Prototyping and Evaluation of an Interactive DoorSign

Aufbau und Evaluierung eines interaktiven Türschildes

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Diploma Thesis

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Abstract

Optimized usage of rooms at university becomes more and more important with a growing number of students. As a student today it is close to impossible to reserve a room for learning. Of course there are rooms known to be available at a certain time, but these can not be booked by students so there is the possibility that you and your learning group will compete with some noisy group of other students who occupied the room as well. To improve that situation the Interactive DoorSign, a prototype developed to manage rooms through an Android tablet attached next to them, was put into beta testing. There are existing projects on the topic which were reviewed in chapter 2. The improvements on the existing concept and development required to put the prototype into testing are described as well, especially the casing that was assembled using rapid prototyping technology is unusual. Details of the security implications, the possible attack vectors on the system and the concerns about the privacy of the users are discussed in chapter 3. The evaluation of the prototype can be found in chapter 4 and 6. The methodology of the evaluation is described. The results show that while the prototype implementation receives a low value on the System Usability Scale (SUS) every user was able to complete the given tasks and was able to learn the interaction with the system quickly.

Zusammenfassung

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Chapter 1.

Introduction

Recent years have seen a rapidly growing demand for smartphone-controlled light bulbs and door locks [1]. Android®@home can be the technology that makes home automation systems available to a whole generation of users. Android, being the most widely used smartphone operating system, interfacing with Arduino, a usable embedded systems platform, makes it possible to develop these control systems rapidly and adapt them easily to the given use case. In case of this thesis the use case is the room control and administration of a seminar room at Technische Universität München (TUM). The question might arise why a university lectures do require the physical presence of students at all. Projects like coursera\(^1\), unterrichtsmitschau\(^2\) or the open university\(^3\) show that teaching itself is possible without large halls, and single courses can have infinite participants. Infinite in theory of course, correcting exercises and exams is still a workload that does not scale as easily as web servers and requires qualified personnel. So, what are the reasons for us to move our physical bodies into that central place through real world transportation, just to acquire information? At this central place there are labs, computers and other machines students are allowed to access if they relate to their work at university. Persons needed to be met to organize the proceeding or discuss work. To paraphrase this, there are shared resources a multitude of interested parties wants to access. But coming back to Android®@Home, how can this technology be used to improve usage of resources at a university? Most of these resources are behind doors. That is why the need for a system to access these doors easily, without the need of complex administration of physical keys, becomes visible clearly. This leads us to an the Interactive DoorSign which should be deployed and and evaluated by user tests. Why is a door sign next to a room needed instead of an mere online representation of the room? The benefit here is that the interested audience can find room related information at its natural place, next to the room. There is no need to find out which room belongs to which institute, who is responsible for it. If one knows where the room is, one can always find out if and when it is available or occupied, by whom and maybe interact further with the system to leave messages and

\(^1\)coursera, https://www.coursera.org/, accessed on 12.3.2013
\(^2\)LMU video online, http://videoonline.edu.lmu.de/, accessed on 12.3.2013
\(^3\)open university, http://www.open.edu/openlearn/, accessed on 12.3.2013
access the room. As the institution providing this system would not have to worry about users bringing their own hardware to be online, which can ease further development and help making the system as accessible as possible. Some methods of authentication might require users to rely on additional hardware though. There are security concerns related to a fully aware ubiquitous computing system [2] but the possible benefits outweigh the security concerns.

This thesis presents the development of the prototype which was the first step required to put the system into beta testing. The prototype was developed with special consideration of accessibility and rapid prototyping in mind. The details are described in chapter 2. The rest of the thesis is organized as follows. Chapter 3 looks at the implications for security that occur when dealing with a computer system that can open real world doors. As chapter 4 outlines, the main goal of this project was to increase the usability of the existing system and put it through a test with potential users. The need to find out where issues or further potential in everyday use can be found was addressed as well as the evaluation of the existing room reservation backend. Chapter 5 describes the methodology used to conduct the user study. Chapter 6 presents the analysis of the results and finally, Chapter 7 contains the conclusion and view on possible further development.
Chapter 2.

Development

This chapter describes the stages of development. Referring to the previous prototype [3] the improvements of the new prototype tested in a real world context are highlighted. To mention the requirements shortly, we want an Interactive DoorSign that enables the user to book rooms, evaluate lectures and unlock the door. A more detailed description of the requirements that were followed can be found in subsection 2.4.1.

2.1. Related Work

Ambient Displays have been the subject of interest for more than a decade [4]. Today they are common at fairs, train stations and other public spaces. Although they are mostly used for advertising or information display (unidirectional communication) with increased availability and increased acceptance of touch interfaces the opportunity presents itself to use those displays for bidirectional communication as well. What are the use cases expected from an Interactive DoorSign? An ambient display next to an office door can inform the passerby whether the room is occupied or not, in addition it can even give details like contact numbers or email. An interactive display can enable the passerby to leave a message directly on the display without thinking about how to write an email. Similar to the Prototypes discussing the social aspects of a public interactive display [5] the owner of the room should have the possibility to update his content on the board to inform about absence, new lectures or sudden changes in the schedule (for example lecture in room x moved to room y). That is the first glimpse on the difficulty of properly authenticating the user on an interface in public space. Taking the described use cases under consideration, if the office is located in a public area where a lot of people walk by there can potentially be a lot of messages. This can lead to a significant administration overhead, quite possibly spam. If the user is asked to authenticate himself the barrier to leave a message is higher then if he can leave messages anonymously, so the probability of unnecessary messages is likely to be lower. This initial interaction, the user seeing the display, maybe checking some of the information on it or leaving a message, can be seen as welcoming the user [6]. While these tests show that the way a door
behaves towards the user results in a feeling of being welcome it is obvious that the interaction with a closed door without the ability to open it is unpleasant. The Interactive DoorSign therefor has a role as a virtual outer office, that is a place a passerby can interact with until he achieves closure. He achieves closure because he obtained the information he was looking for, because he informed the system about his presence or because he authenticated himself and entered the room.

2.1.1. Android@Home

With Android@Home new research questions appear. The wide spread of the Android operating system in combination with the ease of use of the Arduino platform enable researchers to rapidly develop prototypes of ubiquitous computing systems that solve or at least simplify everyday tasks. These systems relate to the Interactive DoorSign in in various ways, partially solving issues that occurred in the development of the prototype as well as partially showcasing or exploring interactions that are likely to occur.

One of the first papers that was found was the implementation of an android based intercom[7]. The android based intercom enables the user to ring at the door, leave a message and authenticate himself to open it. The similarity of use cases is evident. An intercom system handles a similar scenario as the Interactive DoorSign. The possibility of leaving messages in case of absence is important for both, unlocking the door as well. While being a powerful platform for systems requiring real-time behavior android is not designed primarily for that purpose, therefor the effort required to implement such functionalities will be significant [8]. The requirement for a real-time system that handles room administration is achieved through the replacement of JQuery based web application with a native android app and is discussed in [8]. Several studies have been done on Android@Home [1, 9–11]. Most of these tutorials focus on a proof on concept and show basic interaction, for example turning a light on and off through a web interface. None of them provides solutions for multi user interaction with an Android device, secure authentication or acceptance by the user. They proof to be a valuable entry point into development but don’t necessarily provide viable solutions because the requirements in a professional scenario extend those in a experimental or at home scenario far.

2.1.2. Secure Authentication

The importance and the challenges of secure authentication on a mobile device is discussed by several researchers [12–14]. Few of those papers focus on the multi user usage of such a device [15]. The possibility and amount of use cases of a Radio-frequency identification (RFID) based indoor tracking system is emphasized in [16]. The approach, that basic movements like approaching the door or lifting the RFID tag up in front of the door to open it, can result in a variety of
reactions from the user. These reactions are not yet known but the possible alienation of users getting recognized, while others are not, by means not obvious increase the need for tests of user acceptance. The question for secure authentication on a device like the Interactive DoorSign leads to a compromise between simplicity and security. A simple approach would be using a RFID tag on the student identity card and a similar employee card to grant the carrier of the card rights to open certain doors. The flaw of this idea is the possibility to copy the cards and obtain access that is not intended to the copy. A more secure approach would be to use a combination of RFID and personal password. This makes it harder for an attacker, but if users have to enter a password every time they want to open a door, with the chance of typing it wrongly and the duration of the process acceptance will decrease. The number of attack vectors on the system is increased by placing the device in the public space. An attacker can easily use the method of shoulder surfing and implementing password input other then regular keyboard input can result in the necessity of training before similarly short input times are achieved [17, 18]. For example users could be required to paint the glyph for their course on the screen or select the correct thumbnail corresponding to their profile ID. While this concept can decrease input times of the passwords the acceptance of a system the user has to learn can be lower than for one that behaves like the user expects. The approach favored in this thesis therefor goes in the direction of a combination of QR Codes and Near Field Communication (NFC). There is work done on the field of secure authentication via NFC [19] but there was no neutral data available on the security of such systems. Work like the MIFARE attack suggests that the use of NFC as single method of authentication is a doubtful practice [20, 21].

