Master Thesis

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Improving cooperation in smart homes using "Auteamate", a location-aware wearable application

Spatial in-house reminders to facilitate cooperation between inhabitants and smart homes

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Abstract

This thesis focuses on the aspect of collaboration between inhabitants and their smart homes. A context aware system in the domestic space, depending on the sophistication of the system, has limitations which can be overcome by involving users where the system falls short. Previous work has not adequately addressed the aspect of looking into people's perceptions regarding a system which combines context-awareness with user input through smart watches. By installing the prototype system "Auteamate" in multiple households, insights into how inhabitants perceive collaboration with each other and the smart home system could be established. Complementing information available to the system with inputs from users "using humans as sensors" enables the system to overcome its limitations concerning the ability to infer meaningful conclusions and providing users with appropriate support. Results from this thesis can inform the development of future context aware systems in the domestic space to maximize benefits for inhabitants.

Zusammenfassung

Die vorliegende Masterarbeit beschäftigt sich mit dem Aspekt der Zusammenarbeit zwischen Bewohnern und ihren Smart Homes. Ein Smart Home System, dessen Funktion auf dem Kontext der Bewohner aufbaut, kann seinen Limitierungen begegnen durch den Einbezug der Bewohner in denjenigen Bereichen in welchen das System eingeschränkt ist. Bisherige Arbeiten in diesem Bereich haben den Blickwinkel der Wahrnehmung von Benutzern bezüglich Systemen, die kontextsensitive Benachrichtigungen mit Benutzerinteraktion auf Smart Watches kombinieren, nicht ausreichend adressiert. Durch die Installation des Prototypsystems "Auteamate" in mehreren Haushalten wurden Einblicke bezüglich der Wahrnehmung von Zusammenarbeit von Benutzern und dem Smart Home System dokumentiert. Die Ergänzung von Informationen, die dem System zur Verfügung stehen, mit Einblicken der Benutzer unterstützt das System in der Hinsicht nützliche Schlussfolgerungen zum Vorteil der Benutzer zu ziehen. Resultate aus der Anwendung des Systems können zur Nützlichkeit von Systemen beitragen, die auf Kontextsensitivität im häuslichen Umfeld aufbauen.

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1 Introduction

The future domestic environment, among with other dimensions of our life, is currently receiving increased attention from both commercial and academic research as a place of design and IT development. The adoption of smart home technology into peoples lives is therefore gaining traction fueled by the growing interest from academic and industrial research and the resulting availability of easy-to-use consumer technology and lower prices for connected devices [14].

On a global scale the smart home market is estimated to grow from 25 billion US$ in 2015 to 56 billion US$ by 2020 which represents an annual growth rate of more than 17.2% between 2015 and 2020.[1] Not only on the global market, also regarding the situation in Europe it is expected that the volume will grow to more than 4.5 billion US$ till 2017 and there will be more than one million of smart households in Germany by 2018.[2]

Even in Switzerland the current revenue in the smart home market amounts to roughly 70 million US$ with an even higher anticipated annual growth rate of 37% between the years 2016 and 2020 resulting in a market value of 248 milion US$ in 2020. The comparatively high growth rate of 37% in Switzerland compared to 21% in the United States can be traced back to the relatively low current household penetration which amounts to roughly 1% in Switzerland compared to the United State with almost 6%.[3]

Smart homes are getting more widespread and generate more revenue every year, but a lot of persons do not know about the possibilities and are therefore not interested to invest in smart home technology themselves. Technical challenges for end-users are being addressed by ready-to-use kits, emerging standards and increasing cooperation between manufacturers of smart home systems. However, setting the right expectations and providing solutions which are beneficial for the users will have to be in focus to make sure users can realize the potential of smart homes. Therefore researching how people use the various options available to them is important.

1.1 Problem Description and Motivation

The challenges to overcome in order to achieve a broader smart home adoption proposed by several authors, for example poor manageability and inflexibility or interoperability and reliability by Brush *et al.* [9] and Edwards and Grinter [17] respectively, have been addressed by the manufacturers of popular home automation products like Nest, Phillips Hue or SmartThings. However the human aspect and especially interaction and teamwork among inhabitants still has relatively low focus [33]. A key research problem is how people work with and among technology in their everyday lives and what they do with smart technology when they are at home.

One of the challenges proposed by Edwards and Grinter (Inference in the presence of ambiguity) clearly has not been solved appropriately as sensing systems cannot simply intuit the actions of a user and offer help [17]. In some cases, however, this is possible because only limited knowledge is required on the state of the world and information can easily be obtained through appropriate sensors. Computers are able to outperform humans in certain tasks and can even successfully take over some tasks completely, but they require input or assistance from inhabitants in order to have the appropriate information to take over other tasks [33].

[1] http://www.marketsandmarkets.com/Market-Reports/ambient-assisted-living-smart-home-market-95414042.html

[2] http://www2.deloitte.com/de/de/pages/technology-media-and-telecommunications/articles/smart-home-consumer-survey.html

[3] https://www.statista.com/outlook/279/109/smart-home 2016

By improving the cooperation between inhabitants and technology we can overcome one of the limitations; that systems rely on assumptions without validating them and users do not know what the system does. The way how we do household chores could be changed by better incorporating both the smart home system and other inhabitants. A possible solution can be that systems prompt the user to give confirmation if it is unclear whether the user wants something done.

In order to improve the user experience, both the smart home and its inhabitants have to understand the capabilities of what the other party can do [5]. The system should therefore infer the inhabitants' intents if possible and otherwise resort to users to help resolve ambiguities.

Smart home systems collaborating with their users in order to improve the usefulness of the system for every inhabitant while taking in account the heterogeneity of inhabitants as well as strengths and weaknesses of systems will be the future of smart homes.

1.2 Vision and Research Questions

The vision of this approach is to make it possible to improve the interaction between occupants and smart home systems. By creating a prototype smart home system which considers the users' location in their homes, aspects can be studied regarding collaboration and household task execution in a domestic context. More productive chores execution and a sense of accomplishment and recognition by other inhabitants for getting household tasks are aspects which can be assessed by using the prototype system in real households. This connection of routines and automation should eventually lead to a more meaningful relation between the smart home and its inhabitants.

The following research questions are proposed:

RQ1 Can a context-aware task notification system be used to facilitate collaboration between home and inhabitants?

RQ2 How does a context-aware system on a wearable device integrate into inhabitants routines?

RQ3 What limitations do users of such a system experience?

RQ4 What use cases are inspired by a two week long use in participants' own homes?

1.3 Structure

This thesis is structured into seven parts. Section 1 outlines the challenge of fostering human home collaboration to achieve beneficial services for inhabitants and its impact on their routines. The subsequent chapter addresses the theoretical basis regarding smart home challenges and benefits, routines and collaboration in the domestic space as well as the usage of notifications in conjunction with wearables. Section 3 outlines a list of scenarios to be considered as input to the development of the prototype *Auteamate*. The process of designing a prototype system incorporating notifications on smart watches and taking in account user's locations in their homes is described in Section 4. Subsections about related tools, external services, connected devices and their limitations are also included as the implementation of the prototype is a significant contribution to the overall work of the thesis. The following section covers all aspects regarding the execution of the user study with deployment procedures and results from the conducted interviews with inhabitants. Section 6 sheds light on possible improvements to the prototype system and future work in general. The insights gained through the deployment and user study are summarized and discussed in Section 7.

2 Related Work

2.1 Smart Home, Challenges and Benefits

A comprehensive definition for a smart home might simply be that it is a home with built-in smartness, while the specifics are dependent on the angle of the involved parties. Every research team or author defines the scope of the term according to their needs.

One possible definition is the following: Smart Homes are examples for environments enriched with ambient intelligence. A domestic space equipped with sensors and in some cases able to act independently without human intervention [11]. But there are other approaches to the task of outlining smart homes, their behavior and possibilities.

Brush *et al.* take a different stance in their paper published in 2011 and support the hypothesis that current available technology is more closely described by the term *home automation* due to the existing disparate systems and lack of adaption to inhabitants [9].

The term smart home in context of this thesis is defined as a home that can take over certain domestic responsibilities for the inhabitants through the use of sensors and actuators while involving the occupants to obtain information the smart home system cannot sense itself thus utilizing both involved parties' strengths.

A second important term that demands explaining in detail is collaboration in the domestic context. Collaboration in general is defined as "work with others"[4], "action of working with someone to produce or create something"[5]. This definition, however, does not cover the aspect that individuals work together to create or achieve *the same thing*.[6]

Most collaboration requires leadership, although the form of leadership can be social within a decentralized and egalitarian group which can be mapped to household members.[7] So collaboration is a joint effort of multiple individuals to accomplish the same task. Regarding the domestic context the shared goal is to take care of the household obligations. The more distributed the household tasks are among inhabitants and the smart home system, the more it matches the notion of collaboration.

Motivations and Benefits As the definitions for smart homes differ amongst different researchers and different companies developing smart home equipment, the motivations of their research subjects or target buyers differs accordingly.

Concerning the motivation for inhabitants to bring smart technology into homes Mennicken and Huang describe several key factors some of which are *Modern Homes Are Smart Homes*, *Hacking the Home Is a Hobby* and *Smart Homes Save Energy*[8].

Brush *et al.* found that the three most mentioned themes behind smart home system deployments in their observed smart home households were convenience, peace of mind and centralized control [9]. There although was a significant difference between different types of households and their needs, for example monitoring applications were more popular among some families with children and universally uninteresting to the households without [9].

[4] http://www.merriam-webster.com/dictionary/collaborate
[5] http://www.oxforddictionaries.com/de/definition/englisch_usa/collaboration
[6] http://dictionary.cambridge.org/dictionary/english/collaboration
[7] http://whatis.techtarget.com/definition/collaboration
[8] Mennicken and Huang, pp. 150-151, [32]

Another group of researchers who contributed significantly to research regarding usage of smart systems in domestic spaces by deploying such systems in people's homes are Takayama *et al.* They found that reasons for installing smart home technology encompass the following topics: peace of mind, optimize, experiment, entertain and impress others and personalize [39]. As they predominantly observed homes with one person being the main technological driver behind the smart home implementation they found that "having a supportive partner seemed to be highly correlated with overall satisfaction with home automation projects".[9]

They conclude based on in-the-wild studies with participants in their smart homes that benefits for inhabitants realized by smart home technology are currently rather small conveniences which increase the comfort level rather than providing substantial support.

Challenges in Smart Homes Even the amount of *smartness* poses a challenge, because it impacts how inhabitants feel about both positive and negative aspects arising from an increasingly sophisticated smart home system. Brush *et al.* express this challenge with the following statement: People don't necessarily want "full-jetson-type" automation, because they don't live that structured of a life and therefore don't want the routineness of automation.[10] From their perspective, two levels of automation exist: User controlled and rule-based automation. Rules trigger automation based on events or at certain times (event based typically motion sensor based) and (timing based typically sundown, sunrise or related to wake-up or evening routines) [9].

Those autonomous technologies might leave users feeling out of control, especially without appropriate feedback. Autonomous systems are limited by the perception of the users and ease of use of those functions, users might limit applications to the ones they are comfortable using (aspects perceived to be complex by users require following and acting upon a user-manual which they are not inclined to do) [33].

Both the smart home and its inhabitants therefore have to understand the capabilities of what the other party can do. The system should infer the inhabitants' intents if possible and otherwise resort to users to help resolve ambiguities. The definition given earlier in this section states that users might be required to provide input for aspects the smart home system is not capable of sensing on its own. However, as Mennicken *et al.* express: Strengths of humans in certain areas do not necessarily mean that those tasks should be done by humans in every case as they might not want to do them or be interested in doing them [33].

Strengths of humans can nonetheless be complementary to the workings of a smart home system, inhabitants have an understanding of their needs and routines, as well as an intuition about the potential social consequences of technology failures whereas the home could have a comprehensive knowledge of its own technologies and associated challenges [14]. This aspect of distributed strengths and weaknesses leads to the necessity of collaboration. Collaboration with the home can occur in different forms, it might for example be possible for a home to provide suggestions or simulations regarding different configurations which would make the decision process more collaborative.

Coming back to the perspective of Brush *et al.* who divided home automation into two levels; user controlled and the more complex rule-based automation. The aspect of living *with* instead of *in* a smart home might open new possibilities considering most inhabitants do not prefer mere control and complete automation [9].

According to Bly *et al.* a lot of problems with smart devices in general arise from not paying attention to expectations users have regarding their functions and how they work as device ensembles.

[9] Takayama *et al.*, p.5, [39]
[10] Brush *et al.*, p. 2121, [9]

They compiled a list of problem situations from their study participants and found out that many did not fall into categories of broken software or broken hardware. The observed problems arised from broken expectations.

A lot of problems of smart products are anticipated neither by the manufacturer nor the consumer. Some of them originate in the consumer having a rather low domain-knowledge preventing him to anticipate the problem. Most of these *oversights* cause significant problem-time and frustration for home consumers. Bly *et al.* suggest these problems arise from broken expectations. The formation of correct expectations can be hindered by lack of knowledge of the consumer, lack of clarity about the product or other reasons. Misconceptions can even be formed when consumers read product literature [5].

Possible solutions to this problem are that use cases should be defined in a sufficiently fine-grained fashion in order not to have them overlap which could introduce conflicts between the two use cases. The growing complexity of digital homes may often yield conflicting use cases and requirements for technology. Those use cases must become more sophisticated to reflect the multiple interconnected activities in the digital home of tomorrow which will enable consumers to form correct assumptions regarding the features of smart systems and better manage expectations. The key to a beneficial smart home experience is therefore that both the smart home and its inhabitants understand the capabilities and limitations of the other party.

One of the findings from the paper *Seven challenges for ubiquitous computing at home* by Edwards and Grinter from 2001 is still a pressing issue and also concerns the adaption of technology to domestic use and that the social implication of aware home technology needs to be taken care while minimizing the interference by wrong assumptions of the system due to the presence of ambiguity [17]. That smart homes and inhabitants know about the strengths and weaknesses of the other party is of utmost importance to a working relationship.

The more proactive sensing systems become and the more contextual or locational information they infer, the more potential for misinterpretation arises. Context-aware systems are not infallible; some aspects can simply not be sensed or inferred. Because of this limitations, systems need to know what they know, how they know it and how sure they are about it [41]. Conveying the available information to the user in order to foster understanding and trust is a possible application of this finding and was proposed by Antifakos *et al.* [1].

Ultimately, smart homes should evolve into systems supporting their inhabitants by anticipating their needs and acting upon them with as little distraction, attention or configuration as possible. By improving the user experience aspects of smart homes, inhabitants can be better supported in achieving the desired support of domestic routines without imposing a large effort on them to set up and maintain those systems.

2.2 Domestic Routines and Collaboration

In the domestic context, tasks to be done as well as the perception of them is quite different than in the commercial context where automation traditionally started. While process based task-separation and separation of duty based on workflow and responsibility matrices are used in business context, households normally coordinate their activities in a less formal and more personal matter. Designing technology for a domestic context is therefore fundamentally different from designing tech for offices or other workplaces [12]. Concepts of capital production like production, efficiency, business processes and workflow do not apply. But research suggests persons are concerned with efficiency in carrying out household activities [40]. So inhabitants rely on coordination in order to improve the efficiency of their in-home collaboration. There is most often some kind of rotation of tasks and ad-hoc coordination involved, relying on basic yet expressive tools like for example sticky notes.

> It is hard to imagine technology that can replace the richness and flexibility of the sticky note, with its ability to be conveniently placed at any location.[11]

Although the capital production aspects mentioned before do not apply to households, we nevertheless want to deal with domestic responsibilities in an efficient manner and therefore also perceive the home technologies in terms of how a technology can support domestic tasks [32].

