue 5 Interruption of the NFC peer-to-peer connection (Android Beam). This issue was counted *9 times* during the *third phase*.

During the direct interaction the following issues were observed.

Issue 1 *3 times* the participants tried to use touch-functionality on the non-touch screen.

Issue 2 Wrong parameter changed. Users did not realize that they were changing a different parameter than asked *twice*.

Issue 3 Use "OK" button incorrectly. Users left some sub-menus, since they expected another outcome from pressing the "OK" button. This happened *12 times* due to an inconsistent implementation in different menu-trees.

Issue 4 *Twice* users left the expert mode since they pushed the "back button too early". Therefore, they had to navigate back to the specific sub-menu in order to continue with the remaining tasks.

The following issues were monitored during the QR code condition.

Issue 1 Accidentally change another value during scrolling. This issue appeared *8 times* in the *second phase*.

Issue 2 Difficulties with the slider's precision. Users had issues setting a precise value. This issue was monitored *4 times* during the *second phase*.

Issue 3 Wrong parameter changed due to similar naming. This issue was observed *once* during the *second phase*.

Issue 4 A complete task was left out *once* during the *second phase*.

Issue 5 An issue that was observed frequently happened while positioning the smartphone during the *third phase*. In total, it occurred *17 times*.

5.5.2 Qualitative Results

At the beginning of the semistructured interview the participants were asked about what condition they appreciated the most or the least and why. They were able to speak freely and argue about their decisions. In general, most participants preferred the NFC and direct interaction condition. NFC was perceived as an easy and simple approach due to the few steps that were required for the ad-hoc coupling and data transmission phases. In addition, they appreciated the general intuitive way to perform actions. The direct interaction was mostly preferred by participants that belonged to the expert group. Most of them mentioned that they were already familiar with the interaction concept and user interface and appreciated it that no smartphone was required. Other than that, most users agreed that they had major difficulties with the QR code condition due to the scanning of the QR codes that were utilized for ad-hoc coupling and data transmission purposes.

In order to receive some feedback for two specific criteria, further questions were asked after the participants stopped arguing by themselves. The answers given to the question what the users think about the two utilized ad-hoc interaction concepts were as follows. The majority of all participants, independent of their experience level, stated that the NFC-based approach was superior to the QR code condition in many ways. They enjoyed the easiness of the ad-hoc coupling and data transmission phases. They stated that they were able to just hold the smartphone close to the displayed NFC area and in the background everything else worked automatically. Some mentioned that they felt secure performing the required actions due to the given feedback and the possibility to perform changes prior to actually adopting them on the heating system. Most stated that the learning curve was quite steep. Additionally, many claimed that most actions were self-explanatory. As mentioned before, some did not like it to be dependent on a smartphone thus not being able to perform their desired changes without it. The QR code condition was mostly disliked because of the first and third phase, namely the ad-hoc device coupling and the retransmission of the performed changes. That was the case due to the fact that the concept of scanning QR codes was experienced as cumbersome, since many stressful positioning actions had to be performed. Especially the task of letting the hardware prototype scan the QR codes displayed by the smartphone was experienced as challenging. The participants had to flip the smartphone and position it accordingly in front of the implemented camera. Therefore, they had to control the position of the smartphone in a three-dimensional space, thus many controlling operations were required. Additionally, three participants stated that a camera can also pose a privacy risk and a technician stated that in most cases they are working with heating systems in a cellar, therefore in a dark environment, which is unfavorable for an optical approach. Some also disliked the fact that three animated QR codes had to be scanned in the third phase, resulting in a longer waiting time. The direct interaction was mostly perceived as a simple task due to the fact that most people already worked with button-based interactions performed on a complex smart device. In addition some stated that they appreciated it that no smartphone was necessary for the interaction.

The answers concerning the question about the two different system's user interfaces were as follows. The physical user interface based on the direct interaction lead to a secure feeling in several participants. They stated that they know these kind of interfaces and also worked with them in many different occasions. Most of the users complained about the bad visual overview they received during each configuration task due to the small screen and the deep sub-menus. Therefore, they felt lost and did not know where and which parameter they changed. One technician stated that many end customers have similar problems resulting in a complete reset of the device or a call to the service hotline. Mostly, customers are afraid to change a specific parameter and forget about what was modified. Some participants also stated that it was cumbersome to change a specific temperature due to the fact that the plus and minus buttons had to be pushed repeatedly, e.g. change a temperature from 40°C to 90°C. The overall impression on the smartphone-based user interface was that it gave a very clean and broad overview of all parameters and options that are available for adjustment.