There are, however, aspects of the application that lead to a whole new set of attack vectors. For example, the possibility is shown to relay the signal from the Radio Keys through the web for further analysis [22]. This will be discussed further in the chapter 3. The need for more then one channel of authentication is shown by projects presented in 2.2.1.

2.1.3. Webbased Apps

In 2006 Athabasca university introduced a mobile version of their library website with the goal to enable students using library services anywhere anytime [23]. Since then, available hardware became more powerful but some of the challenges remain. The project had found some other interested researchers with similar approaches [24], the core idea remaining the similar. How can we create a mobile version of a university web page, that makes full use of the fact that the user is accessing the information from his smartphone or Personal Digital Assistant (PDA). The challenges mentioned in these papers show that the main difficulty of implementing such sites is not the backend part but in the wide variety of devices looking at the frontend. While a screen design for an iPhone might work fine on an Android device, it won’t be displayed easily on a PalmPilot. When the user interaction is largely based on Javascript there is no guarantee that
older hardware and Javascript engines can display the same page as quickly and fluidly as modern browsers. These considerations led to the conclusion to develop an Application Programming Interface (API) rather than a web interface. Once the API exists web based clients can interact with it as well as native applications. Further evaluation can show which receive higher acceptance.

2.2. Related Projects

Community workshops, like fablabs provide solutions for a similar problem with shared resources that need to be accessed by a variety of members. A fablab is open high-tech workshop [25] that enables amateur users to access high tech machinery.

2.2.1. Fablab Munich doorlock

Hackerspaces like the Fablab Munich\(^2\) are confronted with a similar problem regarding shared resources. There are several active people in a Fablab that need to have access to the ressource, for example the room or machinery. It is important to know who had access in case something breaks, it should be relatively secure and it should have no single component that can be stolen and compromise the system. The solution existing here was developed by Riccardo Giordani. The prototype consists of an old nokia mobile phone, an arduino, some electronic components and the motor that unlocks the door. If a user calls the mobile and his number is registered there he has his individual ring tone. This ring tone is transmitted to the arduino through audio (not hearable from the outside). The arduino expects now a morse code input via the door bell. If the morse code is entered correctly the door will open. While just solving the problem of opening the door to authenticated persons this prototype does it in a very cost efficient and relatively secure way. Even if you loose your authenticated phone and have an entry in your address book the finder still needs to know your personal morse code to open the door. Even if he learns your morse code by watching you when you enter it it is not trivial to emulate your phone number while calling the phone. Amongst other merits this system is a current implementation that uses morse code and in that way teaches its users aspects of technical communication protocols older then the TCP/IP Stack. The fact that an old mobile phone get recycled by building this kind of lock is a interesting aspect of this lock. If there are useful applications that can be built with upcycled phones that can solve part of the question about electronic waste disposal [26]. A big flaw of the System is the fact that not all old mobile phones can be administered remotely. Future work might aim to develop a system based on gnokii\(^3\) to administer these phones. The states of this door lock can

\(^1\)hackerspaces, http://hackerspaces.org/wiki/, accessed on 15.03.2013
\(^2\)fablab munich, http://www.fablab-muenchen.de/, accessed on 8.03.2013
\(^3\)gnokii open source tools for your mobile phone http://gnokii.org/ accessed on 12.3.2013
be found in Figure 2.1. The diagram shows that only after the user called and entered his morse code correctly the door will open.

Figure 2.1.: The states of the Fablab doorlock, UML by Robert Meisenecker, prototype by Riccardo Giordani
2.2.2. Fonera Routers as doorlocks

Another idea from the sphere of hackerspaces is using a cheap router hardware that runs some unix to authenticate the user and enable him to run a script on the router that unlocks the door. A good example for that approach is the Fonera hardware\(^4\) running on OpenWrt\(^5\). In order to have a secure authentication the user has to carry a device capable of Wireless Fidelity (WiFi) and Secure Shell (SSH). The logon to the device happens via SSH, once logged on the user can use terminal commands to open the door. This method can be perceived as not user friendly but it works reliably. The biggest advantage of this system is the price of the hardware. Fonera routers are available around 15€ and provide a reasonably secure system for unlocking the door. The user experience is great for an experienced user who is familiar with a command line interface but most likely will not be accepted by a target group that is used to input through graphical user interface (GUI). This example implementation illustrates that for a technical experienced user group there might be solutions for the unlocking that do not require relatively costly hardware, in terms of energy consumption and complexity of development.

\(^4\)Fon, manufacturer of fonera routers, [http://www.fon.com/de](http://www.fon.com/de), accessed on 4.3.2013
\(^5\)OpenWrt, unix operating system for embedded systems, [https://openwrt.org/](https://openwrt.org/), accessed on 4.3.2013

Figure 2.2.: Opened fonera FON2100 router, running OpenWrt and attached board for control of a door lock.
2.3. Existing Solutions

There are only few existing solutions for door signs that enable user interaction, but some scientific projects that use a door sign to demonstrate ubiquitous computing use cases.

- Interactive and Networked digital Doorsign from ETH Zürich\(^6\) that focuses on the display of room related information and uses real data from the university room management system.

- Hermes project from Lancaster University that differentiates in detail between door signs in different scenarios \(^27\).

- Interactive Doorsign project from NTNU Trondheim that shows how to implement an Interactive Doorsign as part of the common SCRUM development process \(^28\).

The Interactive DoorSign in this thesis aims to evaluate the everyday use of such a system.

2.4. Design of the Prototype

There are different solutions how to mount a tablet sized device on a wall. Most of them do not address the issue of accessibility. The problem is, that average sized people (1.81m according to \(^29\)) find themselves rarely confronted with, such a device on a wall put up in a way that it is best readable for most it won’t be readable for little persons like children or wheelchair users. Furthermore, the prototype should enable a certain kind of user interaction (the user touching the screen) while it forbids other interactions (usage of home button, turn off, change volume). The issue was resolved by designing a new wall mount and using rapid prototyping technology (laser cutter + 3d printer) to manufacture the required parts. To design the enclosure for the device OpenSCAD\(^7\) was used to define a parametric 3d model of the wall mount enclosing the tablet.

2.4.1. Requirements

The requirements listed here concern both software and hardware of the prototype.

- Walk through a set of use cases. The prototype can showcase some typical use cases without any manual assistance or Wizard of Oz setup. Everything should be working similar to a final product, fully automated and with realistic data.

- Mounting on the wall. This is required to collect feedback from colleagues, students and maybe administration. It can also be useful to see how it would withstand the usage by

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passerby’s.

- **Automated manufacturing** The existing wall mount was crafted in a way that did not allow automated production.

Following these requirements lead to the design and construction of the prototype.

### 2.4.2. 3D-printed parts

To model the wall mount I subtracted the size of the tablet from a cuboid large enough to contain the tablet and an aluminum rod making the angle adjustable. The print itself was done on an Ultimaker\(^8\) using Polylactic acid (PLA). The reason to use PLA in this context is that the base of the parts to be printed is fairly large (225mm x 180mm). When printing objects with a large base an effect called warping occurs [30]. This effect relates to the temperature difference during the print. Using a material with as little temperature difference as possible the effect is significantly reduced (PLA is printed best around 210°C, compared to Acrylonitrile butadiene styrene (ABS) which is printed around 240°C). Also using a build platform that sticks well to the PLA helps a lot to avoid warping even with objects that have a footprint of that size. Warping is an effect that occurs especially during the process of fused deposition modeling (FDM), an additive manufacturing process open source 3D printers like the Ultimaker are based on. It describes the contraction of the material on the build platform undergoes while cooling down. This leads to several bugs when either the nozzle pushed the raised corner of the object or the object loses grip from the build platform. The source of the printed parts can be found in ??.