According to Crabtree *et al.* support by technology may encompass performing tasks for inhabitants or coordinate and remind of tasks to be done, so technology can also be used as a means of concerting the activities of household members [12]. One form of task coordination is the assignment of chores and household activities, which has, among other coordinational tasks like information sharing, been covered extensively by Elliot *et al.* [18]. According to Elliot *et al.* the assertion of Crabtree *et al.* [12] that information spaces in the home are interwoven with action and function is to be confirmed. Based on their research providing more background on communication in homes, the five types of communication presented by Elliot *et al.* are the following:

> 1. Reminders and Alerts - are intended or used as a memory trigger
> 2. Awareness and Scheduling - information provides knowledge of the activities and whereabouts of household members
> 3. Visual Displays - are to be shared or admired
> 4. Notices - provide household members with information about activities or people outside the home
> 5. Resource Coordination - information is used to coordinate the sharing of common household resources
>
> Those might not be mutually exclusive. Also people choose many different kinds of paper-based and electronic media to communicate these five information types. The choice is based on the convenience and comfort level of the medium for the sender and recipient rather than the information type.[12]

Locations in the home are concluded to be of the highest importance for coordinational activities, because they convey a richer meaning by providing information accompanied by context [18]. As previously mentioned, sticky notes are a well established form of domestic communication and coordination. Their placement enables the inhabitants to deal with the presented information in a very rich and intuitive way including clues about time (when others need to interact with that information), ownership (who the info belongs to and for whom it is intended) and awareness (of the past or planned actions of others).

Grinter *et al.* also investigated domestic collaboration in the context of routines and technologies taking in account two focus areas of complementary research: focus on domestic collaboration as the routines themselves and studies examining the role of computing [20].

According to Grinter *et al.* routines can be thought of as the interactions householders pursue in order to organize their domestic life. An example for such a routine is the arrival, processing and output of postal mail in family homes. The related findings of Crabtree and Rodden are the following: Inhabitants do not always have to explicitly negotiate the division of work because

[11] Elliot *et al.*, p.266. [18]
[12] Elliot *et al.*, p.254, [18]

they can rely on the visibility of the objects as well as a shared sense of where various postal items should end up [12].

So the usage of visibility of objects and their states and locations among with a shared understanding about the tasks proves beneficial to users for the coordination of tasks in the home [20]. The visibility is very important for task coordination and awareness. Another study into the routines involved in the use of calendars found that shared orientation to the artifact was essential for the negotiation around event scheduling for family members [12].

Cooperation in homes can be supported by technology in a diverse manner but should always take in account locations and common understanding of the involved persons. Visibility of the concerned artifacts and working towards a shared goal also supports this process [20].

Cakmak and Takayama also agree on the importance of mediation between inhabitants and technology and their understanding of the capabilities and limitations of each other [10]. Configuration should also be based on this understanding. The aspect of configuration is considered in context of having to specify schedules or trigger conditions as well as targets for actions for each functionality. In order to simplify matters of configuration for users, Cakmak and Takayama propose to provide the most common functionalities beforehand.

Domestic routines are coordinational and technology can be used as a means of concerting the activities of household members according to Crabtree and Rodden [12]. A locally produced system of communication arises from household members concerting their activities and such a system might consist of ecological habitats, activity centers, and coordinate displays. They use the example of handling mail: collecting, sorting, opening, placing in different locations to support their notion of concerting household activities.

> Although the ecological distribution of communication implies and indeed consists of the flow of information around the home, our studies are not concerned to support the design of work flow systems however they are construed. Rather, we are interested in the interactional dynamics that routinely shape the domestic environment.[13]

Communication has been the growth area of computing (email & mobile technologies) and research suggests this trend might be expected to continue as design moves into the home according to Hindus *et al.* [22].

Presence and Visibility of Smart Systems Both Hamill [21] and Takayama [38] propose interesting perspectives on the presence and visibility of smart systems for users drawing parallels between such systems and Victorian households with servants and domestic robots respectively. Helpful rules for the design of smart devices can be derived from taking in account those rather unusual perspectives.

For the upper class in Victorian households it was natural to have servants and nowadays it is normal for us to have devices like washing machines or dishwashers in every household. So domestic machines have taken over tasks carried out by servants and they will continue to adopt more tasks as capabilities of machines and robots improve.

> In the past, people wanted to minimize their contact with servants and they certainly did not want servants to talk to them unbidden. So why should people today want mechanical, computerized servants to talk to them?[14]

[13] Crabtree and Rodden, p.210, [12]
[14] Hamill, p.248, [21]

So Hamill concludes that (Victorian) servants should be neither seen nor heard and draws a parallel to smart home systems. That we do not want those agents visible stems from distrust [21]. Distrust, however, arises for different reasons; Machines are not thought to be dishonest but are regarded as incompetent; they do not know our intentions properly. Hamill therefore concludes with two rules about the presence of smart systems and control thereof:

- **Control** Put people firmly in control
- **Non-Presence** Keep the devices as unobtrusive as possible[15]

So the system should ask if something is not clear, but otherwise not bother the occupant.

Takayama focuses on robot interaction and draws a strict distinction between interacting with and through robots [38]. The aspect of invisibility-in-use; the difference between perceiving the thing itself and perceiving the world through it is important to understanding its implications. When becoming very familiar with a tool (also for example a car, a pen or even contact lenses) there is a certain "incorporation" of the tool into one's body. The experience therefore becomes a tacit experience rather then a focused, conscious one.

Norman's paradigm claims visibility as the most important aspect of ubiquitous computing systems; when a system is staying out of the user's sight it is also staying out of the user's mind. So a well-designed interactive system does make itself noticeable at some points to make the user aware of system behavior [34].

Agency in the context of personal robotics depends on whether the design focus is to improve the user's sense of her own agency or designing an agentic object for her to interact with which results in more or less agency in the moment. The two concepts of invisible-in-use and agentic cannot be separated distinctively, it would be a great simplification of the problem; A carpenter can switch easily from perceiving a hammer in his hand as being present-at-hand (feeling its weight etc.) to perceiving it as being ready-at-hand (just pounding nails) [38].

> Owners who set their robots to vacuum when no one is home most likely perceive their Roombas to be invisible-in-use, at least when they aren't cleaning the brushes or emptying it out. On the other hand, owners who follow their robots around and encourage their pets to play with the robot are more likely perceiving it in-the-moment than as being an agentic object. They might also have different beliefs about agency at different points in time (in-the-moment vs. reflectively).[16]

Regarding collaboration aspects in homes it boils down to both the smart home and its inhabitants being able to understand the capabilities of the other party and relying on correct expectations [5].

2.3 Context Aware Notifications and Wearables

We only want to be interrupted if it is ultimately necessary and not be bothered by notifications craving for our attention all the time.

There have been a numerous studies looking into how humans perceive notifications with some of them even taking in account situations like driving a car. Kim *et al.* applied machine learning techniques to sensor data and user-annotated driving data in order to determine when drivers are interruptible [29]. They concluded that understanding the current state of the driver and the situation he finds himself are key to knowing whether it is appropriate to interrupt the driver.

[15] Hamill, p.249, [21]
[16] Takayama, p.17, [38]

Context-aware systems, however, are only as reliable as the information on which they base their knowledge of the situation. In practice they often rely on incomplete, inaccessible and uncertain information [1]. Therefore, ambiguous and uncertain context information have to be dealt with. Antifakos *et al.* conducted studies probing this space by looking at how often participants changed settings proposed by a system. They compared how often participants changed settings depending on whether the system-confidence was displayed and the displayed confidence of the system decision. Their experiments show that when the system confidence is displayed, users more often rely on the system. This suggests an increase of the users trust in the system if they have this information visible. They suggest that displays providing an ambient awareness current confidence of the systems would be most suited to provide at a glance information.

So knowing about the system's inner reasoning and to what extend the system is reliable does improve the user's trust in a system according to Antifakos *et al.* [1]. Because decisions made by sensing systems are always intrinsically tied to - in some situations incorrect - assumptions, incomplete and uncertain information, indicating system confidence improves the user's trust in the context-aware system. This assumption was confirmed by their study because the users with information concerning system confidence tend to rely on the system more often which indicates an increase of the user's trust in the system.

The aspect of incomplete or imprecise information was also looked into by Vermeulen and Beale regarding context aware systems [41]. They outline challenges and opportunities related to proactive context or location-aware systems with respect to intelligibility and control in smart homes. Challenges they observed correspond with the findings of Bellotti *et al.* and can be boiled down to the following aspects [4].

> - Context-aware systems are not infallible; some aspects cannot be sensed.
> - Context-aware systems should be intelligible; tell the user
>   - what they know
>   - how they know it
>   - what actions they are taking based on that
>
> And then offer the users control, so that they can intervene when the system makes a mistake. [17]

Intelligibility is most important when something goes wrong and users have little motivation for developing an understanding of the system's behavior as an independent activity [41]. A possibility is to blend support for intelligibility and control into a dialog between the home and inhabitant resulting in a so called mixed-initiative UI. Applications that take usefulness and usability in terms of intelligibility into account are far less likely to be rejected by their users (eg. Microsoft Office *Clippy* was not intelligible and not very controllable and users quickly abandoned) [15].

The human aspect in sensing and context-aware systems is apparent in the interaction between such systems and their users taking in account the five basic questions proposed by Bellotti *et al.* [3]. Those are Address, Attention, Action, Alignment, and Accident, which means that the user needs to be aware of those aspects and systems have to provide control to the user.

To sum up, context aware systems have a limited understanding about the world which might conflict with a user's understanding. Therefore sensing systems should involve the user when necessary to resolve ambiguities.

[17] Vermeulen *et al.*, p.2, [41]

Wearable Devices Smart watches have been proposed by researchers and tech companies for decades and they have been available for interested consumers for a long time. Once I had won a *Ironman Triathlon Datalink* watch in a competition when I was a child, this was around 1995. This watch was able to store contact entries with phone numbers and anniversaries as well as arbitrary lists of text. The communication was only one-way from computer to the watch utilizing a screen blinking method to transfer data from the computer to the watch leveraging the capability of the commonly used CRT monitors.

Figure 1: Timex Ironman Triathlon Datalink[18]

Although limited, the functions of smart watches at this time were on par with other available PDA products and were offered in a form factor fitting around the wrist.

Other mentionable examples would be the *WatchPad* resulting from a collaboration of IBM with Citizen Watch Co. in 2000 [24]. This device already included features common in modern smart watches and smart phones like accelerometer and vibrating mechanism and even a fingerprint reader.

Figure 2: IBM Watchpad[19]

But it was not until 2014 when the creation of smart watches gained traction with many manufacturers creating their own smart watches and companies like Pebble, Kreyos and Neptune presenting their watches at CES [43].

In the same year Google announced the release of the Android Wear operating system along with products made by their partners Motorola, Samsung, LG and Asus [6]. The smart watch used in this study is the Motorola Moto 360 which was first presented in September 2014 [36]. This device is a reasonably priced full-fledged Android Wear device predestined for usage in academic studies also due to its compatibility with any smart phone with Android version above 4.3.

The advent of Android Wear opened up the possibilities for software developers to create wearable apps being able to rely on a stack of available functions and a stable platform maintained by the creator of the most widespread mobile operating system Android [2].

Figure 3: Motorola Moto 360[20]

Android Wear supports both square and round watch displays and is intended to provide *information that moves with you*. Building upon the features of *Google Now*, Android Wear intends to provide you with information appropriate to the current situation, ranging from storm warnings to directions based upon Google Maps [16]. One of the main use cases manufacturers advertise is that information can be made available in a natural and unobtrusive way without having to take a smart phone or an even bigger phablet out of a pocket and unlocking it.

In the next few years, predictably, wearable devices will enter a period of prosperity. The IMS data revealed that wearable devices shipments will reach 92.5 million units by 2016 [26]. According to Juniper's re-

[20]https://upload.wikimedia.org/wikipedia/commons/3/3b/Timex_Ironman_Triathlon_Datalink_velcro_strap.JPG
[20]http://archive.linuxgizmos.com/ldfiles/misc/ibm-watchpad.jpg
[20]http://ecx.images-amazon.com/images/I/81Qkcobv5oL._SX425_.jpg

search, the number of wearable devices including smart watches and glasses will approach 130 million by 2018 [28].

According to Jiang *et al.*, wearable devices will become the mainstream of the development of mobile smart devices and they will dramatically change modern way of life [27]. The development, however, is still in its immature stage and is focused on services that can also be achieved on smart phones with the superseding argument towards smart watches mainly being the form factor rather than providing unique services. Research on hardware materials and battery life also has not achieved a breakthrough, additionally limited screen space is an issue for wearable devices. It will take a long time for wearable devices to become the mainstream of market, but Jiang *et al.* nonetheless see an immense potential to be realized in the upcoming years [27].

Regarding contextual awareness Jiang *et al.* propose that devices often run continuously and collect data but the user does not use the obtained data in most cases. This is certainly the case for wearable devices whose purpose is acquiring data about the person wearing it (eg. fitness tracking devices). But features of wearables also include assisting or reminding the user automatically according to the current context. Watches are also very personal and people oriented devices.

De Russis *et al.* discuss applications for wrist-worn smart home interfaces and propose a preliminary implementation based on a cost-effective watch in their paper *The smart home controller on your wrist* [13].

Using a wristwatch as means to access a smart home system as opposed to traditional (wall switches etc.) and computer or mobile-based interfaces overcomes limitations imposed by these means of access.

> Traditional interfaces are well understood and not intrusive at all, as they are already part of householder's daily activities. PC/mobile-based interfaces, instead, are typically intrusive and impose additional cognitive load.[21]

Wearable computing aims at overcoming part of these user-home interaction issues by enhancing the interfaces to be *more invisible*. Advantages of wearable interfaces, especially concerning the form factors watch and bracelet, are that they are always on the person, users are accustomed to wearing them, they are less likely to be misplaced and they are more accessible.

In conclusion, the most important requirements for wrist-worn human-home interfaces proposed by De Russis *et al.* are readability of the watch display and accessibility of the display because typical scenarios require quick and easy operation [13]. Wearables can therefore be used as notification, sensing and control devices.

Goto *et al.* proposed a wearable action support system for business use based on a web schedule [19]. The proposed system differentiates between different states of activity to show relevant notifications by inferring low-level context and high-level context and subsequently providing appropriate content. Low level context includes walking, stopping and being in the train, whereas high level context includes data points like start, end and place from the connected calendar. Their findings include that people respond faster when low-level context is "stopping", obviously, but also that the response time by smart phone tends to be longer than that by smart watch, it is easier and less time consuming to respond to notifications displayed on smart watches [19].

Koehler *et al.* present a system for adaptive indoor location prediction which predicts when a user will leave his current location and the next location he will transition to [30]. Their proposed system relies on the concept of *significant locations*. Indoor transition times are typically short in contrast to outdoor due to the proximity of the significant locations which are defined as a *set of*

[21] De Russis *et al.*, p.785, [13]

locations where a person frequently spends at least ten minutes and therefore harder to distinct and act upon.

In a paper proposing three scenarios deployed in households to support participants in achieving goals for self-development, Brotman *et al.* observed the effects of prompts and incentives in domestic environments [8]. *Prompts and incentives, however, possess certain potential dangers: Residents might mindlessly move from one prompt to another* as Purpura *et al.* state in their paper "Fit4Life" observing the limitations and possible dangers of the usage of pervasive computing in personal goal achievement especially regarding weight loss [35].

Findings of Brotman *et al.* include that the presence of the home induced an influence akin to peer pressure, creating additional stress that influenced the participants to perform the tasks given (eg. practice playing guitar) which also had an impact on how the system was perceived by the participants. Some participants of the user study of Brotman *et al.* perceived the system as a roommate that checks on them and encourages them to engage in their real world activities (perception as an agent), whereas one participant did perceive the application as "a system someone installed in her home" which resulted in a largely negative experience, while the two others were positive. They conclude that systems might support inhabitants, but also have potentially negative effects on the domestic environment.

Voida *et al.* outlined challenges and recommendations for interface design across multiple wearable devices in their paper "Challenges, Feedback & Notifications : Empirical Explorations to Inform the Design of Interfaces to Motivate and Encourage Long-Term Personal Informatics Use Voida" [42]. They researched the dispatching of notifications across multiple wearable devices and investigated the use of gamification elements related to user's personality types.

One of the main conclusions based on their research was, that some people value receiving notifications like for example signaling their daily goal (eg. FitBit Flex) whereas others perceive them as a nuisance. This issue is grounded in the possible information overload posed by multiple devices and the abundance of notifications in general [42]. Based on their preliminary studies on how worn devices can work together, they propose the creation of rules giving the users the possibility to specify which notifications are disseminated across their wearable display ecologies.