For one participant it lead to a lower inhibition threshold due to the fact that he was more aware of what he was currently changing. Several liked the "accordion" concept that grouped different parameters and gave the possibility to close one sub-menu and immediately switch to another. One also stated that he really appreciated the touch-screen. Other than that several participants complained about the slider and the difficulties that occurred during performing precise inputs of temperatures.

5.6 Implications

After all results that were gained from the performed study were presented this section will analyze the involved implications of smartphone-based ad-hoc interaction concepts with smart devices and direct interactions.

5.6.1 Direct interaction/Baseline condition

The mean score of 70,7 of the system usability scale showed that this condition offered a good usability. However it is important to mention that the score was strongly relying on the experience level of the user and the prior made experiences with complex devices offering minimal user interfaces. This implication is undergirded by the fairly big standard deviation

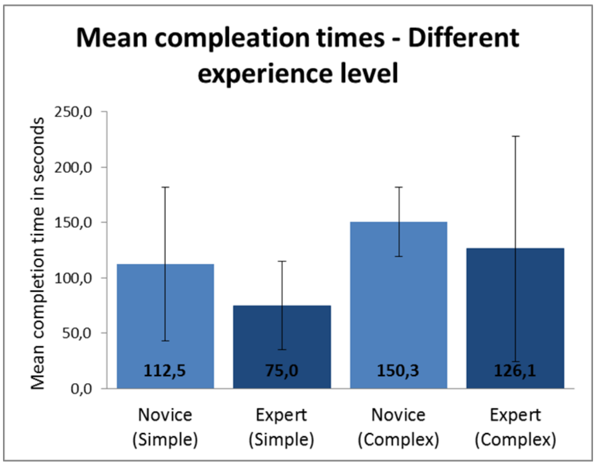


Figure 5.10: This diagram shows the different mean completion times depending on the user's experience level with the UI used for the direct interaction.

of the users' SuS scores and also the very diverse completion times accomplished by them as seen in figure 5.10. This is understandable due to the fact that the input, output and feedback possibilities are strongly limited and the menu structure is very complex due to the complexity of the whole system. Thus, users were mostly fine with finishing simple tasks but struggled with completing complex configuration tasks that also involved a searching process. This can be justified due to the many required button presses that were necessary in order to navigate through deep menu-trees and also the struggle to remember in what level they were currently located. Combined with the two issues 3 and 4, namely using the “OK”- and “Back” button too early or in a wrong way, users needed more time to simply navigate through the menus. In addition it is to mention that the “OK” button shows inconsistent outcomes depending on the current sub-menu. Compared to the other two conditions the direct interaction reached better completion times than the QR code approach but worse compared to the NFC condition, although only one phase instead of three was necessary. The semistructured interviews confirmed the prior made implications that users had mostly difficulties with the very minimal interaction possibilities and feedback modalities. Further implications are that some users preferred the direct interaction due to the fact that they did not rely on a smartphone but still enjoyed the clear user interface offered by a smartphone. Moreover, the younger generation and older users that use their smartphone frequently would consider a smartphone-based approach as a feasible solution.