Figure 2.3.: Left: view of the 3D printed parts in OpenSCAD, Right: wall mount in the real world test setup next to a door

2.4.3. Laser Cut parts

To connect the printed parts and fully enclose the tablet, laser cut acrylic glass plates of 3mm thickness were used. The parts were connected with self-cutting screws that get good grip in the printed parts. The connectors to the wall were laser cut out of medium-density fiberboard (MDF) and glued together. While 3D-printing these parts would be theoretically possible laser cutting them is faster. Studies from Hasso-Plattner Institute also show the advantages of using laser cut objects instead of additive manufacturing (3D-printing) [31]. The advantage is that the required time to manufacture a needed part is reduced. There is less time for the machine to fail, during the 17h needed to print one part of the enclosure on an Ultimaker there are plenty of reasons for the machine to fail due to a tiny mechanical bug. The laser cutter takes approximately 5 minutes to cut one plate, it is more precise and there is less maintenance per operating hour required. The time for one iteration in the development of a fitting enclosure is significantly shorter then on a 3D-printer. The parts drawn in OpenSCAD were most sufficient overall because of existing code that was reused from the modeling of the 3D parts but basically any 2D vector graphics software can be used. 3D models can be translated into laser cut layers easily using the projection function built into OpenSCAD\(^9\).

2.5. Backend

The requirement for the backend was that it should contain the events taking place in the room, it should enable the user to create new events and book the room in the future. Leaving messages was another requirement, addressing the need of evaluation in case of a seminar room and the need of notifying about absence in case of an office.

2.5.1. Django as Framework

The existing backend from [3] was written in Java to run on a Tomcat server. Asking Programmers about which language is best to use for a certain problem can easily result in kind of an intense discussion without result. This is best explained by the identification with what the backend is required to do. So a Java programmer will try to use Java for every project, a PHP programmer will try to use PHP. Previous projects showed that the use of a Java Tomcat Server can be a big bottleneck. Not only the Codebase is huge but also Tomcat Server had some performance issues. A more detailed Analysis of the performance of different web servers can be found in [32]. For the first tests where no user would directly interact with the backend performance with simultaneous requests was not an issue. There would be only a few tablets (less then 5) that might

have simultaneous communication requests with the database. Future stress testing would have to proof which setup of servers is reliable enough to handle simultaneous requests from one tablet per room. To have some objective view on this issue a quantitative comparison of the code, as described in [33]. The analysis of the amount of lines in the java implementation of the backend lead to the conclusion not to use java. The Java Server consists of 3000 lines of code and even with the extended functionality after 2 month of development the Django backend did not exceed 800 lines of code, the largest files being the settings, the database model and the definition of the API (Appendix: A.1).

2.5.2. REST API

The use of a Representational State Transfer (REST) API has two big advantages. First of all it is lightweight compared to other remote procedure call (RPC) like Simple Object Access Protocol (SOAP). The possibility to send and receive just the required data in a lightweight container like JavaScript Object Notation (JSON) is extremely beneficial in mobile applications where bit rate as well as memory is limited [34]. To use it in the interactive door sign prototype has a different reason. One thing that a REST API provides is the possibility to interact with multiple web services and aggregate the data in some form of comprehendible stream. In our case the sources for the data were not defined fully. As an example one of the answers to the question "what would you like to have displayed on the interactive door sign?" was "the menus of the restaurants around campus.". How would we acquire these menus? Well we would send our API to collect the data as a cron job and parse it into a format suitable for display. The other important argument for a API running on the server is adaptability. While the CampusONLINE system (see Evaluation of the existing solution) remains untouched we use the existing Interface to get the data and display it on the tablet. This enables us to fully separate the logic of the interactive door sign from the existing system. Why would we want that? The new interface provides possibilities for interaction that still have to be evaluated but are very promising. These use cases are likely to change over the time of development. Will we use text fields to evaluate lectures? Will events have a responsible person or is there a responsible person per room? The flexibility to adapt the backend logic quickly to these changing use cases is provided by the Django backend (compare fig. 2.4). To interact with the API we defined a pattern of Uniform Resource Locator (URL) that directly represents the elements of the database model, allows filtering and for authenticated users calls that add, modify and delete resources. Illustrating the functionality of the API some examples how to interact with it are listed below. Get all events currently stored use

```
# curl -dump-header -u "user:password" -H "Content-Type: application/json" -X GET https://service.vmi.el.tum.de/doorsign/api/v1/event/
```

Filter all events that take place in-between two slots the gte (greater then equal) and lt (less
then) filters are used to specify the timeframe.

```bash
# curl -d dump-header -u "user:password" -H "Content-Type: application/json" -X GET https://service.vmi.ei.tum.de/doorsign/api/v1/event/?format=json&limit=120 &startTime__gte=2019-03-22T08:00:00&startTime__lt=2019-06-13T08:00:00 &sort_by=endTime
```

A new event is posted into the API using calls like

```bash
# curl -d dump-header -u "user:password" -H "Content-Type: application/json" -X POST -data "startTime":"2013-06-14T08:00:00","endTime":"2013-06-14T09:30:00","title":"the title","responsibleperson": "responsible person", "responsiblepersonId": ""id":1", "room": "room": "sapId": 0509.02.977", "tumonlineId": 3" https://service.vmi.ei.tum.de/doorsign/api/v1/event/
```

If the POST is changed to PUT instead of creating a new event the event is replaced in case it already exists and otherwise created as a new one. Changing POST to DELETE will delete the event.

![Diagram](image.png)

**Figure 2.4.** Diagram showing the entities in the DB of the backend. Rooms are the central entity, in the test setup only one room was used. Persons can be related. Events were parsed from the existing calendar website and users were enabled to create their own events. Events can have messages attached.
2.6. Network Components

In this section the involved hardware as well as possible changes to network architecture to get better control about the required communication are described. Figure 2.5 shows the current topology of the system. With the existing architecture communication through a web service is required [35]. The acceptance of not being able to open the door because connectivity to the internet is lost is hard to grasp for a user. If the server would exist within the local network then the message to open the door would not have to travel through the internet but could remain within the secure university or company network. This does not allow the attacker to sniff the packets at multiple points of the connection, he would have to listen them inside of the campus Local Area Network (LAN). The proposed topology would look like Figure 2.6. The blue line highlights the communication from user through the frontend to the server. The black line displays the communication between server and door lock that happens when the "unlock" command is processed. The green line shows the alternative way of accessing the backend through a web interface for administration purposes. For the implementation of the prototype a Tablet running Android 2.2 was used\textsuperscript{10}. To unlock the door a radio key from TUM was used and controlled through a relay on the Arduino\textsuperscript{11}. To receive TCP connections a network shield was used as well. The final hardware used in the live setup that users evaluated can be seen on Figure 2.7. It is based on Additional hardware required are the digital lock\textsuperscript{12} and the corresponding radio key. How these existing components could be used to interact more directly with the tablet is discussed in Protocol. The cost of implementation might be the reason why computers are not found attached to doors yet. So lets look at the cost of implementing the hardware. It took us approximately 8 hours to install the system (prepare network and electricity, drill through the wall, attach prototype, attach cable, clean up) which can be reduced by using more professional gear and craftsmen. The cost of the hardware can be seen in detail at table 2.1. Compared to commercial systems which start around 1k\euro this seems rather cheap but it would be required to look into the details of warranty and capabilities of the system to compare the quality/price ratio to estimate the real cost of such a system.

2.7. Frontend

For the development of the frontend of the existing android app was aligned with the TUM Corporate Design (CD)\textsuperscript{13}. In the CD guide there is no section about mobile application development. The

\textsuperscript{11}Arduino homepage http://www.arduino.cc/, accessed on 13.1.2013
\textsuperscript{12}Simons Voss digital lock handbook http://www.simons-voss.de/fileadmin/media/produkte/Handbuch_Schliesszyliner3061_VdS_0.pdf, accessed on 21.3.2013
\textsuperscript{13}TUM CD guide http://portal.mytum.de/corporatedesign/index_html, accessed on 13.1.2013
Table 2.1.: The cost of the components required in addition to the existing digital door lock hardware. The amounts listed here are calculated without bulk discount.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>approximated cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Android Tablet</td>
<td>50€</td>
</tr>
<tr>
<td>Arduino board</td>
<td>20€</td>
</tr>
<tr>
<td>Arduino Ethernet shield</td>
<td>30€</td>
</tr>
<tr>
<td>Relay + Proto shield</td>
<td>10€</td>
</tr>
<tr>
<td>hardware cost per door</td>
<td>100€</td>
</tr>
</tbody>
</table>

Figure 2.5.: Diagram showing the network components and hardware parts interacting to provide the functionality of the prototype. One issue is the packet that has to travel to a web server and back again to the door lock to unlock the door.