Wearable devices and especially smart watches offer the possibility to provide users with less interruptive notifications compared to smart phones. By leveraging this capability, smart home systems can be created that integrate better into people's lives.

2.4 Visualization of Smart Home Information

Making the right information available in the appropriate form is the most important aspect of the visibility concept mentioned before. In smart homes, a lot of data is collected through the interaction with appliances and switches which is complemented with other sensor data. But this vast amount of data is difficult to understand if it is represented in form of log entries or in other tabular forms.

In order to provide a more expressive and more intuitively understandable information visualization, the temporal metaphor based *Casalendar* was created, a calendar based representation of past and planned smart home events [23]. The approach proposed by Mennicken *et al.* was to use a traditional family calendar that is found to be often used to coordinate among family members and schedule events for the household community [31].

Evaluation of this prototype was conducted using a VAIO Tap 20 Mobile Touch Desktop, a 20" tablet device running Windows 8. This device was chosen in order to enable the participants to interact with the calendar in a most intuitive way. It was possible to swipe sideways to advance to the next time period, swipe up and down to reveal events in the morning and late evening, a concept we have become used to through the use of calendars on touchscreen devices [23].

The findings from the persona supported expert evaluations revealed the following aspects. Participants liked the fact that the usage of pictograms for primary transport of information was chosen and welcomed the possibility to display additional information if the representation by pictograms was not understood. In general, having an interface that can be used to check whether everything is in order with the house was noted to be a most beneficial aspect [23].

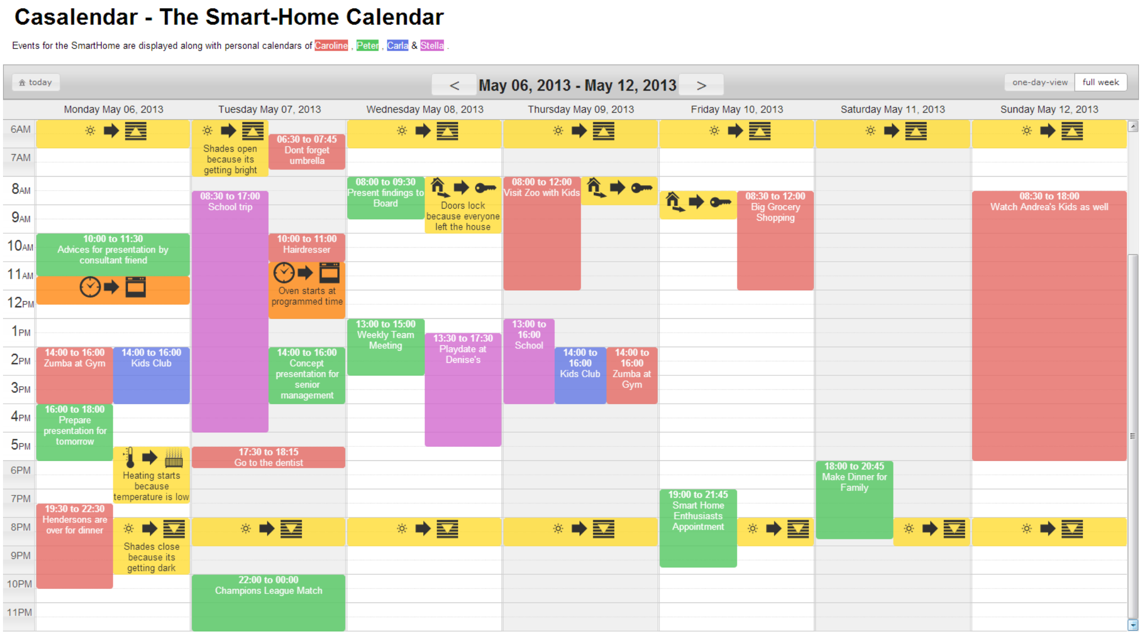

Figure 4: Casalendar Screenshot[22]

The Figure 4 illustrates an example of such a calendar view with incorporated smart home information. A week-view of the fictional Rizzo family is shown with events of the four household members complemented with information regarding the smart home whose events are colored in yellow and orange. The prototype depicted in Figure 4 has only the capability to display events, neither can smart home functions be triggered nor events be adjusted or scheduled. Smart home events, however, contain additional information about the underlying cause and effect of a displayed function. By tapping the event with its icons a textual representation of the function in question is revealed [23].

An interface which makes smart home information available to inhabitants in a familiar and unobtrusive yet expressive way enables the users to consult data that is otherwise complex to access. Especially for users with limited technical knowledge, this approach proved to be a beneficial addition to traditional smart home interfaces [31].

[22] Hofer, p.33, [23]

3 Proposed Application

The envisioned application will incorporate scenarios to support household activities. As a starting point, household activities were researched that can be supported at least partly by means of automation. The obtained household activities were then specified and structured into groups.

3.1 Initial Ideas

As a first step, various ideas for scenarios were developed and visualized in order to be able to pitch the idea of supporting household tasks with wearable support. Two example scenarios are shown below.

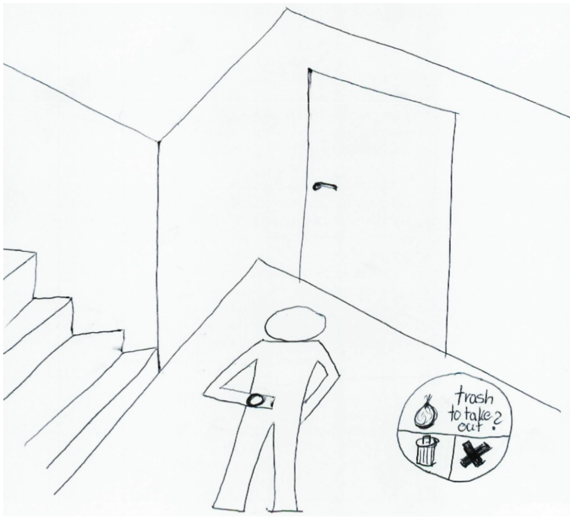

Figure 5: Scenario Idea Trash

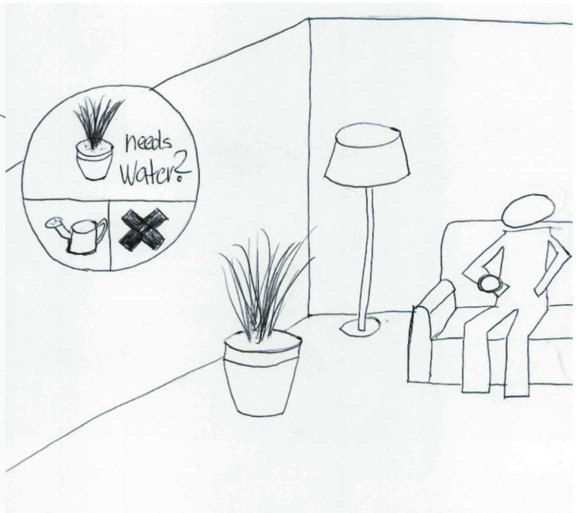

Figure 6: Scenario Idea Water Plant

The drawing in Figure 5 depicts the situation of a person leaving in the morning when a garbage pick-up is scheduled. This person is then asked if there is trash to take out. The second drawing in Figure 6 expresses the following scenario: Nearby users are asked if the plant needs water by taking in account the watering schedule of the plant.

Three of those initial ideas became the starting point for a lot of discussions with other researchers and eventually resulted in numerous suggestions for scenarios. Therefore an analysis of household chores and how they can be supported by technology was conducted.

3.2 List of Scenarios

This section describes the process of creating a list of domestic chores and tasks to inform the development of the a classification of those in context of the proposed system.

In order to compile a comprehensive list of household chores that could possibly be automated, literature concerning domestic routines and their coordination as well as research into potential chores for domestic robots were considered. This academical perspective was complemented with household to-do lists available on websites aiming to support organizing chores by providing daily (morning/evening), weekly, monthly and seasonal checklists[24].

☐ Clean the shower & tub	☐ Unload the dishwasher
☐ Wipe window sills	☐ Make the beds
☐ Dust furniture	☐ Do laundry
☐ Vacuum	☐ Put clean laundry away
☐ Wipe bathroom sink	☐ Empty small trash cans
☐ Pick up toys	☐ Make lunch
☐ Put dirty clothes in hamper	

Figure 7: Sample Chore List[23]

The list depicted in Figure 7 was created by Cakmak and Takayama with the objective towards building a comprehensive tasks lists for domestic robots. Overall, cleaning tasks and organizing tasks dominate the observed chore lists.

Aside from looking into possible use cases for domestic robots, lists of potential use cases for smart home applications were considered from a goal-centric perspective.

Another interesting source contributing to the proposed scenarios was the application of a device-centric perspective. In order to come up with examples that can be incorporated into the prototype, devices that are commonly used in smart homes were considered. However, those devices would need to be available for deployment in the households for the pilot case study. Table 1 gives an overview regarding which devices were considered when looking into automatable domestic tasks.

Camera / Microphone
Door / Window Contact Sensor
Door Lock
Media System
Motion Sensor
Plant Sensor
Smart Light Bulbs
Smoke Sensor
Switchable Power Outlet
Temperature Sensor
Vacuum Robot
Weather Sensor

Table 1: Considered Devices

After compiling those lists of (semi)- automatable tasks and involved devices, several brainstorming sessions with HCI experts, other computer scientists and regular users were conducted to add to the list of possible scenarios. The following Table 2 gives an overview regarding possible scenarios and includes whether they can be fully automated or need to be *au*team*ated* by including occupants as teammates to complement a system's sensing or actuation capabilities.

[23] Cakmak and Takayama, p.93, [10]

[24] http://www.hgtv.com/design/decorating/clean-and-organize/checklists-from-daily-do-its-to-routine-chores

3.3 Possible Scenarios to Include in the Prototype

Action	Semi Auto	Full Auto	Description	Feasible	Cadence
Adjust Temperature	x	x	Ask if the temperature is fine based on sensor readings and not ask the same person again in the same situation afterwards		ongoing
Cleaning of Cat-Litterbox	x		The user is prompted to clean the litter box in periodic intervals, this activity could be awarded with not getting other notifications for chores	x	varies
Cleaning of Coffee Machine	x		Repetition task, cannot be automated but scheduled		Weekly to monthly
Cleaning of flat/house	x		Cannot be taken over entirely by home automation, but everyone would love to get rid of (part of) it		Weekly to monthly
Dusting	x		No automation possible at the moment		
Feed pet	x	x	Could be achieved by using a special feeding device		Daily or every few days
Fill & start / empty dishwasher	x		Ask the person if the dishwasher is almost full and prompt the user to fill it completely and start or ask the person if the dishwasher is filled with clean dishes and remind the person to empty it.	x	between once a day and twice a week
Groceries Shopping	x	x	With a post-it next to the fridge and a beacon, triggering a request to check if someone needs a particular product, so it can be added to the list		Between a few days and once per week
Lawn Mowing	x	x	Requires regular maintenance and initial setup		Every few days
Open or close shades	x	x	Depending on weather predictions to avoid inconvenient heat/cold house and save energy		Daily
Resupply on other "non-food"	x	x	If supplies on something run low, remind the responsible person. Is not easily realizable to know what is needed and what is consumed		About once a week
Switch Lights on/off	x	x	It is not really a chore but one of the most common home automation tasks. Also the light has to be turned off based on (non)-presence	x	Daily
Take a walk with pet	x				Usually daily
Take out Recycling	x		Ask if necessary and remind to do it	x	Weekly to monthly
Take out Trash	x		Day-of-the-Week reminder in the morning when leaving the home	x	About once a week
Tidy up room	x		Just scheduling		Varies
Vacuuming (Roomba)	x	x	Requires regular maintenance and initial setup	x	Once a day to once a week
Ventilation	x	x	Provide fresh air if the window was not opened for a defined period	x	Every day
Washing	x		Reminding the respective person of the termination of the washing cycle	x	About once a week
Watering of Plants	x	x	If a plant was not checked for a number of days, the user is asked to check and/or water the plant. User decides if watering is needed & does the watering	x	Every few days

Table 2: Scenario Suggestions

With regard to being able to implement the scenarios in the households for evaluation, they had to be occurring as frequent as possible. For example it would not have made sense to include a reminder to refill heating oil in the two week deployment phase as this usually happens once or twice a year. The decision to include a scenario for turning on lights in the house was taken with this fact in mind; although it does not constitute as a chore or household task, it is both occurring frequently and a well established smart home functionality.

This (not conclusive) list of possible scenarios was created before commencing the development of the *Auteamate* system in order to inform development. Every observed household had a different set of finally deployed scenarios and those were eventually based on the pre-deployment interviews which are covered in section 5.3. The app development was conducted with those scenarios and easy extensibility in mind and the individual scenarios were then later refined for each household.

Information regarding the implemented scenarios and their configuration possibilities are available in Section 4.7.2. Further details about the deployed scenarios can be found in Appendix A.

4 Auteamate System

This section describes the design process and technical details of the system created and evaluated as a preliminary implementation in this master thesis. After introducing features and components, details regarding the implementation and user interaction are presented.

4.1 Design and Features

As discussed in the previous chapters, the application *Auteamate* was planned to be a prototype smart home system taking in account spatial awareness through Bluetooth beacon technology, notifications on smart watches and include interfaces to multiple sensing and actor systems.

Features of the application encompass the following characteristics:

- minimal, lightweight
- personalized
- spatial / context aware

A comprehensive example of an envisioned scenario is provided in Figures 8, 9 and 10. This scenario relies on the occupant to sense whether the floor is dirty and to confirm if the user wants the vacuum cleaning robot to be started.

The first image is a storyboard depicting the process involved in this example scenario. In the first two stages the occupant enters a region covered by a Bluetooth beacon through which the system launches a prompt asking the user about the floor. As there is no sensor for floor-dirtiness, the system has to rely on the user to provide input in the third stage. The subsequent question in stage four of the storyboard in Figure 8 expresses the question for confirmation of the user, consenting to the start of the vacuum robot. Finally, the last stage depicts the vacuum robot doing the work the user has previously agreed to be started.

Figure 8: Storyboard for Dirty Floor Scenario

The flowchart depicted in Figure 9 illustrates the part of the process where user input is required and gives a hint about possible configuration possibilities, namely the setting of appropriate time spans after which an occupant is asked another question about either the floor dirtiness or the start of the cleaning robot.

In order to illustrate the distinction of those different prompts, a high level flowchart was created. Every scenario execution is initiated by the system upon sensing a beacon; when a user resides within the boundary that is defined for the specific scenario. Depending on the scenario, different prompts can be triggered. The scenarios can be assigned to groups based on whether the action is performed by the home or the occupant, therefore separating them according to user involvement in the actuation.

Another distinction can be made taking in account the kind of input the house requests from the occupant; either the occupant is asked to act as a sensor or to confirm that the system shall take an action.

Therefore, prompts to be displayed to the user are structured into the following categories.

- **Sensing Occupant** The system asks a user to perform a sensing task to acquire information about the state of the environment the smart home system does not know.
- **Confirming Occupant** System asks the user for confirmation before it performs a task on its own.
- **Actuating Occupant** The system knows that a task needs to be performed and asks the occupant to carry it out.
- **(Notification)** Displays a notification to the user eg. that his washing cycle is finished or windows can be closed again.

A second distinction was established by separating the scenarios for which the smart home system can perform the action and the scenarios for which the user is required to perform the action. The high-level flowchart depicted in Figure 11 illustrates those two categorizations among with the initiation of the process by the system.