5.6.2 NFC condition

In the case of this condition it is interesting to mention that only one participant stated that he already used NFC technology although most of them were using chip cards in order to get access to the working facilities. It is worth mentioning since both are based on RFID and NFC. Other than that the NFC condition reached the highest SuS score of nearly 82, although three different phases were necessary for a configuration process. Users appreciated the simple and intuitive way to utilize a smartphone-based ad-hoc interaction concept combined with a smartphone-based user interface. Additionally, the standard deviation was very low (standard deviation = 9,7) implying that most people had a very similar impression. Most stated that nearly all of the necessary steps were hidden and “just worked” by physically touching the marked NFC area on the smart device they wanted to interact with. In addition, this implication was also true for both phases, namely the ad-hoc coupling & initial data transmission as well as the retransmission of the performed changes to the hardware prototype. Here it is important to mention that many participants had issues understanding the “Android Beam” approach during the third phase, namely the authorization of the transmission that had to be performed by the user. It was necessary to touch the smartphone’s screen in order to start the data transmission and most people were unsure of what action was required in that situation. This issue 5 can be overcome by leaving out the authorization step or displaying a better viewable and understandable prompt. Most users had issues to understand the hint given on the screen or simply did not notice it. Although many struggled during the study they never mentioned it as a drawback during the performed interviews. One can argue that two iterations were performed and that the learning effect on how to use the technology was strongly influencing the general impression. The learning effect can be seen in figure 5.9. That means that it only takes an unexperienced user to use a NFC-based ad-hoc interaction concept once in order to learn everything that is necessary. Another implication resulting from the shortest mean completion time, is that a NFC-based ad-hoc interaction combined with a smartphone-based user interface perform better than operating a smart device via the given minimal user interface. This statement is undergirded by the overall lowest standard deviation (standard deviation simple task = 22,6, standard deviation complex task = 29,3) of the different completion times accomplished by the participants. Users generally were able to find parameters very fast even in the case of the complex task sheet involving a searching process. They had a broad overview due to the big and high resolution screen and were able to switch between many different sub-menus in a short period of time. Nevertheless, the smartphone-based user interface lead to the more frequently observed issues 1 and 2. The first one, that users accidentally changed another value during scrolling can be easily overcome by adding an explicit “select” action before a parameter can be changed. The second one, that users had issues configuring a specific value by utilizing the slider can also be easily overcome by adding a plus and minus button next to the slider.

5.6.3 QR code condition

This condition used the same smartphone-based user interface. Therefore, the NFC and QR code condition performed similar during the second phase, namely when the actual configuration had to be performed on the displayed user interface. This can be seen in figure 5.9. The implication is that the worse mean completion times were the result of the other two phases. The first one, when the participant had to scan the QR code displayed by the hardware prototype with his smartphone, still reached reasonable completion times. Whereas the third phase required approximately 25% of the overall mean completion time. This is not acceptable due to the fact that this phase is only required in order to retransmitting the new configuration back to the smart device. This implication can also be undergirded by the statements made during the semistructured interviews. The participants mostly complained about the difficulties they experienced during the third phase, namely positioning the QR codes displayed by the smartphone in front of the hardware prototype’s camera. This issue 5 was observed 17 times and was a result of the multiple degrees of freedom the participants had to keep under control. Additionally, one can pose the assumption that the worst SuS score of approximately 65 is owed to the third phase. Other than that, the QR code condition also revealed a strong learning effect during the first phase. Most participants needed only half of the time to scan the displayed QR code with their smartphone during the second iteration. This learning effect did not occur during the third phase which is understandable due to the bad feedback and performance owed to the lower camera resolution and processing power offered by the hardware prototype.

6 Discussion

This final chapter will summarize the motivation behind the presented work. Furthermore, we will discuss the consequences that can be stated observing our gained insights by utilizing the developed prototype for the performed study. Additionally, the limitations will be mentioned that set the boundaries for the presented concepts and desired goals.

6.1 Discussion

During the process of this master thesis many discussions were conducted with family members, close friends and working colleagues. They were asked about their daily usage of smart devices that are seamlessly integrated into their daily life. At first, many struggled at finding examples for spontaneous interactions with smart devices they came in contact with. However, after several minutes most could list at least three occurrences of interactions and many enumerated up to five or even more very complex devices they used on a daily basis. Mostly, the day starts by using a coffee machine that, in the case of a fully automated coffee machine, offers a mere endless number of features. Other additionally listed smart devices were smart watches, fitness trackers, smartphones, tablets, personal computers, infotainment systems in the car, washing machines, kitchen equipment in general, heating systems for homes, ticket machines, some alarm clocks, public displays, generally machines at work, ATMs, card-reader units used for payments, etc. After listing some devices, most people started to realize the enormous amount of smart devices that we are surround by during our everyday life. After this realization the question was asked, how they appreciated the interaction with these devices. Alongside many positive feedbacks most people started to complain about a huge amount of user interfaces and interaction approaches. This understanding makes the importance of research conducted in the area of ad-hoc interaction concepts obvious. Especially, if one takes into account that the number of actually smart devices with complex features will significantly increase in the next years and decades.