CD colors from the guide were used and instead of the light screen design of the website large areas of the screen black were kept black. The navigation is located on the right and leads the user directly to all views. These views have either informational character (info and about) or provide possibilities to interact (now, reserve and schedule). An informational view displays static Hypertext Markup Language (HTML) which is sufficient for the current state of development. In the interactive now view you see the current and upcoming event, you can leave a message on one of these events and in case there is an event running currently you can open the door (see Figure 2.8). The schedule view of the application provides a good overview what is scheduled in the current week as well as possibilities to interact. In this view new events can be created, existing events can be commented on and it is possible to scroll in the past or future to get information
Figure 2.6.: Diagram showing the network components in a proposed topology simplifying the communication in a way that there can be an offline mode implemented that enables unlocking the door even while being disconnected from the internet.

about the next week or the past one (see Figure 2.9).
Figure 2.7.: The door unlock machine, an arduino attached to a network shield and a relay.
Figure 2.8.: The now view of the application which is displayed in case of inactivity. A start page, that displays navigation on the right as well as the current and upcoming event with possibilities to interact.
Figure 2.9.: The schedule view of the application, showing all events in this room in the current week. This view is scrollable by swiping in the desired direction. Time is split into 30 minutes slots to give an overview about the length of the scheduled events.
Chapter 3.

Security Aspects

Providing a secure system with the existing topology proves not to be an easy task. There are several communication paths involved that can be used to replicate a packet that signals to open the door. The network communication can be attacked by little means but there are other vulnerabilities of the system. The existing system using NFC is likely to be vulnerable to attacks similar to the MIFARE hack [20, 21]. Most university resources are partially public space so the threshold to cross is not the highest for entering rooms. Looking into details what resources there exist worth protecting defines the structure of this chapter. Section 3.1 looks into physical security, preventing the system to be damaged physically or components getting stolen. Section 3.2 describes the possibilities of protocol attacks, like a man-in-the-middle attack. Section 3.3 presents the methods of authentication to be used with the system. Finally section ?? discusses the possible new attack vectors resulting from a compromised Android tablet. What are the risks of the system being compromised? There is work done showing that with raising complexity of a system comes an increased potential for attacks [36]. In case of the Interactive DoorSign the risks are:

- damage the system, preventing users from accessing rooms and from interacting with their schedule
- corrupt the system, change schedules, room occupation or lecture evaluation
- steal data from the system, find out about schedules and evaluations

3.1. Physical aspects

Physical security concerns occur by trying to prevent the tablet from being stolen. This is results in some sort of compromise, in order to reboot the tablet accessing a set of buttons is required. Regular users must be prevented from accessing those (on/off, volume, home screen). To allow this maintenance to happen easily and at the same time preventing the tablet form getting stolen the casing reflects that. The prototype can be stolen using a crosstipp screwdriver and removing eight
screws from the case. Even if you use some lockable hinges to build a more secure casing the thief willing to break the casing will be able to steal the tablet. One way that can be prevented is to attach part of the enclosure to an essential part of the tablet. This raises the difficulty for a thief to steal an undamaged piece of hardware (compare Figure 3.2). Attaching the tablet to the casing permanently is not a good idea in cases when you have to transport the whole casing to do hardware maintenance on the tablet (replacing batteries, sd card). One of the possible ways to overcome the mentioned issue is to maintain a android service \(^\text{1}\) running that listens to the accelerometer or the compass data and alerts the backend if the accelerometer data changes drastically. That attaches the location of the tablet to its enclosure through software but would work in case the thief does not find a way to turn the device off before removing it from the casing. The solution chosen to implement was to monitor the prototype through a webcam and tell the user that he is recorded (compare Figure 3.1). The other attack vector related to the tablet is that someone replaces the hardware with his own device to fish for passwords or other user information. This is prevented by video surveillance in the prototype but this won’t be appropriate for live deployment. Why not you might ask? Well first of all it would lead to an almost complete surveillance over all the campus with the door sign installed at every entrance. This results in some privacy issues. Another issue is, the amount of data generated by thousands of webcams would be immense. Lets assume one frame needs to be taken per ten seconds because stealing or replacing the tablet in less then ten seconds seems unlikely. \(6 \times 60 \times 24 = 8640\) Frames per day need to be taken. \(480 \times 360 \times 3\text{Byte} \approx 500\text{kB}\) Approximated size of each frame. \(8640 \times 500\text{kB} \approx 4\text{gB}\) Amount of raw data collected per camera per day. This amount of data just to make sure the rather cheap hardware does not get stolen or replaced seems to much to solve the issue of preventing theft. For every tablet secured in that way hardware of equal or bigger value is required to secure it. Surveillance is no good solution but this reasoning shows two requirements. First of all the tablets need some method to authenticate themselves as valid members of the network of door signs. This is required to make it more difficult for an attacker to replace the tablet by his own device. The other requirement is it to make it difficult to steal the tablet. The recommended approach is either branding the tablets massively (front and back) with the university CD or running software processes that notify security when location of the tablet is changed. The first approach would drastically reduce the resell value so the motivation to steal the tablet would be reduced as well. The software monitoring of the tablet could enable security personal to catch the thief quickly.

\(^{1}\)Android Service http://developer.android.com/guide/components/services.html, accessed on 19.3.2013
3.2. Protocol

Attacking the protocol is possible at several points. As shown in Figure 2.5 the communication between tablet and server as well as between server and arduino goes through some non trustworthy networks. This is rather risky because the encryption on an arduino won’t stand the brute force of a set of graphic cards. The library used previously (TrueRandom) to implement some encryption has significant flaws leading to the random numbers being not random but clustering around 0 and powers of 2. Android itself is vulnerable to attacks as well especially when the attacker can gain physical access to the device [37]. Using a Trusted Platform Module (TBM), disabling Android Debug Bridge (ADB) and enabling communication paths between trustworthy components can be used to increase the security of the system.

3.3. User

The method applicable to authenticate the user on the door sign is another set of questions. The issue here is that the door sign is not aware of user credentials which are needed for allocating the requested resources. Another thought is the use of authentication channels every user is able
Chapter 3. Security Aspects

Figure 3.2.: The opened Android Tablet and the WiFi Antenna highlighted in red. The antenna can be attached to the casing to make theft of the tablet more difficult.

to utilize. The authority to tell students that they need to use an android smartphone is not possessed by university. Actually there is no control over the hardware they are going to bring or interact with university systems. So the need exists to implement a solution of authentication that does not rely on a specific hardware.

- **One-Time-Password** Similar to the Transaction authentication number (TAN) we use for online banking we could provide the user with a list of tokens on an auxiliary channel (Short Message Service (SMS), chip cards or email). This would provide a relatively secure method of authentication but a big administration effort.

- **System Password** This concept refers to a password set by the responsible person of the event. So for example to enter a certain seminar you need to get the password for that seminar.

- **Puzzle** Assuming that most seminar groups have some common knowledge this can be used that to ask for certain pass phrases. While not being secure, this approach might help with the goal of transferring knowledge to the group attending the seminar. Especially if the difficulty of the questions increases over the duration of the seminar. This can lead to a positive effect on attendance because if a lesson is skipped several times the attendant is
no longer able to open the door.

Other than that there is the need of identifying the user.

- **Phone number** Assuming every student and employee of the university has a mobile phone, the number is used as a user identification method. Similarly to the fablab munich door lock (mentioned in subsection 2.2.1) the user would call the door lock and then enter a password.

- **Biometry** The camera on the door sign can be used to recognize certain physical criteria of the user, for example the ratio of thumb length to hand size or distance between eyes. Measuring the electric potential of fingerprints [38] could provide another method of identifying and differentiating users.

- **ID Scan** Documents like the student ID can be read through NFC, QR-Code or Optical Character Recognition (OCR). These can be used as a method of identification, similar to a username but not as single channel of authentication because if a static NFC token is used for authentication not only can it be stolen as easily as a regular key but it can be copied by anyone familiar with radio communication.

- **Behaviour** Using the behavior of the user to identify him is known as implicit authentication [39]. It might not be the best choice for authentication because it requires some time to recognize the user inputs.

These approaches need to be combined to a two channel authentication to be relatively secure.

### 3.4. New Attack Vectors

Why is there a section about new attack vectors? As the previous sections show existing parts of the security system can be exploited. But what happens if by some attacker can highjack the tablet device and install his software on it? What can he in a worst case scenario do?

1. **Phishing** - install custom similarly looking software on the tablet and store user input (ask for username pw combinations instead of relatively secure authentication method).

2. **Getting Radio keys** - assuming the Android tablet is capable of NFC, a corrupted copy of the software can copy tags or read the radio signals sent to open the door [40].

3. **Accessing data** - assuming the user gets access to the tablet via ADB

The visible security risks in the Interactive DoorSign can be topic of future security audits. The prototype does not fulfill the need for security of such a system.
Chapter 4.