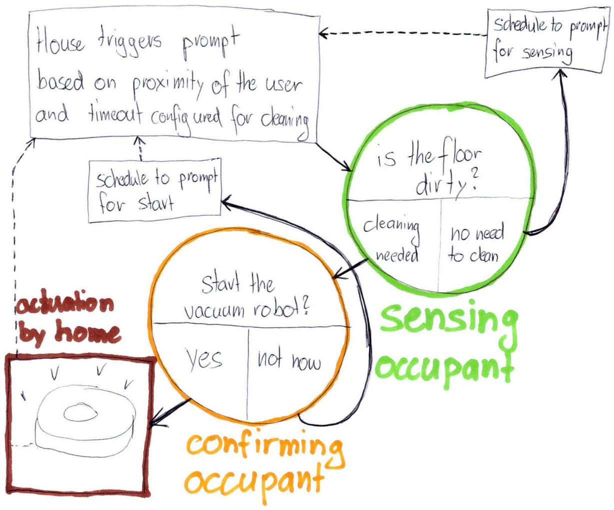

Figure 9: Flowchart for Dirty Floor Scenario

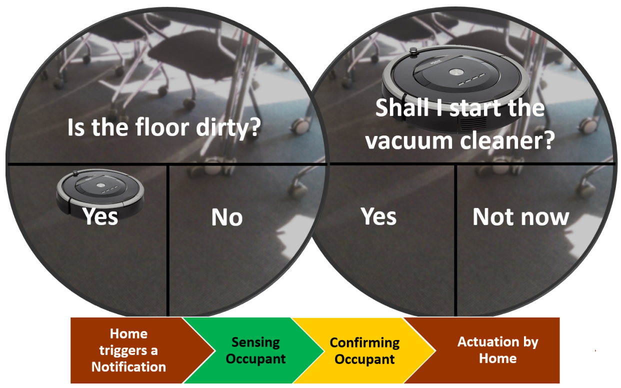

Figure 10: Workflow for Dirty Floor Scenario

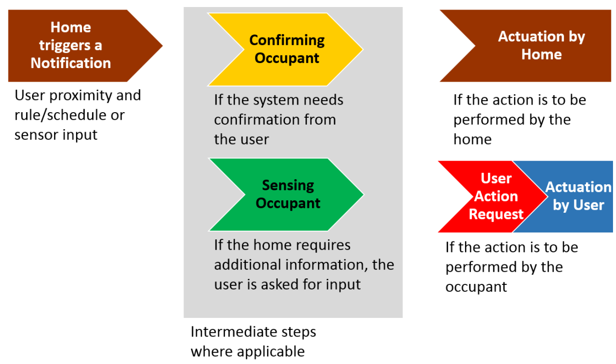

Figure 11: High-Level Flowchart

The scenarios can therefore be discerned into four quadrants which are displayed in Figure 12. If the inhabitant is prompted to confirm an action ultimately performed by the system, the scenario falls into the upper left quadrant whereas scenarios for which the system also relies on sensing input by the user but are ultimately performed by the system fall into the lower left quadrant.

All scenarios on the right side involve the user performing the household task because either devices to automate the function are not available or it was not feasible to include them in the study for this thesis. While scenarios in the upper right category involve sensors to inform the system about the necessity of tasks so that the occupant is only asked to perform those tasks when required, the lower right quadrant consists of contextual reminders. Those reminders are, as well as all other prompts, initiated by proximity to a beacon and were only sent to the user if the defined timeout for the scenario was exceeded. Users are both responsible for sensing whether the task is really necessary and the subsequent execution. So those reminders are configured regarding place in the home, distance from this place, specific time slots when they occur and also timeouts between executions. Although the system is dependent on the user for sensing and actuating, it nevertheless plays a crucial role in asking the user in the right moment to do so which differentiates this function from simple notifications that appear randomly or at specific times. One of the most illustrative examples is when users near the apartment door are asked if there is trash to take out and subsequently asked to take the trash out on Tuesday morning, as there is a trash pickup scheduled for Tuesday morning.

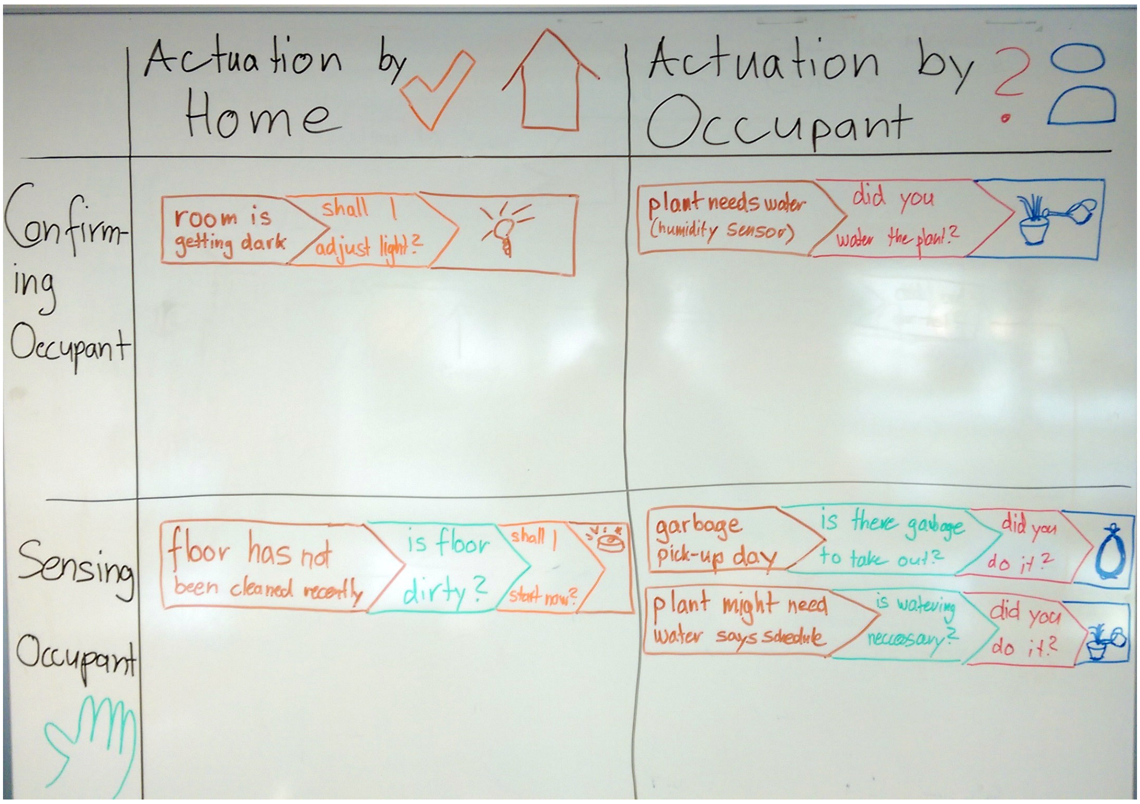

Figure 12: Scenario Classification

4.2 System Components

The main components of the Auteamate system and involved communication channels are depicted in Figure 13. After the mobile phone picks up the signal of a beacon, it connects to the database and, if appropriate, sends a prompt to the smart watch that is subsequently received and processed by the phone. Details about each component are available in the subsequent chapters.

Figure 13: Hardware Components[25]

4.2.1 Beacons

There are multiple beacon vendors that offer various beacon types tailored to specific use cases. Examples of these beacon types and their manufacturer are depicted in Figure 14 The types of beacons used with the Auteamate application are from the vendor Estimote, the two specific types used are their so called *Estimote Beacons* and *Sticker Beacons* [7].

Figure 14: Beacon Examples[26]

In general, those beacons work like a lighthouse transmitting packets at defined time intervals [37]. Those packets are transmitted over Bluetooth Low Energy (BLE) and the frequency and type of the transmitted packets

[25] http://ecx.images-amazon.com/images/I/81Qkcobv5oL._SX425_.jp,
http://cdn.cultofandroid.com/wp-content/uploads/2014/10/nexus2cee_n6lf3.png,
http://beekn.net/wp-content/uploads/2013/12/estimote-2-beacons.png,
https://en.wikipedia.org/wiki/File:Firebase_Logo.png

[26] https://fpf.org/2014/12/11/understanding-beacons-guide-addresses-widespread-confusion-about-the-new-technology/

can be adjusted, currently only by using the official Estimote app for iOS devices. Concerning the Auteamate application, the most rudimentary frames are sufficient as only the beacon ID is needed to distinguish the different beacons from each other. The beacons are then placed in locations in the homes according to the scenarios they represent. This does not necessarily mean that the beacon is right where a possible actuator (eg. a lamp) is placed, but at a position that most accurately covers the area in which a user interaction should take place.

4.2.2 Android App

The Android Application is the main component of the Auteamate system, incorporating communication with the other components and controlling the workflow and data access. Features include the discovery of Beacons in the vicinity, access to data regarding scenarios and configuration, handling of prompts to be sent to the wearable component, actuation of automated functionality and usage statistics gathering.

4.2.3 Android Wear App

Android apps in general can push notifications to an Android Wear devices, but have only constricted templates available and can offer no other control than either dismissing the notification or opening the respective app on the mobile. In order to have customized notifications and advanced actions presented to the user via a smart watch, an Android Wear app needs to be developed. The Android Wear app developed in this thesis is a minimal application consisting of classes that are responsible for communication and prompt / notification display. Its main responsibility is displaying prompts in a minimal and lightweight fashion, requiring only simple input (Yes / No / ignore) and sending responses by the user back to the mobile. It can also send the user notifications that require no input.

The two figures below depict an exemplary confirmation prompt and a notification. Whether the occupant would like the light on the balcony switched on in Figure 15 and reminding the inhabitant that the washing cycle he started is finished in Figure 16.

Figure 15: Confirmation Prompt for Light

Figure 16: Washing Machine Notification

4.2.4 Databases

There are three kind of storage used for the Auteamate system; Local storage on the Android device, JSON-based storage offered by Firebase and a MySQL-based relational database. Each of those components fulfills a distinct objective.

Local Storage on Phones The local storage on the Android device is used to store key-value pairs enabling the application to map user ids to user names and household ids to household names without them being available on an environment controlled by other parties. Additionally, certain data points that only have to be available to a single user are stored locally on the device. These are local configuration values like the logging level controlling the verbosity of the log processes.

JSON-based Firebase Storage As a means of primary storage for the Android application, Firebase was used as a JSON-based storage which is explained in detail in Section 4.5. This database facilitates data sync among clients, retains the current state of the scenarios in the households and enables interfacing to other systems. It is also the component that receives log data from the Android applications.

Available entities in the Firebase storage are the following:

- Core Entities
  - beacons
  - scenarios
  - scenarioStates
- User Interactions for Dashboard
  - userInteractionLogs
- Continuous Logging Entities
  - log1Beacon
  - log2ScenarioState
  - log3Condition
  - log4SensingPromptSent
  - log5SensingPromptReceived
  - log6ConfirmingPromptSent
  - log7ConfirmingPromptReceived
  - log8ActuationPromptSent
  - log9ActuationPromptReceived
- Application Logging Entities
  - beaconSensedLogs
  - errorLogs
  - infoLogs

  - debugLogs
- Entities for Acquiring Values from External Devices
  - deviceStatus

The first three objects represent the core entities of the Auteamate system that are shared among the users and are accessed every time a beacon is sensed by the application. User interaction elements are written to the database every time a user answers a question that was displayed on the watch. The *userInteractionLogs* entities are presented to the user in a dashboard on the mobile, taking in account the most recent one or two (depending on whether there are one or two prompts for the particular scenario) instances for every scenario in the defined household.

The continuous logging entities are explained in detail in section 4.8.3 and provide input to the continuous logging process which aggregates the logs for every scenario execution. Finally, there are certain data objects representing the state of sensors or devices like plant sensors or washing machines.

MySQL-based Relational Database A MySQL based relational database is used to aggregate the log data available on the Firebase storage. One of the main advantages of using a relational databases is the availability of querying functions to quickly filter and sort logged events to gain insight about user interactions.

4.3 Development Tools and Technologies

Android and Android Wear projects are developed using Java and can therefore be coded with any available Java-compatible IDE. For Android development, however, the IDE recommended by Google is the IntelliJ[27]-based Android Studio[28]. This IDE incorporates numerous features that are convenient for Android and Android Wear development. Ranging from the built-in Gradle build system to the integrated ADB (Android Debug Bridge) which also enables debugging of applications on the watch using Bluetooth. As in any IDE, support for version control systems is built-in and in this case used to connect to the Auteamate repository on Github[29] in which the source code of this project is stored.

4.4 Libraries

The library *Android Beacon Library*[30] developed by Altbeacon was used to facilitate Beacon detection and ranging. It can be configured to detect a wide variety of available Beacons and includes the possibility to scan for beacons in the background without the need to open the app.

Other dependencies include the Google Play Services components for the mobile to wearable communication, the Android support library for wearables and the Firebase Android client library.

[27] https://www.jetbrains.com/idea/
[28] http://developer.android.com/sdk/index.html
[29] https://github.com/kallyope/auteamate
[30] https://altbeacon.github.io/android-beacon-library/index.html

4.5 External Services and Components

As means of storing data used by the application instances, the Database-As-A-Service provider Firebase was chosen. Firebase is essentially a json storage that can be used with various clients or using a REST API.

As a second non-android related entity used in the project, a web server was set up to run cronjobs and facilitate log data retrieval and storage in a mySQL database. The server reachable by its domain *auteamate.com* executed certain actions using scripts written in PHP that were scheduled to run by cronjobs.

The decision that the user should not be involved in the task of switching the light off after confirming to switch it on and leaving the area made it necessary to introduce an always-on element in the system. While the Android phones were mostly powered on, they might not be connected to the Internet at some times, because it needs to be possible for a user to leave the house (thus leaving the coverage of the WiFi network and therefore Internet connection) right after switching on a lamp. Thus, a solution needed to be found that accommodates for the absence of all mobile devices. The element has to be able to act independently and not be dependent on a user being at home and having his device connected to the WiFi.

Therefore a simple PHP script available in Code Example 1 was created that accesses the Firebase database in order to acquire the current state of the particular lamps, compares it to the current time stamp and if it is necessary to switch them off, executes a command using the Maker service on IFTTT to switch those lamps off. In detail, the following excerpt from the script responsible for switching off the lights was scheduled to run every five minutes.

```
$json_filename = "json-files/deviceStatus.json"; // filesystem configuration
$output = shell_exec("curl -o $json_filename
\"https://blazing-torch-4126.firebaseIO.com/deviceStatus.json\"");
$jsondata = file_get_contents($json_filename); // read json file contents
$data = json_decode($jsondata, true); // convert json to php array
$timestamp = time(); // get current timestamp
date_default_timezone_set("Europe/Zurich"); // set timezone for date()
$timespan = 60 * 5.5; // 5minutes 30sec

if ($timestamp>$data['lamp-white2']){
if ($timestamp>$data['lamp-white2']+$timespan){
echo "lamp-white2 has been off already, do nothing";}
else {
echo "switching lamp-white2 (Stube) off
because $timestamp is bigger than " . $data['lamp-white2'];
$output = shell_exec("curl
\"https://maker.ifttt.com/trigger/switch_white2_off/with/key/buL7h\"");}}
else {
echo "keep lamp-white2 on till " . $data['lamp-white2'];}
```

Code Example 1: PHP Script Turning Off Lights if no Inhabitant is Near the Beacon Anymore

Additionally, a script for log aggregation is scheduled to be executed every ten minutes, this script is responsible for aggregating all logs that belong to the same scenario execution which are triggered by sensing a beacon. Further information regarding continuous logging and log aggregation are available in Section 4.8.3.

Finally, two backup scripts responsible for logging persistence were created as well. Their execution frequency was set to once a day, as they were merely responsible to backup logs and user interactions.

Furthermore, the service from IFTTT and Maker[31] were used to interact with certain devices which are explained in detail in the following Section 4.6.

4.6 Sensors and Actuators

Figure 17 depicts the deployed devices for the shared flat in the second household with some of the cabling as well as two mobiles and two smartwatches. Beacons for the plant sensors and the roomba were directly attached to the devices themselves.

Figure 17: Deployed Devices in the Second Household

[31] https://ifttt.com/maker

The following sensors and actors were incorporated in the system:

- Sensors
  - **Window Sensor** Part of the SmartThings system [32]
  - **Plant Sensor** Parrot Flower Power sensor from Parrot inc.[33]
- Actuators
  - **Light Bulbs** Philips Hue kit including two switchable white light bulbs and a colored light[34]
  - **Vacuum Robot** iRobot Roomba with WiFi module for remote control[35]

Apart from those devices, a lot of cabling, chargers and even a secondary WiFi access point were used in order to ensure sufficient coverage in the basement for the washing machine scenario.

The integration of the sensors was achieved using the proprietary interfaces of the respective companies to the service of IFTTT [25]. Using a recipe like the one available in Figure 18, both the trigger and action channel can be defined. By using the *Maker Channel*, arbitrary web requests can be carried out when the related sensor triggers. In this case, an object containing the time when the next watering should occur is written to the Firebase storage so that the Auteamate application can check if watering is necessary if a user approaches the plant monitored with that sensor.