Coming back to the focus of this master thesis, namely smartphone-based ad-hoc interaction concepts, the opportunities are apparent. Users mostly carry their smartphones with them as found out by Dey et al. [DWF+11] and they offer an enormous amount of possibilities in order to enable a pleasant and enjoyable interaction with other smart devices. Most of us are also used to the interfaces created for smartphones, thus are feeling save and secure by operating them. Therefore one can say that user interfaces realized on smartphones are without a doubt superior to most smart device's interfaces by nearly all means. This statement can be undegirded by the insights gained during our performed study. Most participants had no issues using the presented user interface implemented on a smartphone, although the developed prototype was by far not ready to be a final product. Additionally it is to mention that no real designer was involved into the creation of the presented smartphone-based user interface. Furthermore, the time limitations of a master thesis made it not possible to realize a perfect solution without imperfections. Improvements could include hints on specific configuration possibilities informing and maybe warning the user about possible effects and harmful consequences, displaying the old value and the currently changed value, etc.

In order to enable a smartphones-based interaction possibility for smart devices the second big topic addressed in this master thesis had to be evaluated, namely ad-hoc device coupling concepts. These concepts are necessary in order to enable a communication between a smartphone and smart device. The presented research was based on a purely NFC and QR code concept. Both were chosen in order to enable a direct physical interaction that uses intuitive and very well known concepts. The study results showed that a NFC approach was superior in terms of intuitiveness, likability and the additional concepts an user would have to learn before utilizing it. Most participants of the conducted study have stated that they would appreciate this concept without any second thoughts. Moreover, it offers a basic security aspect without the need of utilizing a prior shared secret due to its physical properties of only working in a very close proximity. Additionally, the overall mean completion times of a smartphone- and NFC-based ad-hoc interaction showed that users required less time to complete simple everyday tasks as well as very complex ones without even knowing the actual user interface. The implication is that it is definitely a feasible solution in order to interact with smart devices of every kind in an ad-hoc manner.

Next to the tested concepts the evaluated baseline, namely a direct interaction with the minimal user interface offered by a heating system, showed that users still appreciate the concept of not being reliant on an additional device like a smartphone. The participants performed quite well in terms of completion times and issues and felt secure utilizing the direct interaction. Here it is important to mention that the deviations between different users were strongly noticeable and the performance of interactions was strongly dependent on the prior experiences with the actual user interface as seen in figure 5.10. That implication can be extended to interactions with all different kinds of user interfaces offered by various smart devices. Here it gets obvious that for a truly ubiquitous environment a direct interaction would not meet the expectations.

6.2 Limitations

The conducted theoretical and practical evaluation of smartphone-based ad-hoc interaction concepts with smart devices revealed some limitations that will be discussed in the following part.

6.2.1 Smartphone-based ad-hoc interaction concepts

Speaking of the two tested ad-hoc interaction concepts between a smartphone and a smart device one can say that the one based on QR codes revealed most limitations during our evaluation. For this approach to work a camera and screen are required. The screen element could be a problem for the real world due to the fact that not every smart device offers one. That is especially true for displays with better quality, which would be required for a fast and reliable interaction experience. Additionally, many users would be afraid of the fact that every piece of technology implements a camera that can pose a privacy risk. The cameras are also relying on the surrounding light conditions and therefore pose a risk to the robustness of the whole concept. Thus, too many essential factors are speaking against this approach. Another limitation that is true for both approaches is the necessity of a smartphone. Not every person has a smartphone, thus a minimal user interface would still be necessary in order to enable an interaction that is feasible for every customer. Despite that the NFC-based approach would still be possible if only a NFC module would be implemented in every smart device. The result would be that the usability could be significantly increased by offering an additional, more powerful user interface implemented on a smartphone.

6.2.2 Smartphone-based user interfaces

Naming limitations for a smartphone-based user interface is quite difficult, since the performed evaluation showed exclusively positive results. Here the same problem could be named that an additional device would be necessary in order to interact with a smart device. However, this issue will get less important in the future due to the fact that most users probably will be in possession of a smartphone. Other than that a hybrid user interface is imaginable divided onto the smart device and the smartphone. The direct interaction could be utilized in oder to enable simple and more frequent tasks and the more powerful smartphone-based user interface could be utilized for more complex and cumbersome tasks. In detail, the smart device's user interface should be kept as simple as possible with only one or maximal two levels of the menu. In contrast the smartphone-based user interface could exploit all input, output and feedback optionalities. Performing of complex configurations and handling of errors could for example be supported by meaningful prompts containing information gained from the internal storage or maybe also from the Internet.