Usability

While Usability as a general term means that frustration while using the software product or website is absent [41], usability in this case refers to a hardware prototype as well as the software. The importance of an accessible and usable prototype is already discussed in chapter 2.4. This chapter is more specific about the use cases defined in the scenario of a seminar room and proposes research questions under consideration of the existing solution for room reservation. What problems do users encounter when confronted with a closed door? Some users just want to enter the room, as they expect their seminar to start soon. Other users are looking for a quite room for learning or writing or team work. Maybe the room must not be absolutely quite because you want to have a learning group? Some users might need a computer desperately, where is the next available PC? These scenarios are applicable to students, not so much to university staff. Is there a corresponding set of cases for the staff members? They might want to notify the students that the location of this weeks lecture is moved to another room. Or they might want to change the time slot of their event because there is a guest lecturer coming in this week and he will be talking for 3 hours straight instead of the regular 2 hours seminar.

This breaks down to these basic interests a user likely has when standing in front of the door.

- Acquire information
  - Is the room available?
  - How long / when will it be available?
  - If I can use it and there are other persons in it, are their restrictions? (occupied resources, required to be quite)
  - The lecture was moved to another location, where to?

- Leave information
  - I want to remove the event I created (or postpone, or move to another location).
– I want to leave feedback (for example: "the lecture was great", "there was a mistake on the slides").

– I want to request maintenance (the lightbulb broke down, printer is not working).

• Interact with resources
  – I want to open the door.
  – I want to unlock the Computerized Numerical Control (CNC) mill (or other experimental setup).
  – I need to turn up the heater

Based on this categorization we defined 3 basic use cases for the door sign. One use case from each category so that we can evaluate them separately.

• Reserve the room for a specific date in the future

• Evaluate an event that took place in the room earlier

• Open the door

The details of the study and how it was conducted can be found in the next chapter 5. The first use case "open the door" seems to be the most relevant for an interface attached to a door. Even in cases where one should not be able to open the door directly sufficient feedback about why one is not allowed to open the door now might be needed. So we conducted the SUS based test [42] to find out the acceptance and general difficulty in using the door sign (1). This question reflects the need of showing that the interactive door sign is relatively easy to use and might therefore lead to an increased usage of rooms.

4.1. Research questions

The research questions were asked developed through the project (up to the point where the questionnaire was designed). At the start of the project the most superficial question was "will the user ever feel safe interacting authenticated with a public display?". Especially when being warned explicitly about ongoing surveillance (compare Figure 3.1). But when more and more functionality was added it became immanent that the possible scenarios extending the room usage were of higher interest. To specify that, formerly it was not possible as a student to reserve a room at university for a casual or spontaneous activity like a learning group. That would change with an Interactive DoorSign. But can there be drawbacks from enabling students to allocate university resources? The example usage scenario "unlock the CNC mill" was chosen to illustrate the implications of a non qualified person getting access to potentially dangerous machinery. This danger might require representation in the university organization schema, where the rights to
open doors can change more dynamically, as a student might acquire the rights to open the CNC machine testing laboratory by attending the CNC testing seminar. For the first stages of the interactive door sign this is of no concern as we the evaluation was done with seminar rooms only, but this leads to the question about what the user feels should be controlled by the door sign (4) and how his attitude towards university resources would be, implying he used them while being authenticated. Would he feel that it would be his task to leave the room tidy (6)? To provide a merit as valuable as the risk of misuse we tried to add a functionality that would smooth another recurring process at a university daily routine. In this case we chose the evaluation of lectures as a use case. Right now this evaluation is done using paper questionnaires that can be returned to the lecturer anonymously. But by handing the task of evaluation to the person evaluated you generate a certain bias and the effort required to first print, then handout and recollect paper questionnaires can not be underestimated. This leads to the hypothesis that if you could evaluate each lecture separately every week you could not only give the lecturer the chance to improve during the term but also motivate the students to participate more regularly in these evaluations because they themselves (not only the students hearing the lecture during the next term) would benefit from reaction to the feedback (5). This is the list of research questions again in short.

1. SUS, general acceptance?
2. are there any security / privacy concerns related to the use of such a system?
3. Can the user finish the given task? Where do difficulties occur?
4. What other resources of the room would be nice to have controlled by the tablet?
5. If we have an interface to evaluate lectures with one tap, what should this evaluation look like? Should it be done anonymously?
6. Would you feel responsible if you find the room in a messy state?

These questions will be answered in chapter 6.

4.2. Evaluation of the existing solution

The existing solution for room reservation at TUM is a web portal called CampusONLINE\(^1\), which essentially acts in interaction with Lightweight Directory Access Protocol (LDAP) to provide functionalities around resource allocation. For example room reservation and inviting colleagues.

A very basic evaluation of the user interaction with the CampusONLINE portal was done by trying to book a room through the portal and measuring the required clicks and time needed to reserve a room. For this tryout an account on the TUMonline development server was granted (compare

\(^1\)CampusONLINE \url{http://campusonline.tugraz.at/}, accessed on 15.4.2013
The amount of clicks required to reserve a room on the interactive door sign and through the CampusONLINE portal is equal, it requires 5 clicks in both cases. The time it took us to reserve a room through CampusONLINE is significantly longer (70 seconds compared to 33 seconds on the interactive door sign). There are two simple explanations for this fact. One is that the persons conducting the tests were more familiar with the android application recently developed than with the tool used for room reservation occasionally. The other explanation is that CampusONLINE is a lot more complex than the Interactive DoorSign application and there are some inconsistencies. For example if you view the schedule of a single room, you expect the fields of the calendar to be clickable and they are (they get a highlight effect on them if you click) but they do not enable you to book the room on the date and time you just specifically selected (compare Figure 4.2). The creation of an event itself is straightforward (a web form with the usual input methods) but quite complex (compare Figure 4.3). For example you can enter the name of the responsible person while creating the event. If you get the corresponding Extensible Markup Language (XML) though, it contains only one responsible person per room. The three buttons at the bottom of the form are quite confusing as well ("save", "save and close" and "abort and close") because modern browsers will not allow the window to closed by javascript. That means only the "save" button does exactly what it is telling to do. Only the filter function that can create weekly events except on holidays seemed especially useful.
4.3. Evaluation of the existing information display

The existing solution to display room related information is to post paper schedules next to the door. A valid argument against this method is the same as against the paper based evaluation of lectures - the effort required to print, post and dispose the paper sheets displaying information already available online. Trying to think of a potent argument for the paper schedules looking into energy consumption turned out to be interesting. Due to the expectation that it should act as an information display in its idle state this means that the display would be running all the time. It can be turned off by night. Some of the sensors in the tablet can be used to monitor the presence of users around it and turn off the screen if there are none [43]. This would require some sensors to be running instead of the screen which will reduce energy consumption. According to our experiments the 10’ Android Tablet consumes approximately 10 Watt. In one week the tablet would use 1,6kW if it was running all the time which has to be considered a lot compared to an existing solution that does not consume energy. On the other hand we did not research how much
effort it is to place the right schedule in front of the room every week. The main disadvantage of the paper schedules is the inflexibility. To update the schedule posted in front of the door someone has to update the system, print the current week again and replace it manually. As soon as functions that minimize the energy consumption of the system are implemented the fully automated schedule display should exceed the paper schedules if we take the required manual work into account.
Chapter 5.

Userstudy

Conducting the user study was one of the more challenging tasks during this thesis. Mostly because in-between terms it is hard to get a user group of significant size to use the tablet at university. That and the early stage of development are the reasons why we used a relatively small target group for evaluation. Why can a smaller user group be used in an early stage of development? According to [44] a small user group (5-10 people) can highlight the problems with the interface. As some basic problems were found during the evaluation design improvements can be drawn from the conclusions.

5.1. Research methodology

To select the methods for conducting the usability study we used some of the practical guidelines described in [45]. The users got three tasks to complete with the door sign, these tasks were verbally described and should showcase the capabilities of the system.

1. Reserve the room on a free time slot the following friday. The issue here is that there are already events scheduled for fridays, so the user has to find an available time slot. He needs either to go to the schedule view and long tap on the free timeslot or find out a free time slot through trial and error using the reserve button. After trying the reserve button repeatedly we gave the hint to use the schedule view.

2. Evaluate a lecture in the past. The issue here is that the user needs to find a lecture in the past and long tap or double tap on it. Because already being introduced to the schedule view in the previous task this was easily completed by most users.

3. Open the door. The user had to find back to the now view or wait for a timeout and press the unlock door button.

To the first group of participants a video demonstrating the tasks to execute on the Interactive DoorSign was shown. The amount of questions asked by the users who saw the video in comparison
to the users who did not see the video was approximately the same. This indicates that the short
tutorial given in the video was not helpful to the users because it did not clarify the separation of
long tap and tap. The complete list of untranslated questions can be found in section A.3.