Figure 18: Recipe on IFTTT Connecting a Plant Sensor to Auteamate through Maker

Regarding the actuation of devices in the household, direct requests to the involved devices can be sent by the Android application after receiving the confirmation of the user to do so. This is possible because the device receiving the input from the watch is connected to the WiFi at this moment and can therefore transmit directly to either the Philips Hue Bridge or the WiFi-module of the Roomba. By leveraging Android's *HttpURLConnection* functionality, requests containing JSON objects with or without authentication can be sent to the defined actuation devices.

[32] https://shop.smartthings.com/#!/products/smartsense-multi
[33] http://www.parrot.com/de/produkte/flower-power/
[34] http://www2.meethue.com/de-de/produkte/
[35] http://store.irobot.com/irobot-roomba-770/product.jsp?productId=11305110

4.7 Data Structure

In order to represent the functions of the Auteamate application, a data model centered around the notion of a *Scenario* element was created.

4.7.1 Platform Entities

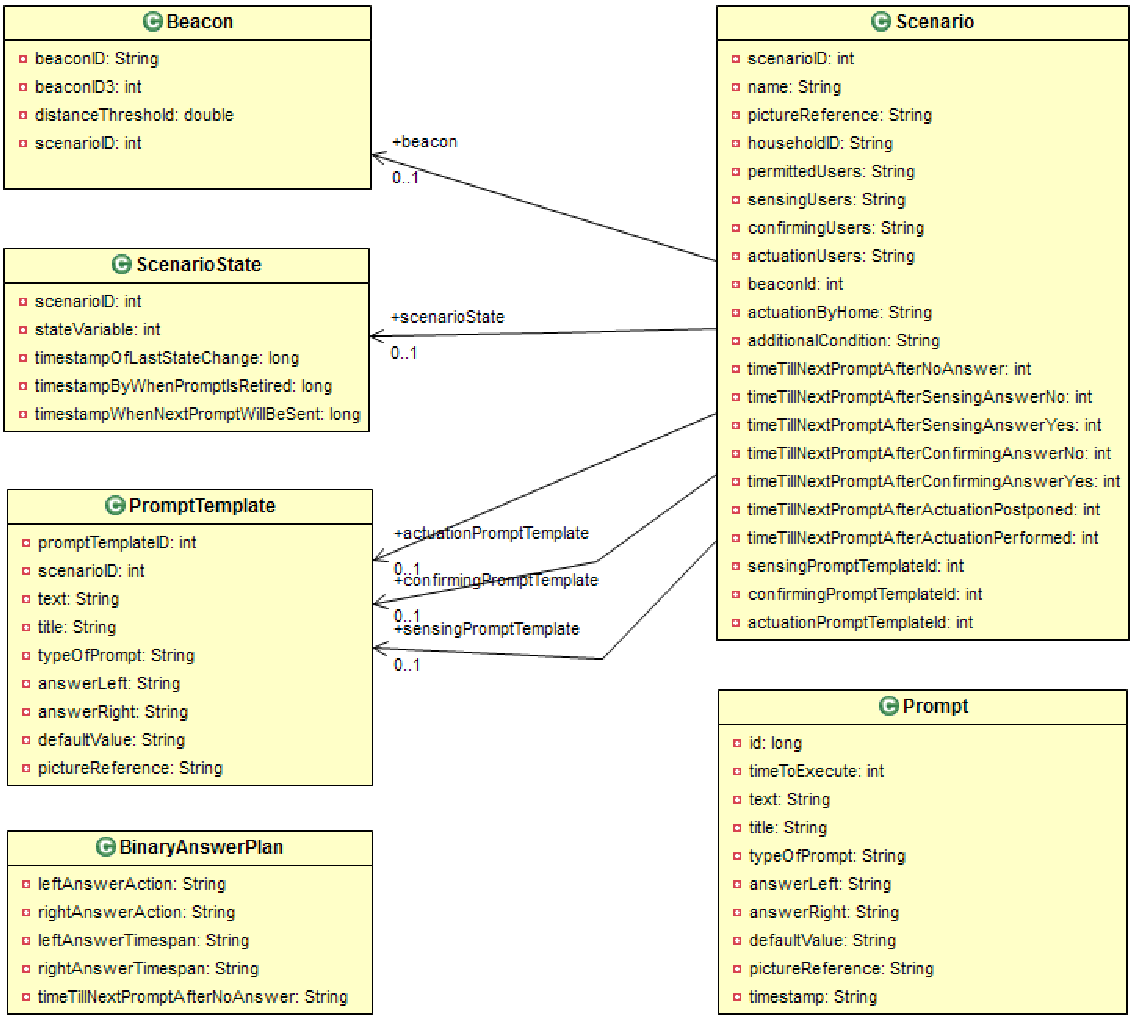

Figure 19: Platform Entities

The platform entities in Figure 19 depict the data model that represent the most relevant entities used in the Auteamate application. Main components are *Scenario*, *ScenarioState*, *PromptTemplate* and *Beacon* which are the only ones represented in the database, the other two entities are used as data transfer and aggregation objects.

Each *Scenario* has a reference to a *Beacon* which initiates the control flow upon discovery. All scenarios, beacons and prompt templates are only modified during configuration. The *ScenarioState* object, however, holds the current state of each *Scenario* and its related timestamps. Those states and timestamps are updated whenever a prompt is sent to a user or a corresponding answer is given by a user.

Every scenario can have up to three instances of *PromptTemplate* representing the sensing, confirmation and actuating prompts displayed to the user in conjunction with the particular scenario.

4.7.2 Scenarios

After the pre-deployment interviews that were conducted with the inhabitants of the households, the concrete scenarios for each of them were planned and configured. Finally, the following scenarios were integrated into the Auteamate application:

Scenario Name	**Sensing Prompt**	**Confirmation Prompt**	**Actuation Prompt**	**Notification**
	User is asked if...	User is asked if	User is prompted to	Remind user
Lamp Scenarios		...he wants the light switched on		
Vacuum Cleaning Robot	...the floor is dirty	...he wants the robot to start		
Washing Machine		...he just started a washing cycle		...if cycle finished
Plant with Sensor			...water the plant	
Plant without Sensor	...the plant needs water		...water the plant	
Garbage Disposal	...there is trash to take out		...take out the trash	
Garbage Small Cans	...small trash cans need emptying		...empty the small trash cans	
Laundry	...there are enough clean clothes		...take care of laundry	
Ventilation	...it is necessary to open the windows		...open the windows	...to close windows

Table 3: Scenarios in Application

Some of the listed scenarios were implemented for several instances. Especially the scenarios including lights and plants were configured for multiple lamps and plants.

Configuration Possibilities For each scenario, a range of values can be adapted. Starting from general aspects of the scenario like name or icon to texts and icons of specific prompts.

Every scenario has an associated *Beacon* and *ScenarioState* object as well as *PromptTemplate* elements representing the prompts as explained in Section 4.7.

Code Example 2 contains an exemplary scenario and its configuration aspects. First of all, the associated beacon object is configured taking in account the icon on the beacon for easy recognizability, the beacon's minor identification (id3), the threshold and the associated scenario id. After that, the scenario state is initialized with the associated scenario id, the initial state and the three timestamps (last state change, by when a prompt sent to the watch is retired and the point in time until a prompt is enqueued).

Each prompts' allowed users can be defined making it possible to restrict certain persons from receiving prompts. Furthermore, if there is a confirmation prompt defined, the related actuation has to be added and will be executed if a positive confirmation prompt for the scenario is received from the watch. Using those configuration possibilities, each scenario and its corresponding prompts can be configured to the individual needs of the household.

```
Beacon beacon10 = new Beacon("Bike",22644,4,10);
ScenarioState scenarioState10 = new ScenarioState(10, 1, sysTime, 0, sysTime);

Scenario scenario10 = new Scenario(10,"FloorDirty");
scenario10.setPictureReference("roomba");
scenario10.setHouseholdID("1003");
scenario10.setSensingUsers("7,8,9"); // users 7,8 and 9 are allowed to sense
scenario10.setConfirmingUsers("7,8,9"); // users 7,8 and 9 are allowed to confirm
scenario10.setActuationUsers("0"); // there is no actuation for scenario 10
scenario10.setBeaconId(22644);
scenario10.setTimeTillNextPromptAfterNoAnswer(5*60); // - 5min
scenario10.setTimeTillNextPromptAfterSensingAnswerNo(20*60*60); // - 20 hours
scenario10.setTimeTillNextPromptAfterSensingAnswerYes(0); // - immediately
scenario10.setTimeTillNextPromptAfterConfirmingAnswerNo(600); // - 10 min
scenario10.setTimeTillNextPromptAfterConfirmingAnswerYes(20*60*60); // - 20 hours
scenario10.setTimeTillNextPromptAfterActuationPostponed(0); // - not in use
scenario10.setTimeTillNextPromptAfterActuationPerformed(0); // - not in use

scenario10.setSensingPromptTemplateId(11);
scenario10.setConfirmingPromptTemplateId(12);
scenario10.setActuationPromptTemplateId(0); // actuation by user does not exist
scenario10.setActuationByHome("startRoomba");
scenario10.setAdditionalCondition("");

PromptTemplate promptTemplate11 = new PromptTemplate(11,10); // prompt 11 (sensing)
promptTemplate11.setText("Ist der Boden dreckig?");
promptTemplate11.setTitle("BodenDreckig");
promptTemplate11.setTypeOfPrompt("binary");
promptTemplate11.setAnswerLeft("YES");
promptTemplate11.setAnswerRight("NO");
promptTemplate11.setDefaultValue("NO");
promptTemplate11.setPictureReference("floor");

PromptTemplate promptTemplate12 = new PromptTemplate(12,10); // prompt 12 (confirming)
promptTemplate12.setText("Den Staubsauger Roboter starten?");
promptTemplate12.setTitle("RoboterStarten");
promptTemplate12.setTypeOfPrompt("binary");
promptTemplate12.setAnswerLeft("YES");
promptTemplate12.setAnswerRight("NO");
promptTemplate12.setDefaultValue("NO");
promptTemplate12.setPictureReference("roomba");

writeBeaconToFirebase(beacon10);
writeScenarioStateToFirebase(scenarioState10);
writeScenarioToFirebase(scenario10);
writePromptTemplateToFirebase(promptTemplate11);
writePromptTemplateToFirebase(promptTemplate12);
```

Code Example 2: Example of a Scenario Configuration

4.8 Control Flow and Conditions

Two sequential processes are central to the Auteamate prototype. The first process is triggered by sensing a beacon, whereas the second process is started upon receiving a user's answer to a prompt on the connected smart watch.

4.8.1 Beacon Sensing, Reasoning and Prompting

Every execution of a scenario is started by the system when a beacon is sensed. The ID and the distance between the sensed beacon and the mobile are then used to call the database about whether the beacon belongs to a scenario of the household and whether the distance is below the defined threshold. Upon return and if the beacon was found in the database, logging takes place so that every beacon sensing event is documented, even if the distance was above the defined threshold. Details about logging can be found in the next section 4.8.3.

If, however, the sensed beacon is within the defined distance, the *scenarioState* for this scenario is acquired which contains information about the current state of the scenario in question; whether a prompt is ready to be sent or has already been sent to the watch. In the latter case, it is checked if the prompt to the user has already expired or not, if yes, the state is reset and the execution is continued, otherwise the application terminates here to give the user time to answer the prompt that was already sent. In the other case, if there was no prompt already sent to the user, it is checked if the prompt in queue is ready to be sent to the watch or requires more time to become relevant again. For example after watering a plant, a timeout of more than one day is set.

The *Scenario* itself is requested from the database if the time stamp was already reached. This element contains all the configured attributes of a scenario, ranging from timeouts between prompts to prompt templates and additional conditions. Those additional conditions are checked next; they can represent time of day, day of the week or sensor readings. For example the scenarios for light should only be active if it is dark and also take in account the case that the particular light might already be on, so there is an additional condition defined representing this state. The same applies to scenarios involving plant sensors and sensors that register when a window was opened.

If the defined additional condition is true, the prompt template for the applicable prompt of the scenario is used to set the timeouts to the scenario state and assemble the data transfer object to be sent to the connected watch using the watch-communication classes. The data transfer object contains the question, possible answers, associated actions and the log id that was defined when sensing the beacon.

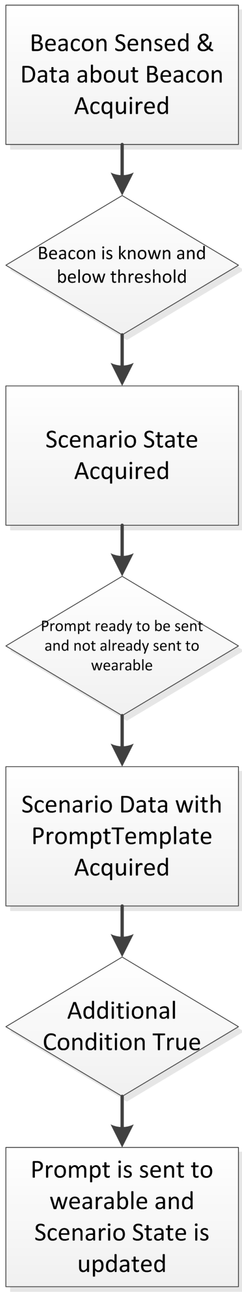

Figure 20: Control Flow

4.8.2 Answer Processing and Actuation

Upon receiving an answer from the paired watch, the corresponding scenario state is acquired and the user's answer is logged. Depending on the answer given by the user, a subsequent prompt is sent (eg. the user sensed that the floor is dirty, ask immediately if the vacuum robot shall be started) or an action is performed by the system. If the user confirmed that he wants the system to carry out an action like starting the vacuum robot or switching the light on, the applicable command is executed by the *ActuationStarter* class. Finally, the scenario state is saved according to the user's answer and the state of the associated devices is also reset. For example if the user indicated that he watered a certain plant, the time stamp is reset till the assigned sensor indicates that it is time to water the plant again.

4.8.3 Logging

The following paragraphs regarding log functions explain the two distinct kinds of logging that were implemented in the Auteamate application. All logging functions are carried out by the abstract class *LoggingHelper* whose class diagram is available in Figure 21.

Application Logging Because log data using the Android built-in logging system can only be acquired through the use of the Android Debug Bridge (ADB), it was decided to build a separate logging mechanism that logs application internals (debug, info, error logs) to the Firebase storage for retrieval without having to attach the Android device to a computer running the ADB software for logging. This offered the possibility to acquire crucial log data to retrieve points of failure during testing and deployment while allowing to walk around freely with the device.

In the application configuration screen, it is possible to set a logging flag which influences the kind of logs that are written to the database. A flag of 0 indicates that no application logs except errors are saved, whereas the flag 1 restricts logging to logs with level info. If the flag is set to 2 or higher, both application debug logs and verbose beacon-sensing information are written to the database.

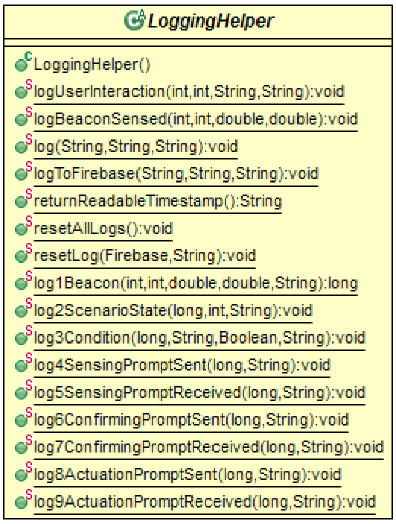

Figure 21: LoggingHelper Class

Incremental Logging of Scenario Executions Because one of the application's main use cases is the logging of user interaction and beacon sensing, a secondary logging mechanism was created with each log entry originating in the sensing of a beacon and documenting the application's inner reasoning about timeouts, additional conditions like time of day or sensor input to the transmission of questions to the user and responses.

In the previous section 4.8, steps among the control flow are explained in detail. A log id consisting of the milliseconds when the beacon was discovered is then passed along the control flow and every relevant interaction from system or user side is logged to the database with this log id. This offers the possibility to see each instance of a scenario execution from a holistic perspective.