7 Conclusions

In this thesis two smartphone-based ad-hoc interaction concepts with smart devices were introduced in order to evaluate the possibilities of utilizing smartphones to interact with various devices in an ubiquitous environment. The three evaluated approaches were the direct interaction realized on a heating system's physical minimal user interface, an approach using a NFC-based coupling and data transmission procedure and a smartphone-based user interface and a similar one only utilizing QR codes for the device coupling and data transmission. The results of the performed study showed that a NFC-based ad-hoc coupling and data transmission approach paired with a smartphone-based user interface were superior to a direct interaction on a smart device's minimal user interface. The mentioned approach performed better in terms of completion times during simple and complex configuration tasks and the perceived usability and likability. Our second approach based on QR codes had several issues concerning the usability, therefore performed worse than the other two tested conditions in every aspect. The conclusion is that the introduced NFC-based approach is a feasible concept that could simplify interactions with smart devices by utilizing intuitive, secure, fast and easy to understand interaction techniques and concepts.

7.1 Future Work

Having proven that one of the suggested concepts can be used in reality one can state that the idea of ad-hoc interactions and user interfaces based on smartphones can lead to an easier way to interact with various different smart devices offering minimal user interfaces. Currently, one of the biggest problems is the fact that each and every device presents a completely diverse user interface, leading to cumbersome interactions and long learning phases. Many people struggle in finding the same functionality on different devices due to various menu structures and designs. This leads to frustration and insecurities therefore many tend to simply not use the given interfaces. In many different researches the idea of smart devices was proposed, that simply store an user interface internally in a meta-form. In the event of an user approaching and trying to interact with it, the necessary information can be transferred to the smartphone and the actual user interface can be created dynamically with respect to current design standards. This idea strives for consistency which is currently a big issue with different smart devices and their presented user interfaces. That said, the consequence is that a smartphone-based approach using a very simple ad-hoc device coupling concept and an usable user interface is one of the favored approaches that would lead to an ubiquitous computing environment that does not end in frustration and confusion of the users.

8 Appendix

1. Consent form
2. Study Pre-Questionnaire
3. Introduction (German)
4. System Usability Scale (German)
5. Semistructured interview guide & Task sheets (German)

University of Stuttgart
Germany

Human Computer Interaction Group (MCI), VIS
Prof. Dr. Albrecht Schmidt

Consent Form

DESCRIPTION: You are invited to participate in **a research study** about: **"Exploration of Smartphone-Based Interaction Methods with Smart Devices**". The study explores two new ad-hoc interaction concepts, used to configure a heating system, namely an optical and NFC-based approach.

TIME INVOLVEMENT: Your participation will take approximately **60 minutes**.

DATA COLLECTION: For this study, we will collect your demographic information using this form. During the study, you will continuously be observed and written notes will be taken for made errors and the needed completion time. Additionally you will be asked about your own impressions and feelings that you can recall from your memory after finishing each task.

RISKS AND BENEFITS: There are no known risks associated with this study. We guarantee that the privacy of your information is completely preserved throughout the study process. Benefits include experiencing state-of-the-art technology.

PARTICIPANT'S RIGHTS: If you have read this form and have decided to participate in this project, please understand your **participation is voluntary** and you have the **right to withdraw your consent or discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled**. **The alternative is not to participate.** You have the right to refuse to answer particular questions. The results of this research study may be presented at scientific or professional meetings or published in scientific journals. Your identity is not disclosed unless we directly inform and ask for your permission.

CONTACT INFORMATION: If you have any questions, concerns or complaints about this research, its procedures, risks and benefits, contact the following person:

Dennis Root, Researcher (dero1@hotmail.de)

University of Stuttgart
Germany

Human Computer Interaction Group (MCI), VIS
Prof. Dr. Albrecht Schmidt

APPARATUS: We will hand you a smartphone and present you with a hardware prototype that is standing for a heating system. Both devices are used only for the particular session and are utilized to enable an ad-hoc configuration of the heating system with a smartphone.

Consent to participate in the research study

- ☐ I have read and understood the information sheet.
- ☐ I understand the purpose of this study and agree to participate.
- ☐ I understand that I may terminate my participation in the study at any time .

By signing this document, I confirm that I agree to the terms and conditions.