5.1.1. Who is the target group?

The target group for this interface is everyone who might require usage of a room at university.
Or even everyone who can allocate university resources. This can be split into employees of the
university who can book rooms already through the online system evaluated in section 4.2. The
other big user group consists of students, who can not book rooms today but might be in need
of usage of silent rooms for spontaneous learner groups. The third group of users is the external
speaker group giving talks at university.

The goal of the prototype is to improve the overall experience of everyone concerned about booking
a room at university or using a room. In comparison to the existing system the Interactive DoorSign
was described as simple and well structured by the participants. The impression of TUM employees
was mostly that they would like to have one for their room at university and that they consider
this interface to be helpful.

5.1.2. How was the questionnaire implemented?

The questionnaire was conducted through soscisurvey\(^1\) using a combination of single select (socio
demographic questions, expected room usage), multiselect (further functions) and likert scale
questions SUS. The participants were asked to fill out the questionnaire directly after they solved
the use cases.

5.1.3. Analysing at the Data

The evaluation of the data was done using Numpy\(^2\) and Matplotlib\(^3\) for the box plots. The bar
and cake diagrams were drawn using LibreOffice\(^4\). The data was either separated by user group
(students, university employees or external speakers) or observed as one group. To present results
that encircle an average value the box plot technique was used. Questions

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\(^1\)online questionnaire https://www.soscisurvey.de/, accessed on 1.3.2013
\(^3\)python plotting http://matplotlib.org/, accessed on 15.5.2013
\(^4\)LibreOffice http://www.libreoffice.org/, accessed on 1.5.2013
5.2. Challenges

Finding enough participants for the questionnaire proved to be rather difficult. As the first session of questions was done during midterm season there were not many students to be found at university. A second term of questioning was conducted to compensate for that. As mentioned above the use of a explanatory video did not familiarize users with the long tap interaction. This explains why most users expressed difficulties during first interaction with the schedule view.
Chapter 6.

Evaluation

The evaluation of the user study is the topic of this chapter. The research questions will be answered.

6.1. Sociodemographics

The participants of this study were gathered from 11/03/2013 till 19/03/2013 and from 15/04/2013 till 26/04/2013. There were 10 university employees, 4 students and 9 external speakers taking part in the study. External speakers being an euphemism for people not directly related to TUM right now. The age distribution of the participants is displayed in Figure 6.1.

6.2. System Usability

When looking into the results from the system usability scale the expected outcome is an overview on the acceptance of the system. Overall the system usability score averaged around 21 (see Figure 6.2) which is very low given the fact that SUS commonly averages around 70 [46]. This result was rather surprising because every single participant expressed that they liked the idea of an Interactive DoorSign and all of them were able to complete the given tasks. This shows that even (or maybe especially) users who like the system overall and relate to it have defined expectations how the system should work and don’t adapt easily to unfamiliar interactions. The fact that all participants answered they felt comfortable using the system in discrepancy to the low usability score highlights that the participants liked the idea of the system but felt issues with its usability. Knowing the system has a low SUS does not tell us where the flaws in the interface may be so we need to investigate another set of data. The first set we are looking into is the importance of different views (see Figure 6.3). A vast majority of the participants found the now view and the schedule view to be extremely useful. The reserve view and the open dialogue were rated important as well, only the message view was not perceived as important. While this does not
Figure 6.1.: Age distribution of the participants. Since the participants did not have to specify their exact age just the groups are listed.

tell us where problems in the user interface are located it shows that the evaluation functionality of the door sign was not rated as equally important as the other views. It can also indicate issues with the rating through a free text field (compare section 6.5). Another set of questions was aimed specifically at expected difficulties the users might have with the interface (Figure 6.4). Those questions were answered using a likert scale.

**Question 0:** The interface was easy to operate. Most participants disagree with this statement. This concurs with the overall impression of flaws in the usability of the system.

**Question 0:** All control elements were found directly. Most participants strongly agreed with this statement. This indicates that the placement of the controls was not the issue that led to rating the usability low.

**Question 0:** The delay until the door opens was annoying. Most participants agreed that the delay was annoying. While this indicates an issue with the network latency that delays the
opening of the door it can not be seen as a mayor problem with the interface.

**Question 0:** It was easy to use a free text field for evaluating the lectures. Most participants strongly disagree with this statement. This clearly shows that there is an issue with the free text field as a method to evaluate lectures. Subsection 6.5 goes into alternate methods of evaluating lectures on the Interactive DoorSign.

**Question 0:** The control elements were arranged logically. Most participants agree with this statement. This concurs with question 2 and shows that there is now issue with the layout or position of the control elements on the Interactive DoorSign.

Some participants complained about the user interface in general and being asked to specify the complaint it turned out that they had difficulties with the interaction with the schedule view. Some users found it hard to select a free time slot when tapping directly on the reserve menu item. Almost all users expressed difficulties related to the long tap or double tap interaction. Another source of complaints was the timeout while entering a name of the event.

This leads to the following recommendations for improving the user experience.

- Remove or rename the reserve button from the menu. As it is redundant and does not provide the expected functionality it is confusing for the users. It could be renamed to something like "reserve now" or "authenticate to unlock now" which is the intended use of this button.

- Simplify the interaction with the schedule view to use only single tap and swipe events. Differentiating these two proofs to be difficult in Android 2.2, that is the reason for the existence of the long tap or double tap interaction.

- Find a way of implementing the timeout in a way that it is reset by user activity and does not affect a user actively writing on the tablet.

- After text input from the user accept the tap on "ok" to continue to the next page of the dialog.

### 6.3. Privacy issues

The research question in this section is about possible privacy issues with the system as well as it is about what users would wish for from evaluation. The mixture of these not directly related topics likely lead to some distortion in the results. Asking the users explicitly whether they suspect privacy issues with the system does not resolve the question because every user relates differently to the handling of his data. For example the student with good grades might have
different concerns then the student with bad grades, a professor might have different interests then a research assistant. Therefor the set of questions was put in strong relation to a topic, the improvement of evaluation, everyone at university can have similar interests in. The privacy issues were already discussed in chapter 3. To specify what privacy related concerns there might be some scenarios are defined. Alice reserves a room for a math learning group. This information is publicly available for all students. Mallory living in the same student home uses that information to steal from her room. He can do that without having to worry about her coming back before the room reservation ends. This is a privacy concern with the system working perfectly fine. If we assume that there are relations to be discovered in the system that are not intended it gets worse. For example finding out the relation matrikel number to name of student in the system can be used to research the exam results of the person and publish them in a social network. As these concerns are hard to put in question we asked things every user participating in the study can relate to because he just walked through the use case of evaluating a lecture and can imagine the issue of privacy in this context. The questions asked are the following, answers are given as a likert scala.

**Question 1:** If the lecturer can find out who I am, I do not want to give him a bad evaluation because i would expect him to give me worse grades in return. This translates
Figure 6.3.: The most important views for the users. The most important views are the ones from where the user has the most options to interact with the system (now view and schedule).

Question 2: If the lecturer can find out who I am, I do not want to give him a bad evaluation because I would expect him to give me worse grades in return. This translates into "I have a privacy concern".

Question 3: My evaluation is factual if I leave it anonymously. This translates into "I would prefer anonymous evaluation".

Question 4: If I get a bad grade I would rate the lecture lower. This admits a mutual relation between evaluation from the lecturer (grades) and evaluation of the lecturer.

Question 5: I would be happy if the lecturer would ask me after a bad evaluation what he can improve. This translates into "I don’t have privacy concerns".
Figure 6.4: Set of questions to indicate where the difficulties of the users were located using the Interactive DoorSign.

Question 6: If I would have to enter my username and password directly on the tablet I would have privacy concerns. This asks explicitly if there are privacy concerns while interacting with a public interface.

Question 7: I had privacy concerns using the system. This asks explicitly if there are privacy concerns with the system.

The answers to question 1 indicates that at least some users have privacy concerns if the lecturer can relate their evaluation to their person. On the other hand question 4 indicates that the group of participants strongly wishes to be included personally in the evaluation of lectures and does not have privacy concerns related to that. While only few participants would admit that they are affected by mutually giving bad grades to their lecturer (Question 3) most of the users feel that their evaluations would be factual if left anonymously (Question 2). The majority of users had concerns when entering their password on a public display (Question 5) but had no objections against the overall use of the system (Question 6). When asked directly about privacy concerns (Question 7) every single participant answered that he did not have privacy concerns using that system. While this gives no conclusive answers about how evaluation through this system should best be implemented this set of questions shows that most of the users have at least some privacy concerns when personally affected. This demands strongly for a method of authentication that
Figure 6.5.: The plot of privacy related questions.

does not involve entering authentication information publicly and for a system that keeps users anonymous from each other.