4.9 User Interaction

As depicted in the storyboards and flowcharts in section 4.1, user interaction is to be as minimalistic and lightweight as possible. Therefore the application offers limited input and output and no user accessible configuration. The user interfaces for the watch and mobile phone are presented below.

4.9.1 Prompts and Notifications on Watch

In order to keep the application as simple as possible, only questions that require a binary (yes or no) answer were included in the final prototype. The design of the Auteamate application, however, would make it possible to include other questions upon creating an appropriate template for the wear app.

Each of those binary prompts included a symbol representing the scenario and a written question for the user to answer by tapping one of the icons on the bottom of the screen. An exemplary sensing prompt can be found in Figure 22. More exemplary prompts are available back in Section 4.2.3 on page 34

Figure 22: Sensing Prompt for Orchids

4.9.2 Dashboard on Phone

The dashboard can be used to see information about answers given by all inhabitants of the household. Besides scrolling, no interaction is possible through this interface. It's purpose is to make available the newest information for each scenario. So the most recent one or two (depending on whether there are one or two prompts for the particular scenario) answers given by an inhabitant of the household are displayed.

Scenarios are represented by the icon that is also displayed on the watch upon asking the question. This blue icon is accompanied by a short form of the prompt text, an icon for the answer, the name of the responder and how long ago it occurred.

In Figure 23, six scenarios are visible with the two different prompts for the vacuum cleaner scenario on the bottom and the two latest prompts for the plant with sensor on top.

User interactions are written to the database every time a user answers a question that was displayed on the watch as explained in section 4.2.4. The *userInteractionLog* entities are presented to the user in a dashboard on the mobile, taking in account the most recent one or two (depending on whether there are one or two prompts for the particular scenario) instances for every scenario in the defined household.

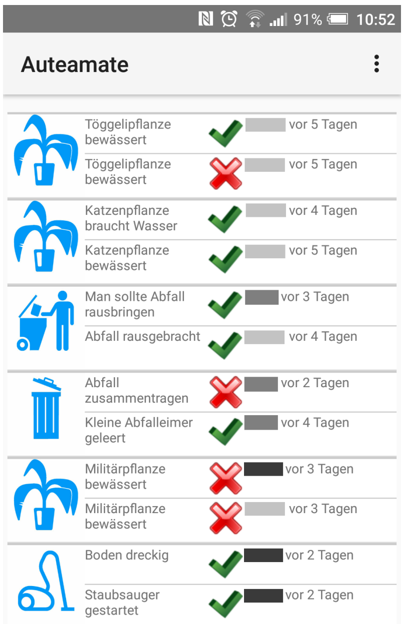

Figure 23: Scenario Overview Dashboard

4.10 Limitations of the System and Related Issues

4.10.1 Beacon Sensing

In the current state of the prototype, it is sometimes possible that a scenario execution is not started or initiated with a delay because the sensing of the beacons is not optimal. This stems from two issues that are both related to battery life and a design decision. Firstly, the beacons or nearables, which are broadcasting Bluetooth packets for the mobile devices to pick up, have their sending frequency limited due to their built-in battery that is neither rechargeable nor replaceable. By adjusting those sending frequencies a reasonable balance between sensing accuracy and battery life had to be found. Secondly, the beacon sensing part of the application is started in the background upon installing the Auteamate application on the mobile device which impacts the battery life of the devices even when the application is not currently open. This is intended since beacon sensing has to keep working even if the user's phone was not unlocked or active for hours. The newer versions (above 6.0) of the Android operating system use a function called *deep sleep* in order to reduce battery consumption during phases of inactivity which might cause the application to be halted, but this background sensing function needs to keep running in order to enable the phone to pick up beacon signals reliably. In an approach to counteract this limitation posed by the deep sleep function, the beacon scanning application is restarted every five minutes (which is the minimal time span after which an *AlarmManager* can be invoked). Other configured scanning intervals as defined in the application and executed by the *Handler* function of the operating system are then able to start again.[36]

As mentioned in Section 4.4, the open beacon library from Altbeacon was used for the application. This library, although being one of the most versatile and customizable beacon libraries, does not appropriately support all packets sent by Estimote stickers. Of the three different kinds of packets sent by the stickers, only one is picked up by the library. This can be attributed to the fact that this particular Estimote stickers protocol was not even published when the development of the Auteamate application started. Other libraries like the official library by Estimote would be able to handle the sensing of Estimote stickers in a more efficient manner because they support the nearable's most broadcasted packets, but every beacon application would nevertheless be exposed to the deep sleep function of the Android operating system. Beacon sensing accuracy and battery life of the used devices have to be balanced in order to achieve a satisfactory user experience.

Another problematic aspect regarding beacon sensing is the fact that every device has different Bluetooth sensing and processing hardware. Although this has not been an issue for the two main deployments of this study because every participant was issued with an identical phone for the duration of the study, this could lead to some devices picking up the beacon signals more reliably thus displaying prompts more often resulting in an uneven task distribution among inhabitants.

4.10.2 Connection Reliability

Because the states of all scenarios have to be synchronized among clients, calls to the database holding that information are necessary for the functioning of the application. The device consequently has to be able to reach the database infrastructure to access this information which in absence of cellular radio connection means that the phone has to be connected to the WiFi network of the household. Both households involved in the study had a rather big parameter to cover with its WiFi access points which occasionally caused the mobile devices to lose connectivity.

[36] http://altbeacon.github.io/android-beacon-library/resume-after-terminate.html

There is evidence of certain beacon detections having been delayed because the database was not readily available due to Internet connection issues that can be attributed to poor WiFi reception. In the second household, this problem was handled by installing a second access point to boost coverage in the basement especially for the washing machine scenario. While this measure improved the connectivity, it did not solve the occasional disconnection of the phone from the WiFi network due to system-induced power saving measures. A possible solution would be to install SIM-cards with data connection so that the operating system of the mobile phone can fall back to a cellular network connection when saving power.

4.10.3 System Initiates Prompts

By design, every scenario execution (checking of timeouts and conditions possibly resulting in a prompt to the user) is triggered by the sensing of a nearby beacon. So a user has no possibility to initiate a system action on his own. Additional information about this limitation and how users of the system perceived it is available in Section 5.5.2.

This design decision is intended to simplify user interaction and reduce the amount of controls the users are exposed to during the short two-week deployment period.

4.10.4 Interfacing with Diverse Systems

In order to be beneficial for users, a smart home system needs to be able to interact with systems that the users have in their households and offer easy extensibility through open interfaces. Currently sensors are connected using the possibility of the event-based system offered by IFTTT and a shared database to keep track of device states and actuation devices are triggered directly by the Android app.

Another aspect regarding connectivity to sensing and actuation systems is the fact that in the current state of the Auteamate application, the Android application directly interfaces with those systems using a shared database. This limits the execution of tasks to situations when at least one occupant's mobile device is in the home WiFi network to send the command to the device. One exception was the PHP script that was executed on a web server to enable the possibility to turn off lamps automatically without an inhabitant having to be at home which is explained in Section 4.5. Additional information about interfacing with other systems can be found in the future work chapter in Section 6.1.1

5 User Study

In order to evaluate the prototype and acquire data and insights about the usage of the prototype, a twofold approach was chosen; a user study with deployments in two households and a third deployment in the household of two experts regarding human computer interaction. It should be noted that the study participants do not constitute a representative sample of households as the participants were recruited from the authors' circle of acquaintances and friends and both households evaluated, were located in the same village. These aspects place restrictions on the generalizability of the described findings, but nonetheless provide interesting insights into how participants without smart home knowledge experience deployments of such systems in their households.

5.1 Study Approach

The user study consisted of an initial pre-deployment semi-structured interview at least a week before deployment and a final post-deployment interview after deployment.

5.1.1 Study Participants

Six participants from two households were involved in the pilot study deployment, one of them was female. Average age was 30 with a standard deviation of 12.1. None of the participants had prior experience with smart home systems. All participants reported to own a smart phone and indicated that they use their smart phone several times a day. So they all had a certain familiarity with those devices, but otherwise do not posses technical knowledge about computer science or smart home systems. The deployment phases for each household had a length of two weeks during which the participants used the system on a daily basis.

In addition to the two households mentioned above, two other participants were involved with extensive knowledge about home automation and human computer interaction due to their employment as computer science researchers. They also have prior experience with smart watches. Both had been using an Apple Watch prior to the study deployment for at least half a year. The Auteamate system was deployed in their household in order to obtain high level feedback about the interaction with the system and its implications.

In the following sections, results from participants include the two households for which a full deployment and post-study interview was conducted. If input from the expert household is relied upon, it will be explicitly mentioned.

5.1.2 Scheduling of Interviews and Justification

For the main study participants, two interviews were conducted with all members of the household. A pre-deployment interview took place to both inform the tailoring of the system to their households and acquire information about their household routines. The post-deployment interview was mainly geared towards establishing how the system impacted their household routines and to elicit limitations as well as possible additional functions that were inspired by the usage of the system.

5.2 Households

Two households, one of them a family home in a semi-detached house and the other a shared flat in a rented apartment, were considered in the study, both were located in Malters near Lucerne in Switzerland.

5.2.1 Information about the Persons and Households

The setting of the two households observed in detail is quite different. Whereas the first household consists of a family; a mother living with two of her adult sons who are both currently pursuing an additional education, the other household consists of a shared flat of three men aged 26 to 27 all currently working full time.

5.2.2 Implemented Scenarios for Each Household

In the two previously mentioned households, a vacuum robot, two plants with sensors, one plant without a sensor, three lamps, a small trashcan emptying, a garbage pickup and a washing machine scenario were deployed. For those two households, post-deployment interviews were conducted and log data was investigated. The scenarios for those two households were very similar apart from the naming of certain devices, which can be attributed to the fact that the family home, due to the age of the children, is also organized like a shared flat. Two of the three participants mentioned this aspect during their pre-deployment interviews.

For the expert household, different scenarios were prepared based on the input gathered in the pre-deployment interviews and high level feedback was obtained after the deployment phase. In this case a vacuum robot, a plant with a sensor, a plant without a sensor, three groups of lamps, a small trash can emptying, a washing machine, a ventilation and a laundry scenario were deployed. Detailed information about the deployed scenarios in all three households is available in Appendix A.

5.3 Pre-Deployment Interviews

Interviews at least one week prior to the deployment phase were conducted with all three households.

5.3.1 Goals of the Pre-Deployment Interviews

The semi-structured pre-deployment interview was conducted in order to obtain information about existing routines, which of those tasks could be (semi) automated, how inhabitants coordinate their household tasks, if and how they schedule or track their work and if some of those tasks pose any problems. A list of possible scenarios was also presented to the participants, they were then asked if those tasks are applicable to their household and if they would be feasible to address in the study which was used to improve deployment preparation and provide input for configuration of the scenarios.

5.3.2 Insights About Household Tasks

The two observed households both have a quite similar set of household responsibilities to deal with. Members of household number two, which is a shared flat, have a distinct set of tasks to do on their own and certain tasks that concern the whole household. The first household also shared this characteristic which can be attributed to the fact that although being a family, their responsibilities are distributed like in a shared flat. All three participants of the family household even mentioned this as one of the notable characteristics of their household: "We are a family that lives like a shared flat, we all have our own spaces and household responsibilities." This resulted in the fact that all participants had to look after their own room themselves, do their laundry and buy their own sanitary products and other personal belongings.

The remaining tasks that concern the whole household are distributed among all inhabitants. In the case of the family home, the specific tasks are allocated to one person and the time when they are supposed to do the tasks is not fixed. For the shared flat inhabitants, however, the time when they take care of their tasks for the household community is fixed in terms of usually being executed on Saturday or Sunday. They normally change who does the specific tasks in order to distribute the workload more evenly. In conclusion, task allocation is not fixed, the time when performed is. This directly contrasts the family home mentioned before, where the task allocation is fixed and the time is not.

As the family household is rather flexible when to perform the household tasks, those tasks are often postponed and done at a time when it is more convenient. One participant mentioned that he does not do his tasks if he knows that he will have some spare time to do them in the upcoming days. But he carries them out when he knows he will be busy the next days, even if he has limited time at the moment.

Several participants mentioned that the use of the system allowed them to easily postpone tasks and they knew that they will be prompted again, so they do not have to think about that task anymore. It was also found that the visibility of household tasks has an impact on whether those tasks are an issue for the participants.

5.3.3 Insights About Collaboration

The fact that there are both tasks that concern the whole household and tasks that only concern one person has an impact on how the participants coordinate their tasks and work together. Inhabitants of the family home have expressed that they were quite often reminded about their tasks for the household community if they were necessary. The shared flat participants mentioned that usually someone of them mentions the fact that cleaning was necessary and then they shortly discuss who takes over which part resulting in a short re-allocation of those tasks. So they coordinate their responsibilities for cleaning the apartment in a rather ad-hoc fashion without keeping a schedule or plan.

Both households did not have any schedules or plans on paper or in electronic calendars. All participants said that they do not use any planning or tracking tools in order to keep the overhead for organizing household tasks as low as possible. One of the shared flat inhabitants also mentioned that a few years ago when they had another person living with them, they had such a list in which everyone could write down what they did for the household to have some kind of proof to show their flat mate at the time that he has to do some tasks. This proved useful to distribute responsibilities more equally in the past, but was not continued after a change of tenants because it was no longer necessary.

Some tasks were dealt with by one person only, according to their possibilities. While two members of the shared flat household have their own cars and take care of cardboard, glass and other recycling tasks requiring large or heavy things, the third inhabitant concerned himself more with ALU or PET recycling which is lighter and can be carried when walking to the grocery store.

5.3.4 Scenario Selection and Tailoring

Several scenarios that were introduced in Section 3.3 were included in the interview questions in order to find out whether it makes sense to deploy them in the households. The applicability of those scenarios was assessed by probing the participants about their household tasks and habits regarding tasks that are often forgotten or pose other problems.

A likert scale table with scenarios which could possibly be deployed geared towards establishing a baseline for later comparison was added to the questionnaire. Results for the six participants are available in Figure 24. The scale went from 1 to 7 with one being *not helpful at all* and seven representing *very helpful*.

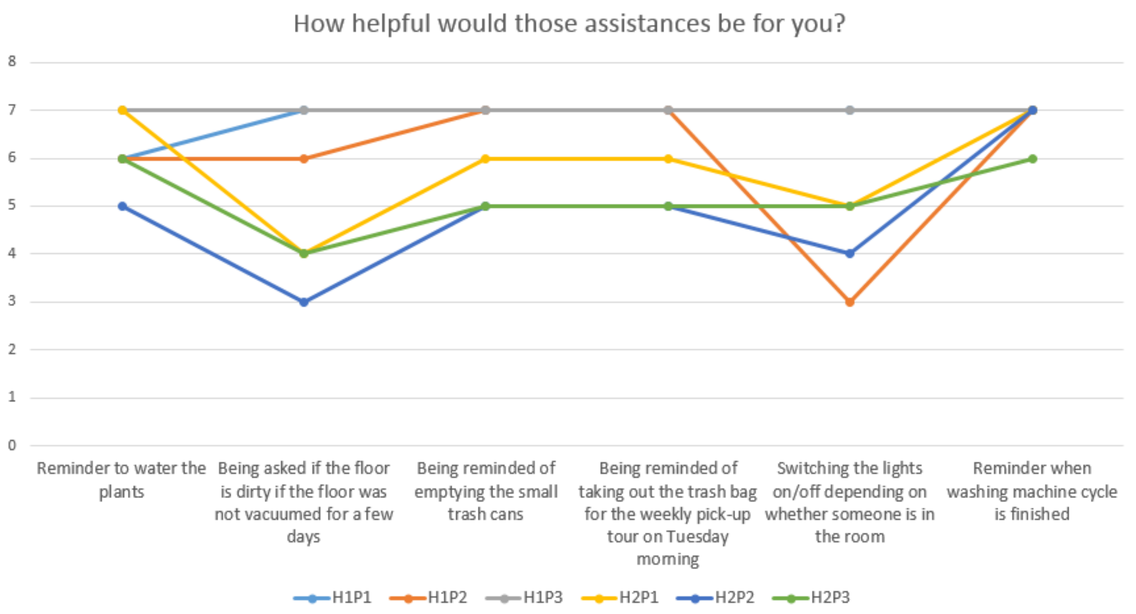

Figure 24: Anticipated Helpfulness of Assistances before the Deployment

Assistances for which the benefit is clearly understandable achieved higher ratings with the reminder when a washing cycle is finished being the one rated most helpful by the participants. Reminders about plants and trash disposal were also rated comparatively higher than the others, whereas assistances involving a system taking action were rated lower.