Name: _________________________ *Signature, Date:* _________________________

University of Stuttgart
Germany

Human Computer Interaction Group (MCI), VIS
Prof. Dr. Albrecht Schmidt

Study Pre-Questionnaire

A. Demography

Gender: ☐ male ☐ female ☐ other

Age: _____________

Profession / Course of studies: ___________________________________

B. Technology experience

What is your experience level with configuring heating systems?

☐ Novice ☐ Expert/Technician

Have you already had experiences with QR codes?

☐ yes ☐ no

Mention examples please:

____

____

Have you already had experiences with NFC technology?

☐ yes ☐ no

Mention examples please:

____

____

For what purposes do you use your smartphone?

☐ Voice and message services ☐ Internet/Browsing ☐ Various applications

☐ Controlling other devices (e.g. remote control)

Einleitung - Studie

Worum es geht:

- Hardwareprototyp → Heizung UND Smartphone → wird zur Konfiguration verwendet
- Zwei neue Ad-hoc Interaktion sollen getestet werden→Vgl. mit direkter Interaktion

Ablauf:

- Zustimmungserklärung
- Fragebogen zu Person
- Studie
    - Drei Durchläufe jeweils Aufgaben und System Usability Scale am Ende
- Offenes Gespräch mit Eindrücken

Anmerkungen:

- Baseline: Button-Kombination für tiefes Menu am Baseline Interface
- Prototyp: Knopf einmal drücken lassen
- Prototype: NFC Bereich zeigen → Handy einfach dranhalten
- Prototyp: Wo ist Kamera
- Baseline & Prototyp: Nicht über Sinnhaftigkeit der Einstellungen nachdenken
- Baseline & Prototyp: Nichts kann crashen→einfach probieren

Fragebogen zur System-Gebrauchstauglichkeit

1. Ich denke, dass ich das System gerne häufig benutzen würde.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

2. Ich fand das System unnötig komplex.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

3. Ich fand das System einfach zu benutzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

4. Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

5. Ich fand, die verschiedenen Funktionen in diesem System waren gut integriert.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

6. Ich denke, das System enthielt zu viele Inkonsistenzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

7. Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit diesem System sehr schnell lernen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

8. Ich fand das System sehr umständlich zu nutzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

9. Ich fühlte mich bei der Benutzung des Systems sehr sicher.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

10. Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

Semistrukturierter Interviewleitfaden

1. Welches System hat Ihnen am meisten/wenigsten gefallen? → warum/warum nicht?

2. Wie hat Ihnen explizit die Interaktion des NFC und QR-Code Falls gefallen?
   a. Kompliziert?
   b. Einfach?
   c. Schnell/langsam?

3. Wie haben Ihnen die jeweiligen Benutzeroberflächen gefallen?
   a. Einstellungen finden
   b. Verwendete Elemente
   c. Usability allgemein

Aufgabenblatt A _1

1. Aktivieren/Deaktivieren Sie bitte die Heizung.
2. Stellen Sie bitte die Solltemperatur auf XX °C ein.

Aufgabenblatt B _1

1. Stellen Sie bitte die maximale Heizleistung auf XX % ein.
2. Stellen Sie bitte den Wert des Pumpenkennfelds auf „Delta-P geführt XX“ ein.
3. Aktivieren/Deaktivieren Sie die Thermendesinfektion bitte jetzt.

Aufgabenblatt A _2

1. Stellen Sie bitte den Warmwasser/-Heizungsmodus von „Komfort/Eco“ auf „Komfort/Eco“ Modus um.
2. Stellen Sie bitte die Notbetrieb Solltemperatur auf XX °C ein.

Aufgabenblatt B _2

1. Wählen Sie bitte bei der Einstellung „hydraulische Weiche“ die Option „ XX “ aus.
2. Stellen Sie bitte die maximale Warmwasserleistung auf XX % ein.
3. Wählen Sie bitte bei der Einstellung „Pumpe an PW2“ die Option „ XX “ aus.

Aufgabenblatt A _3

1. Aktivieren/Deaktivieren Sie bitte das Warmwasser.
2. Stellen Sie bitte die maximale Vorlauftemperatur auf XX °C ein.

Aufgabenblatt B _3

1. Stellen Sie bitte den Pumpennachlauf auf XX Minuten ein.
2. Stellen Sie bitte die Taktsperren-Zeit auf XX Minuten ein.
3. Wählen Sie bitte bei der Einstellung „Pumpe Kessel“ die Option „ XX “ aus.

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Decleration

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

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