6.4. Further functions

Another set of questions was dedicated to finding out what further functions users would like to have on the tablet and what other devices should be controlled by it. One question asked "Which other resources in the room should be controlled by the door sign?" Multiple selection was possible and as Figure 6.6 shows most users wished to control lights, beamer and wireless LAN through the door sign. Especially university employees felt it would make sense to control the beamer. In the free text field where you could propose additional resources to be controlled by the door sign two users mentioned it would be nice to control the coffee machine remotely, two users wanted the blackboard to be controlled.

6.5. Evaluation of lectures

The question which other functionalities users wish for on the Interactive DoorSign was asked with multiple selections possible and translated into What other functions would you like
Figure 6.6.: The resources of the room users wished to be controlled by the door sign. The wishes what should be controlled by the Interactive DoorSign differ strongly by group of participants.

to see on the Interactive DoorSign? The Figure 6.8 clearly shows that the most important additional informations to be displayed on the DoorSign would be indoor maps (like from the NAVVIS project\(^1\), feedback about the state of the room and menus from restaurants surrounding the campus. The other options, a quiz or a browser were found to be of lower importance. Three participants said that they would like to request maintenance through the DoorSign or report damages to the room. That puts additional emphasis on the importance of leaving feedback about the state of the room. One user said that he would like to see relevant news on the DoorSign.

\(^1\)NAVVIS project page [https://www.lmt.ei.tum.de/forschung/projekte/navvis.html](https://www.lmt.ei.tum.de/forschung/projekte/navvis.html), accessed on 30.4.2013
Figure 6.7.: The evaluation methods the participants wished for. The five star rating method has a high popularity.
Figure 6.8.: The additional functions users wished for on the application. Maps, feedback about the state of the room and menus from surrounding restaurants have the highest priority.
Chapter 7.

Conclusion

To conclude this thesis the following chapter presents the conclusions drawn from the user study and gives suggestions about future work.

7.1. User Study

The results from the evaluation show that there are still issues with the usability of the system (discussed in section 6.2). A feasible approach on solving the issues would be to use a more established schedule view, one that users are already familiar with because it appears in other context as well. Also helpful can be to port the frontend Application to the current Android version and use the interaction metaphors from that version instead of making up new ones. Another helpful enhancement would be to repeat the user study after the bugs in the current User Interface (UI) are fixed. While there are issues with security, authentication and usability the overall positive feedback on the prototype shows that a device like the Interactive DoorSign can be helpful to change the room reservation process to be more flexible and usable by students or university staff. It can also help to provide and ambient information display that helps a passerby to acquire all room related informations necessary and maybe even further informations on the surrounding. If the Interactive DoorSign would increase room usage at university and therefor help studying more efficiently can not be shown by a single prototype in front of one room. It would require to roll out several prototypes and test the for the increase of room usage.

7.2. Future Work

One topic of future work can include an implementation of the prototype using different hardware addressing specific issues. For example a epaper interface could be used to address the energy consumption of the tablet. Another topic not yet addressed are the legal implications of a system of Interactive DoorSigns, for example used in a corporation, works committees could have objections
against the DoorSign because it can be used to monitor the entering and leaving of employees more closely and (using technology like NFC) without them noticing. If it can be assumed that most students and staff members are using smartphones anyway there might be the approach of leaving the DoorSign out and providing similar functionality as a application for the smartphones most widely spread. The danger here is to leave out persons who can not afford or do not want to use a smartphone. This is what makes a paper based system appealing. It is more energy efficient, it can provide the core functionality of displaying schedules so there will be no decrease of functions available to users without smartphones and for the group using smartphones it can provide the extended functionality (room reservation, unlock doors) as well. To further improve accessibility implementation of further languages and a language switcher can help users to interact with the door sign in their preferred language.

An even more interesting topic for future work would be to extend the functionality of the DoorSign to remotely control other resources of the rooms and improve the capabilities to leave feedback. As soon as users can control the room through this sort of interface they are likely drawn towards further use cases. Lights are the most requested additional function but if the Interactive DoorSign has informations about the size of the room and the attending audience it could schedule repetitions of the lecture in case there was less then 70% attendance. Provided the lectures were recorded. As soon as there is indoor navigation existing at TUM, through the Navvis project or other technology, the Interactive DoorSigns can be used to provide directions to anyone unfamiliar with the location of his next seminar. If this is working stable the usage of rooms can be changed more dynamically then it is the case right now. For example the one lecture about radio signals in a "basics of communication protocols" can easily be hold in the radio laboratory, while all other lectures would still take place in the seminar room.

Looking outside the scenario of a university, the Interactive DoorSign could as easily improve the usage of meeting rooms in a corporation as it could improve the usage of seminar rooms at university. To specify this, a reoccurring issue in some corporations is document distribution. If there is a regular meeting for collecting ideas hold in a specific room there is a corporate interest to gather the documents distributed in this meeting. This causes some administration, because not only all the participants have to be known, they also have to send their contribution to a central instance who then distributes the collection. If the entry criteria for attending such a meeting would be changed to "upload the pdf of your document to this tablet before the meeting" not only would the system be able to distribute the documents automatically but also it would no longer be required to know exactly who is attending beforehand because along with his name the participant has to leave the pdf. This can decrease administration efforts and facilitate spontaneous collaboration. Another use case from outside the university scenario would be the use in a caring home. Provided that the UI is easy enough to use for the inhabitants it could improve the comfort of the care taking persons. To give a concrete use case, one of the issues in taking care of people suffering from dementia is that they loose orientation where they are regularly. That means that
in order to avoid a panic, someone has to be present and calming the person down, telling him who and where he is. In this scenario the Interactive DoorSign would act as a life support and monitoring device. By measuring pulse of the inhabitant and noise level in the room the system could distinguish whether the inhabitant is in a panic or not. In case of a panic the system then would play a sound file defined for that inhabitant telling him where he is and if the panic lasts it would notify the nursing staff. In the context of a registration office an Interactive DoorSign could be used as well. The scenario here is that there is a lot of waiting required to get a stamp on a form. This waiting time remains unknown to users until they get their turn. An Interactive DoorSign could print out a QR tag that leads to a URL displaying the remaining waiting time dynamically. This would enable users to spend their waiting time not in the hall in front of the offices but elsewhere, just being required to check the remaining waiting time regularly and going back to the office in case the remaining waiting time is less then some minutes. This could reduce the frustration related to waiting time in registration offices.

While the possible benefits and use cases eased by the Interactive DoorSign are plenty the study shows that there is still work to be done to increase acceptance and solve the question of secure authentication.
Appendix A.

Appendix

A.1. python backend

    find . -name '*.py' | xargs wc -l
    135 ./models.py
        0 ./src/init.py
        0 ./src/app/init.py
      10 ./src/app/admin.py
    141 ./src/app/api.py
    136 ./src/app/models.py
      16 ./src/app/tests.py
      36 ./src/app/views.py
          0 ./src/locker/init.py
         3 ./src/locker/models.py
      16 ./src/locker/tests.py
      11 ./src/locker/urls.py
      18 ./src/locker/views.py
     14 ./src/manage.py
    152 ./src/settings.py
      40 ./src/urls.py
      75 ./src/xml export.py
          3 ./src/xml parser.py
    806 total

A.2. OpenSCAD code of 3d printed parts
kamerabstand zu zentrum = 75;
bildschirmbreite = 125;
bildschirmhoehe = 225;
breite = 183;
hoehe = 278;
schraubeneck = 20;

```plaintext
translate([0,0,$t\times10+30]){
difference(){linear_extrude(height=20){difference(){
union(){
    square([200,300], center=true);
}
}
minkowski()
{
cube([160,257,40], center=true);
cylinder(r=10,h=40);
}
translate([0,-200,0])cube([220,400,50], center=true);
translate([-45,150,10])rotate([90,0,0])cylinder(r=7, h=50, center=true);
}
mirror([0,1,0])difference(){linear_extrude(height=20){difference(){
union(){
    square([200,300], center=true);
}
}
}
}
minkowski()
{
cube([160,257,40], center=true);
cylinder(r=10,h=40);
}
translate([0,-200,0])cube([220,400,50], center=true);
translate([-45,150,10])rotate([90,0,0])cylinder(r=7, h=50, center=true);
```

translate([0,0,$t*5]){
  difference(){
    linear extrude(height=20){
      difference(){
        union(){
          square([200,300], center=true);
        }
        square([bildschirmbreite,bildschirmhoehe], center=true);
        //kamera
        translate([kamerabastand zu zentrum,0]) circle(r=4, center=true);
        //bohrungen
        translate([-breite/2,hoeheschraubeneck]) circle(r=1.5, center=true);
        translate([-breite/2,schraubeneck,hoeheschraubeneck]) circle(r=1.5, center=true);
        translate([-breite/2,hoeheschraubeneck]) circle(r=1.5, center=true);
        translate([-breite/2+schraubeneck,hoeheschraubeneck]) circle(r=1.5, center=true);
        translate([0,-30]) square([220,250], center=true);
      }
    }
  }
}

translate([0,150,10]) rotate([90,0,0]) cylinder(r=6, h=100, center=true);
}

mirror([0,-1,0]) difference(){
  linear extrude(height=20){
    difference(){
      union(){
        square([200,300], center=true);
      }
      square([bildschirmbreite,bildschirmhoehe], center=true);
      //kamera
    }
  }
}
A.3. Survey questions

In this section the questions from the survey are listed in german language, in which the survey was conducted.