In general, household tasks that are clearly visible when necessary were not perceived to be a problem. Both households were universally uninterested in any reminders about their dishwasher, the participants mentioned that this would only introduce additional overhead without offering any benefits, because it is clearly visible what needs to be done.

Additionally, questions aimed at finding out about frequency of execution of household tasks were included. The rationale behind these questions was to find out which tasks make sense to in the deployment, because it was decided to focus on tasks that occur frequently due to the short time available for deployment. Input regarding how often tasks are performed also informed the configuration of the timeouts set in the scenario configurations.

5.4 Deployment Procedure and Study Conduction

The procedure of deploying the smart home devices and equipping the participants with phones and watches was structured in three steps.

First the devices were installed in the households. This proved to be quite time consuming and posed certain difficulties caused by the layout and characteristics of the flats. Mainly the availability of power sockets, placement of network devices and coverage of the WiFi access points were an issue. Of course the participants' preferences had to be taken in account as well.

The participants were provided with the devices and accompanying chargers at least three days before installing the rest of the smart home equipment. When handing them the devices only information about the smart watches and phones in general but no explanation regarding the Auteamate application was provided. Therefore they had to be instructed concerning the usage of the watch and phone user interface. The participants were subsequently shown how the prompts of the system will be presented and how to answer the prompts as well as how to ignore prompts by swiping them off their wrists.

Finally, the preliminary configuration regarding distance thresholds and timeouts was tested, discussed with the inhabitants and refined to match the household as close as possible. Following these tests and adjustments, the participants were invited to walk around their homes and explore the possibilities of the system in-situ. During this phase, the scenario timeouts (time stamp by when the system asks again about a certain scenario) were constantly being reset to ensure every participant had the opportunity to see every prompt in action.

After this presentation phase, the participants were asked to report any problems with the system as soon as possible and given the opportunity to ask questions about the system, involved devices and acquired log data. Participants were also asked to keep the phones and watches with them during the study duration, recharging them overnight besides their beds and taking them with them when they leave the house.

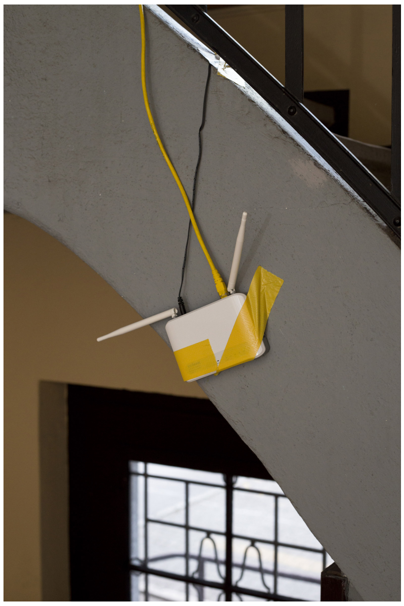

Figure 25: Additional WiFi Access Point to Cover the Basement

Figure 26: Stairway with Cables to the Additional Access Point

Home Automation Devices Installing the devices turned out to be a challenge itself, even though the interfaces and all configurations that were possible in advance were already defined and tested. The exact placement of lamps and other devices needed to be in accordance with the household routines and preferences of the participants. Also the configuration of the home network devices that were already in place regarding the integration of the Hue Bridge as well as the WiFi module of the Roomba had to be done so that the commands originating from the participants' phones are correctly transmitted to the devices.

Figure 27: Beacon Placed Besides a Window

Figures 26, 25 and 27 depict selected installation aspects of the deployment. Section 4.6 contains a picture with all deployed equipment in the second household as well as additional information regarding the involved devices.

5.5 Findings of the Post-Deployment Interviews

After the two-week period of the deployment, a second semi structured interview was performed with the six participants. The questions were based on input from the pre-deployment interviews, logging data and other informally obtained feedback during the study. The objective of the post-deployment interview was to shed light on the aspects covered by the proposed research questions. The aim of these interviews was therefore to elicit possible impacts on collaboration, what limitations the participants perceived, what use cases the system inspired and what future applications such a system could have.

Logging data acquired during the deployment phase was used to complement the participants' statements given in the post-deployment interviews. Because the expert household provided high-level feedback regarding the use of the system and its implications, post-deployment interviews were only conducted for the first two households.

5.5.1 Perception of the System

As all six study participants had neither prior experience with smart watches nor smart home systems, using a system integrating those aspects was therefore a new experience for them. First of all, the concept of receiving notifications on a watch was perceived to be a novel experience, but expected by the participants due to the information given before the study.

In general the system was perceived to be beneficial as one of the participants mentioned "it makes things easier because it reminds about certain things and can even perform certain tasks on its own". It also had an impact on how much thought had to be spent on whether tasks like watering plants were really necessary.

However, one participant mentioned that the usage of the system did not have an impact on how he perceived household tasks and their execution. The person in question was used to rarely having to think about household tasks as the other flat mates usually came up with the suggestion to get their chores done.

5.5.2 Limitations

One of the most limiting aspects of the deployed system perceived by the interviewees was the necessity to keep both the smart phone and smart watch with them all the time. This also included having to recharge both devices on a daily basis. Almost all participants mentioned that this is fine for such a user study lasting only two weeks, but if they wanted to have such a system deployed for a longer time, this would become an issue for them. In order to counteract the possibility of the participants forgetting to take the devices with them it was encouraged that participants use the smart watch as their alarm clock in order to remind them to put the watch on when getting up. The thought behind this request was that otherwise the interactions with the system would neither be possible nor be tracked during the morning routines before leaving the home. Having to carry around an extra device and charge it daily were perceived as a nuisance by most inhabitants, however, one person mentioned that she really liked that she had to take off her watch during the night which led to a calmer sleep and provided her with an unobtrusive clock on the nightstand.

Figure 28: Kitchen Lamp

Figure 29: Plant With Sensor

Figure 30: Vacuum Robot

The accuracy of the system regarding spacial awareness was also mentioned by two persons. One member of the second household said that the system often asked him about the plant outside his bedroom when he was in his room which annoyed him. This happened on 2 or 3 evenings. Another member of the second household mentioned that he was sometimes prompted about the light in the living room, although he was currently standing on their balcony. The reason for both those prompts that were expressed to be annoyances can be traced back to suboptimal beacon placement and/or beacon threshold configuration. Apart from those two instances, participants did not express that they were annoyed by the prompts. Even those two participants remarked that it was not that bad of a nuisance since it took only a few seconds to deal with the falsely appearing notification.

Other limitations mentioned by the participants were that the system sometimes asked about a fact or requested the person to do a task repeatedly although they did not have time to give an answer or perform the task. The prompts were perceived to be less appropriate depending on the circumstances. Situations when participants did not like the system sending them prompts was for example in the morning while in a hurry, during lunch or while reading. One participant living in the first household mentioned that sometimes the system asked to check if the plant that is not equipped with a sensor needs water long before watering was really necessary but the same participant also added that "this did not concern me, because I only had to tap "no" on the watch and I liked the fact that I was reminded of my beautiful plants from time to time."

The participant who previously took care of the plants in the second household mentioned that he was asked to water one of his plants far too often considering his experience concerning this particular plant. This inaccuracy can be traced back to the configuration of the plant sensor used for this plant. Watering schedules are dependent soil humidity levels which differ from plant to plant which resulted in a wrong assumption of the needed water.

5.5.3 Inspired Usages

The possible additional use cases both based on devices already present during the study and new applications ranged from strictly household task faced use cases to more general usages of reminders or supporting systems.

Some functions already available in the home automation context astonished the users, especially the possibilities to start devices like the vacuum robot and the lights from the watch. That so many devices can be connected to each other and how this equipment can work together to achieve a holistic system controlled via smart watch was met with excitement by two users.

Ideas regarding future extensions of the presented system or other applications that support tasks in the domestic context were already mentioned during setup of the system and were complemented during the final interviews. It can be proposed that the usage of the system by persons who had no prior experience with smart homes or home automation technology inspired them to think ahead and anticipate their own needs with regard to home automation. In order to elicit possible automation scenarios for households it could prove to be beneficial to expose the interested persons to even a short period of usage of such systems "in the wild" before they have to decide which possibilities they want to have implemented in their homes as mentioned in Section 2.1.

Suggestions made by the participants regarding improvement of the Auteamate system are explained in Section 6.1.1 whereas general smart home applications that were inspired by the usage of the system are briefly explained here. Three participants mentioned that a door locking system would be nice to have that either works with a localization technique that was used during the study or biometric access, also the heating system could adapt to the inhabitants since it already knows who is at home at which time.

Further two participants expressed they would like to have more advanced robots in their household if possible. Robots with capabilities for window cleaning, wiping the floor and dusting were mentioned.

Other possible applications for reminders were mentioned as well. Especially reminders inferring from context that the stove or burner needs to be turned off in case you forgot it (safety) or that a device is not longer necessary to be operational (conserve energy). Reminders not even necessarily in the domestic context were also discussed; for example reminders to check if all lights of your car work or oil and tire pressure are ok. The rationale behind those reminders, as expressed by the respective participant, was that reminders make sense if things are not visible at the moment.

Further use cases ranged from more sophisticated lighting for every room and new features like for example presence simulation, electronic locks, advanced robots that could dust on their own or wipe the floor, irrigation systems for plants, food-dispenser for cats, heating based on presence, also other reminders were mentioned like fetching the mail, or very infrequent things like checking the heating oil or even tasks regarding their cars; check lights, oil, tire pressure and so on.

Finally one participant mentioned that he would like to have a guest mode if he were to have sophisticated smart home functions installed in his home. Other persons should be able to use the flat "in a traditional way" if he is not present.

5.5.4 Effect on Collaboration

Collaboration, meaning working together to achieve the shared goal of fulfilling the household obligations in an efficient way, was answered in the affirmative by most participants. One of the participants also mentioned that the household tasks were performed more thoroughly because the system notifies the inhabitants about the necessity of them. For most participants the knowledge about necessity of such tasks had an effect on their motivation to do those tasks. For example three participants said that they did the task right away if they had time, two of them attributed this to the fact that they like to keep their to-do list clean and do not like to postpone things that can be dealt with immediately. One of these participants also mentioned that he sometimes intentionally did not do the task that was asked for by the system in order to *leave some work for the others*.

Regarding coordination between inhabitants, the system had various impacts. The dashboard available on the mobile phone provided means to see who most recently performed each task. Four of the six participants consulted this overview from time to time to see if tasks are being done by the others as well as checking up on the system if they suspect that the system might not work properly because they have not been prompted recently. He then could see that the particular task he thought he had to do was already performed by another person as one participant added.

Another impact mentioned by more than half of the participants was that the kinds of tasks they did themselves had changed. For example one person did previously never water the plants in their flat and started doing so when the system asked him to do it. Similarly, one person never took out the trash in the recent months, but did so after the system reminded him.

A more equal task distribution among inhabitants was mentioned by three participants. One of them described the effect with the following statement. The system assigned tasks to other persons in the household which led to the situation that certain things were already done without me having to assign it to someone or doing it myself. The effort was therefore distributed among the inhabitants more evenly.

The fact that some inhabitants have not been involved in certain tasks prior to the study led to discussions how to perform specific tasks. For example it was discussed about how much water particular plants needed because the person who was prompted by the system to water the plants does normally not water the plants. The use of the system therefore mixed up the responsibilities for certain tasks and, at least temporarily, redistributed task execution among the inhabitants.

Members from both households mentioned that it is common that they remind each other of tasks they should perform which they do not like doing. The burden of having to remind others and being reminded by them for certain tasks could be shifted to the Auteamate system. Three participants mentioned this to be beneficial to them. Also two interviewees explicitly expressed that the system was able to remind inhabitants in a more neutral way. Other household members tended to remind each other in a more reproachful way according to those two inhabitants.

5.5.5 Scenarios and System Functions

In general, participants liked the scenarios better for which the system was able to perform the necessary actions. This can partly be attributed to the fact that users expressed that they are fascinated by seeing devices in action after confirming to start them on their watches. It was also mentioned that they are happy that the system can take over certain tasks for them.

The questionnaire for the post-deployment interviews also included a likert scale table. This time listing the specific scenarios installed in the households. Differences between the results given in the pre-deployment interview and after the deployment phase are visualized in Figure 31.

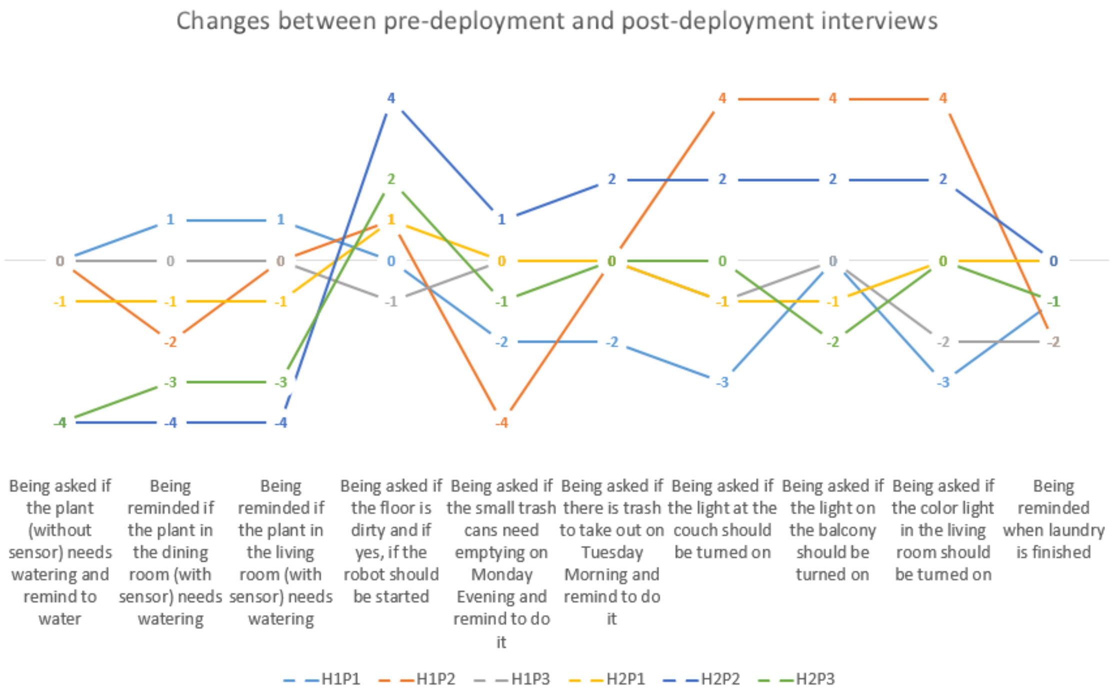

Figure 31: Difference Between Anticipated and Perceived Helpfulness

Results from the pre-deployment interviews revealed a preference for scenarios whose benefits were easily understandable and a relative disfavor for scenarios involving system actuation. The answers given by participants in the interview after the deployment, however, present a different situation. The two scenarios rated highest in total were the vacuum robot scenario introduced in Section 3 and the scenario that reminds occupants to dispose of the trash on Tuesday morning. Scenarios related to plant watering have been rated lower after deployment, especially by the members of the second household. From the result given by the participants and their responses in the interviews it can be deduced that knowledge about the system's capabilities and the expectations of the users affect their perception of usefulness.

	Actuation by Home	Actuation by Occupant
Confirming Occupant	Lights	Plants with Sensor Washing Machine
Sensing Occupant	Vacuum Robot	Plant without Sensor Garbage Takeout Small Garbage

Table 4: Scenario Quadrants

Table 4 lists the scenarios integrated in the Auteamate system with respect to the quadrants established in Section 4.1. Scenarios involving actuation by devices were slightly favored over scenarios involving user actuation by the inhabitants based on the interviews. But the perceived usefulness depended mainly on how simple it is to use and how clever a scenario integrates into their routines. The scenario reminding users when the washing machine they started is finished required very limited input but provided a simple assistance which resulted in a high perceived usefulness.