A.3.1. System Usability Scale

The Questions in this subsection were answered by a likert scale.

1. Ich denke, ich würde dieses Programm gerne häufiger benutzen.
2. Ich fühlte mich sehr sicher bei der Benutzung des Programmes.
3. Ich finde, das Programm ist einfach zu benutzen.
4. Ich könnte mir vorstellen, dass die meisten Leute sehr schnell lernen würden dieses Programm zu benutzen.
5. Ich finde, die verschiedenen Funktionen in diesem Programm sind gut integriert.
6. Ich finde das Programm unnötig komplex.
7. Ich denke, ich würde die Unterstützung einer erfahreneren Person brauchen um in der Lage zu sein das Programm zu benutzen.
8. Ich musste eine Menge lernen, bevor ich mit diesem Programm zurecktkam.
10. Ich denke es gibt zu viele Inkonsistenzen in diesem Programm.

A.3.2. Soziodemographie

The possible answers to the questions in this subsection are listed in brackets behind the question.

1. Welches Geschlecht haben sie? (Männlich / Weiblich)
2. Wie alt sind sie? (<15 / <20 / <25 / <30 / <35 / <40 / <45 / <50 / <55 / <60 / <65 / >65)
3. Bitte wählen sie den höchsten Bildungsabschluss den sie bisher erreicht haben. (ohne Abschluss / Schüler / Volks- oder Hauptschulabschluss / Mittlere Reife / Abgeschlossene Lehre / Fachabitur / Abitur / (Fach)hochschulabschluss / Anderer Abschluss)
4. Was machen sie beruflich? (Schüler / In Ausbildung / Student / Angestellter / Selbstständig / Arbeitslos / Sonstiges)
5. Möchten Sie zu dieser Befragung oder zum besseren Verständnis Ihrer Antworten noch etwas anmerken? (Freies Textfeld)
6. Was ist ihre Aufgabe an der TU München? (Student / Mitarbeiter / Externer Dozent)

A.3.3. Nutzerfragen

1. War die Bedienung des Prototypen schwierig? (Likert Skala)
   a) Das Interface war einfach zu bedienen.
   b) Ich habe alle Bedienelemente direkt gefunden.
   c) Die Verzögerung beim Warten auf das Aufsperren empfand ich als störend.
   d) Die Bewertung von Veranstaltungen über ein Textfeld war einfach.
   e) Die Bedienelemente waren logisch angeordnet.
2. Welche Geräte beziehungsweise Ressourcen des Raumes sollten noch über das Türschild zu steuern sein? (Fenster / Rollläden / Beamer / Licht / WLAN / Heizung / Sonstiges)
3. Welche Funktionen würden sie auf dem Türschild bevorzugen? (Chatsystem mit anderen Räumen / Quiz / Anzeige von Speisekarten aus der Umgebung / Browser / Karten / Bewertung des Raumzustandes / Sonstiges)
4. Welche Art der Bewertung würden sie auf dem Türschild bevorzugen? (Freies Textfeld / Like Button / 5 Sterne Skala / Schulnoten / Karma / Sonstiges)

5. Wenn sie ihren aktuellen Stundenplan / ihr aktuelles Arbeitspensum bedenken, wie oft pro Semester könnte ihnen eine Raumreservierung an der Uni Zeit sparen / eine bessere Nutzung der Zeit ermöglichen? (nie / 1-2 / 3-5 / 5-10 / mehr als 10)

   a) Sie haben den Raum gebucht, jemand ihrer Komilitonen/Kursteilnehmer verschüttet eine Limonade. Sie fühlen sich verantwortlich für die Beseitigung des Flecks.
   b) Sie finden den Raum in verwahllostem Zustand vor. Sie machen den Raum wieder nutzbar.

7. Wie nützlich fanden sie die folgenden Funktionen des Türschildes? (Checkbox, Mehrfachauswahl möglich)
   a) Jetzt Ansicht
   b) Wochenübersicht / Stundenplan
   c) Reservierung
   d) Auf sperren
   e) Bewertungs / Nachrichtenfunktion

8. Würden sie die Bewertungen von Veranstaltungen lieber anonym oder authentifiziert abgeben? (Likert Skala)
   b) Meine Bewertungen sind sachlich wenn ich sie anonym abgebe.
   c) Wenn ich eine schlechte Note bekomme bewerte ich die Veranstaltung niedriger.
   d) Ich würde mich freuen wenn ein Dozent nach einer schlechten Bewertung nachfragt was er verbessern kann.
e) Falls ich meinen Benutzernamen und mein Kennwort am Tablet eingeben müsste hätte ich Bedenken bezüglich der Sicherheit meiner Daten.

f) Ich hatte Bedenken bezüglich der Sicherheit meiner Daten wenn ich das System benutze.

9. Fühlten sie sich wohl bei der Benutzung des Interfaces? (Ja / Nein)

10. Hatten sie in der Vergangenheit bereits einmal Bedarf an Raumreservierung an der TU gehabt? (Ja / Nein)

11. Nennen sie einen Punkt der ihnen am Besten oder am Wenigsten gefallen hat und gegebenenfalls Verbesserungsvorschläge. (Freies Textfeld)
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<td>6.3</td>
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<th>Description</th>
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<tr>
<td>ABS</td>
<td>Acrylonitrile butadiene styrene</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>CD</td>
<td>Corporate Design</td>
</tr>
<tr>
<td>CNC</td>
<td>Computerized Numerical Control</td>
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<tr>
<td>FDM</td>
<td>fused deposition modeling</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>GUI</td>
<td>graphical user interface</td>
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<tr>
<td>GV</td>
<td>Ghostview</td>
</tr>
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<td>HCI</td>
<td>Human Computer Interaction</td>
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<tr>
<td>HMI</td>
<td>human machine interface</td>
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<td>HTML</td>
<td>Hypertext Markup Language</td>
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<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>JSON</td>
<td>JavaScript Object Notation</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LDAP</td>
<td>Lightweight Directory Access Protocol</td>
</tr>
<tr>
<td>MDF</td>
<td>medium-density fiberboard</td>
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<tr>
<td>NFC</td>
<td>Near Field Communication</td>
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<tr>
<td>OCR</td>
<td>Optical Character Recognition</td>
</tr>
<tr>
<td>PDA</td>
<td>Personal Digital Assistant</td>
</tr>
<tr>
<td>PLA</td>
<td>Polylactic acid</td>
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<td>REST</td>
<td>Representational State Transfer</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<td>--------------------------------------------------</td>
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<td>RFID</td>
<td>Radio-frequency identification</td>
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<tr>
<td>RPC</td>
<td>remote procedure call</td>
</tr>
<tr>
<td>SOAP</td>
<td>Simple Object Access Protocol</td>
</tr>
<tr>
<td>SMS</td>
<td>Short Message Service</td>
</tr>
<tr>
<td>SSH</td>
<td>Secure Shell</td>
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<tr>
<td>SUS</td>
<td>System Usability Scale</td>
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<tr>
<td>TAN</td>
<td>Transaction authentication number</td>
</tr>
<tr>
<td>TBM</td>
<td>Trusted Platform Module</td>
</tr>
<tr>
<td>TUM</td>
<td>Technische Universität München</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
</tr>
<tr>
<td>URL</td>
<td>Uniform Resource Locator</td>
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<tr>
<td>VMI</td>
<td>Fachgebiet Verteilte Multimodale Informationsverarbeitung</td>
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<tr>
<td>WiFi</td>
<td>Wireless Fidelity</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible Markup Language</td>
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