The median time till a user tapped an answer to a question after sending it to the watch was around 8.5 seconds for the first household and around 9 seconds for the second. Values were slightly lower for confirmation prompts (the prompts asking for confirmation before the system itself takes the action) between 7.9 seconds and 8.4 seconds in household one and two, respectively. The time till the participants answered sensing prompts and actuation prompts in which case the user is required to do something first was a little longer. For example the prompts to water one particular plant equipped with a sensor in the second household took a lot longer to answer than prompts for confirmation regarding turning on the light in the same room.

A possible reason for this difference that is consistent in the observed households is that the user needs to either check on something for sensing prompts or actually do something for actuation prompts whereas he can let the system do the work in case of confirmation prompts. One participant also mentioned that he considered doing a task in terms of how much work it entails. *If a prompt would result in a lot of work for me I would think twice if I accept the task.*

In the beginning of the deployment, participants in both households slightly tended to give answers for the prompts more often. During the subsequent ten days of the study they left them unanswered more often. That they were eager to use the system during the first days makes sense and can be attributed to the novelty effect such a system has. Other effects regarding the percentage of answered prompts happened due to absence of household members or cannot be explained with the existing data.

Grouped by time of day, there were differences regarding the weighted percentage of answered prompts; between 4pm and 11pm prompts were answered with a chance between 6 and 7 times higher than during the remaining 15 hours of the day (37.5% to 5.5% in household one, 50.7% to 7.8% in household two). While this can largely be attributed to the fact that there are a lot of unanswered prompts during the night due to the phone and watch sometimes not being in the bedrooms, resulting in the system falsely assuming occupants are near plants or lights because the devices were left there. On the other hand this result can also point towards the fact that participants tended to deal with the prompted tasks if they had the necessary time, which was available more abundantly in the evening as four participants mentioned.

Three participants finally mentioned that they liked that the system told them to do things because it makes them more efficient. *A lot of things are dealt with right away, so those tasks do not pile up over time.* Or as another participant puts it: *What I liked in particular was that when a prompt* *appeared you could either do it right away when you had time which had a positive impact (sense of having accomplished something) or postpone the execution for myself or someone else without having to feel guilty about it or having to remember that it needs to be done.*

Input concerning the concept and the deployed prototype was also obtained from the third household consisting of experts in human computer interaction, home automation and computer science in general. Their input is structured into two main aspects; linking of place and time and meaningful repetition of prompts.

One of the limitations of the study prototype previously expressed is that beacons near the participants' devices sometimes were not sensed in a usefully short timespan. The time delay before displaying a prompt to users impedes the connection between location and interaction for users. The usefulness is reduced if, for example, a prompt appears 20 seconds later, asking whether the occupant wants to be reminded when the washing machine has finished the washing cycle.

Regarding the meaningful repetition of prompts it was found that it is beneficial to have prompts displayed based on the context. For example if it is getting dark (or based on time of day) a confirming prompt appears to inquire about switching on the light. The repetition of this question, however, is difficult to acquire; on one hand users should have the possibility to change their answers if circumstances change, but on the other hand users should not be bothered if input is not necessary. As a possible solution, a control interface could be introduced based on the proximity to the surrounding scenarios that affords changing a previously given answer. For example if a user answered "No" for a prompt to switch the light on at 6pm and stays in this area, he might want to switch the light on at 6:30pm. An interface offering the possibility to update the answer could therefore reduce the need to repeat prompts after certain times and thus alleviate the possibly annoying effects on users. The balance between annoying the users with numerous prompts and providing them with meaningful assistances regarding their household routines is difficult to achieve.

6 Future Work

6.1 Prototype Improvement

6.1.1 Functional

The most important functional improvement of the Auteamate system would be to offer the possibility to initiate smart home functions from the smart watch started by the user without the system having to prompt for input.

In the current state of the application, users are provided with prompts that they can answer. Those prompts are sent to the watch of the inhabitant based on proximity, scenario timeouts and additional conditions. Participants said that they were interested in initiating such functions even if *the system does not think it is necessary*. Because it might take a moment for the system to notice a user being in proximity of a scenario, the user should be offered the possibility to start an interaction on his or her own.

Regarding tasks, users expressed the need for a possibility to *check [a task] off the list* even if the system does not ask someone to do it. For example sometimes one might want to water all plants in one go and be able to tell the system that they were watered so it can keep track of what was done.

New features of the application could include offering the users the possibility to start system actions themselves. By displaying all nearby scenarios for which the execution can be taken over by the system, users have more control over the devices installed in their homes.

In order to improve the accurateness of the prompts regarding lights, brightness sensors could be installed. As opposed to a time-based estimation of brightness, this feature would make it possible to display prompts regarding the light more accurately.

Another feature that was mentioned by a participant would be the following: A scenario which prompts every person in the household (not somewhere specific) to empty their small trash cans on Monday evening so that the person who will take out the trash on Tuesday morning only has to take one trash bag.

Finally, by including an always-on central coordination device, as most smart home systems currently have, operation of devices (e.g. switching off the lights) can be done more easily when no inhabitant is present and additional features can be enabled. For example the feature to schedule the start of the vacuum robot to a certain time when nobody is at home.

6.1.2 Performance

As the aspect of beacon sensing was a limitation imposed by using the chosen Altbeacon framework and the way Bluetooth beacons work in general, improvements regarding beacon detection would improve the usability and experience for users. To enable the system to sense beacons more accurately, a reasonable balance between battery life of the devices and beacon scanning intervals and durations needs to be achieved. By using a beacon library more suited to the particular type of beacons could prove to be beneficial because it could offer the possibility to pick up other beacon frames sent which occur more frequently thus improving responsiveness.

The time from beacon sensing to the display of a prompt on the participants' smart watches was normally between half a second and a second but in some cases took up to four seconds depending on the connection of the mobile phone. Because there are three calls to the database in case of a prompt being sent to the user, those times vary depending on the connection to the database.

An approach that can improve the responsiveness of the application greatly is to flatten data structure; instead of having the beacon data, scenario state and the scenario date in separate entities, an aggregate entity could be retrieved from the database. This would increase the amount of data transferred but reduce database calls down to one per scenario execution.

Another possible approach to reduce the number of database calls could be to include the possibility to cache certain information like the beacon IDs and their thresholds locally. As more than 90% of all scenario executions result merely in the beacon distance being greater than the defined beacon threshold, this would greatly reduce the calls to the database for those frequent cases.

6.2 Casalendar Integration

Instead of displaying the performed tasks in the dashboard depicted in Figure 23 in Section 4.9.2, those tasks could be displayed using an interface based on the one described in the related work Section 2.4 about visualizing smart home information.

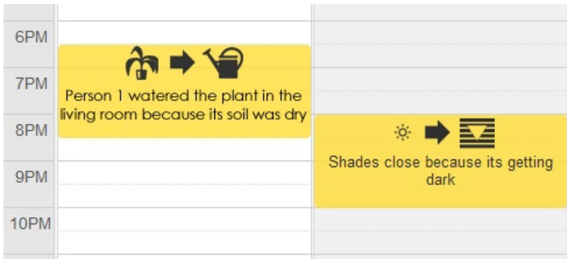

Figure 32: User Action Displayed in Casalendar Interface[37]

As the Casalendar interface is intended to support existing interfaces it could be added as an alternate representation only. The form factor of the dash board in the Auteamate system is also different (smart phone screen) compared to the Casalendar interface on a bigger touch screen.

Figure 32 gives an impression on how a household task performed by an inhabitant in the Auteamate prototype could be represented in the Casalendar interface among automated smart home actions.

The possibility to have an overview regarding the actions taken by other occupants and the smart home system was confirmed to be beneficial by the participants of the user studies. Making this information available in a more naturally understandable way as Mennicken *et al.* described could prove to be beneficial to the understanding of the smart home system [31].

[37]Based on Hofer, pp.76-79, [23]

7 Conclusion

In this chapter the findings from the previous sections are consolidated and discussed. Strengths and weaknesses of the approach are summarized and an outlook is provided.

The overall goal of this thesis is to provide information regarding the improvement of collaboration between inhabitants and smart homes taking in account their respective capabilities. By deploying a prototype system in participants' households, inputs regarding the impact of using such a system as well as limitations and perceived benefits could be identified.

In general it can be said that the usage of the Auteamate system had an impact on collaboration. By involving the users as an integral part of the smart home system and thus relying on their capabilities to provide input and carry out actions, inhabitants felt more involved an understood the limitations of the system better.

Can a context-aware task notification system be used to facilitate collaboration between home and inhabitants? Collaboration is understood as a joint effort of inhabitants to accomplish a task, in this situation doing the household tasks. The participants expressed quite different attitudes towards working together to accomplish that goal: Inhabitants of the first household used the system to track what was done, discussed for example how much water a particular plant needs after being prompted to water it and overall perceived a more equal task distribution among inhabitants through the use of the Auteamate system.

Participants of the second observed household however expressed an impact on collaboration only for the one scenario that impacted them all equally, the scenario that reminded to dispose of the garbage on the designated day.

How does a context-aware system on a wearable device integrate into inhabitants routines? Having notifications on the smart watch is a new concept for the participants. The perception of the system reminding you of something you need to do compared to the perception of another person reminding you is quite different. Whereas a prompt by the system is perceived to be neutral, occupants reminding other inhabitants appear more reproachful.

Overall, the system integrated well into their routines according to the interviewed inhabitants. Fewer household tasks were forgotten and in both households some tasks were assigned to other persons than the ones doing them normally which the participants perceived as beneficial and might serve as an indicator for changing routines.

When the participants were asked what they would like to keep after the study, everyone mentioned at least the vacuum robot, but also added almost every element used in the study and instantly came up with new ideas what they could do with the lamps for example. Generally, there are certain limitations to the study evaluation. As both the time and resources for evaluation were limited, study participants were recruited from the personal contacts of the author and as there were only two households with three persons each involved, the pool of participants is too small to be able to generalize findings without restrictions. On the other hand due to the realistic setting of the user studies, the participants were able to experience the proposed system in their own homes instead of a lab environment which contributes to the validity of the observed findings.

What limitations do users of such a system experience? A clear limitation perceived by participants was that they had to carry around an extra phone and a watch and recharge both overnight. Also the reliability of the system in terms of immediately asking about a scenario as soon as one approached the designated area was sometimes limited; it took a few moments till the system sensed the beacon and prompted the user. As the connection between place and time is crucial to the benefits offered by context-aware systems, this constitutes a current limitation of the Auteamate prototype system.

What use cases are inspired by a two week long use in participants' own homes? The interviewed participants came up with a lot of great examples for smart home use cases both during the installation of the equipment and at the final interviews. The proposed use cases ranged from examples including devices used in the user study to new devices that should be created and also included examples not necessarily in the domestic space.

The usage of such a prototype system over the two week period made the participants aware of both positive and negative aspects of such systems and they got an insight into the possibilities offered by smart home systems. Having the possibility to experience a smart home system in one's own familiar home environment can thus be beneficial to the understanding of the capabilities and limitations of such systems.

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Appendix A Deployed Scenarios

Scenarios Household 1 – Family Home

5min timeout between each prompt without answer(once one is sent, it takes 5 min for the next if there is no answer) exception for the three scenarios with lamps (just 2 minutes after no answer or yes, but only if light is off)

10	**Roomba**		**YES → PROMPT**	**NO → 20h**
22644	Bike	**4m**	**YES → START + 20h**	**NO → 10m**
20	**Plant without sensor**		**YES → PROMPT**	**NO → 3d**
61086	Chair	**2m**	**YES → 3d**	**NO → 50m**
30	**Lamp Living-Room**		**YES → 2min**	**NO → 5min**
50536	Shoe	**3m**	**LIGHT_BELOW_THRESHOLD_OR_ALREADY_ON**	
40	**Garbage (take out)**		**YES → prompt**	**NO → 1d**
34675	Fridge	**3m**	**TUESDAYMORNING**	
50	**Garbage(collect small trash cans)**		**YES → prompt**	**NO → 1d**
38464	Door	**3m**	**MONDAYEVENING**	
60	**Plant with sensor 1**		**YES → 1 day**	**NO → 5 min**
55871	Dog	**3m**	**PLANT_DRY_palme-nord**	
70	**Plant with sensor 2**		**YES → 1 day**	**NO → 5 min**
63874	Bag	**3m**	**PLANT_DRY_topfpflanze-sued**	
80	**Washing Machine**		**YES → 85 min**	**NO → 2 min**
52972	Generic	**4m**	**WASHING_MACHINE_NOT_IN_USE**	
90	**Hue Bloom**		**YES → 2 min**	**NO → 5 min**
34885	Car	**3m**	**LIGHT_BELOW_THRESHOLD_OR_ALREADY_ON**	
100	**Lamp Balcony**		**YES → 2 min**	**NO → 5 min**
40449	Bed	**3m**	**LIGHT_BELOW_THRESHOLD_OR_ALREADY_ON**	

Scenarios for Household 2 – Shared Flat

5min timeout between each prompt without answer(once one is sent, it takes 5 min for the next if there is no answer)
exception for the three scenarios with lamps (just 2 minutes after no answer or yes, but only if light is off)

10	**Roomba**		**YES → PROMPT**	**NO → 20h**
22644	Bike	**4m**	**YES → START + 20h**	**NO → 10m**
20	**Plant without sensor**		**YES → PROMPT**	**NO → 3d**
61086	Chair	**2m**	**YES → 3d**	**NO → 50m**
30	**Lamp Living-Room**		**YES → 2min**	**NO → 5min**
50536	Shoe	**3m**	**LIGHT_BELOW_THRESHOLD_OR_ALREADY_ON**	
40	**Garbage (take out)**		**YES → prompt**	**NO → 1d**
52972	Generic	**3m**	**TUESDAYMORNING**	
50	**Garbage(collect small trash cans)**		**YES → prompt**	**NO → 1d**
38464	Door	**3m**	**MONDAYEVENING**	
60	**Töggelipflanze (with Sensor)**		**YES → 1 day**	**NO → 5 min**
55871	Dog	**3m**	**PLANT_DRY_palme-nord**	
70	**Militärpflanze (with Sensor)**		**YES → 1 day**	**NO → 5 min**
63874	Bag	**3m**	**PLANT_DRY_topfpflanze-sued**	
80	**Washing Machine**		**YES → 85 min**	**NO → 2 min**
50706	Jan1	**4m**	**WASHING_MACHINE_NOT_IN_USE**	
90	**Hue Bloom Kitchen**		**YES → 2 min**	**NO → 5 min**
34885	Car	**3m**	**LIGHT_BELOW_THRESHOLD_OR_ALREADY_ON**	
100	**Lamp Entry**		**YES → 2 min**	**NO → 5 min**
40449	Bed	**3m**	**LIGHT_BELOW_THRESHOLD_OR_ALREADY_ON**	

Scenarios Household 3 – Expert Household

5min timeout between each prompt without answer(once one is sent, it takes 5 min for the next if there is no answer)
exception for the three scenarios with lamps (just 2 minutes after no answer or yes, but only if light is off)

110	**Roomba**		**YES → PROMPT 2**	**NO → 20h**
60516	Door	**4m** (distanceThreshold)	**YES → START + 20h**	**NO → 10m**
120	**Plant without sensor**		**YES → PROMPT 2**	**NO → 3d**
37489	Chair	**2m**	**YES → 3d**	**NO → 30m**
130	**Lamps Living-Room**		**YES → 2min**	**NO → 30 min**
46609	Shoe	**3m** cond:	**LIGHT_BELOW_THRESHOLD_AND_LAMP_OFF**	
140	**Lamps Dining Room**		**YES → 2 min**	**NO → 5 min**
23620		**3m**	**LIGHT_BELOW_THRESHOLD_AND_LAMP_OFF**	
150	**Lamps Bedroom**		**YES → 2 min**	**NO → 5 min**
37434	Bed	**2m**	**LIGHT_BELOW_THRESHOLD_AND_LAMP_OFF**	
160	**Garbage(collect small trash cans)**		**YES → PROMPT 2**	**NO → 1d**
19789	Fridge	**3m**	**MONDAYEVENING**	
170	**Plant with sensor 1**		**YES → 1 day**	**NO → 5 min**
41226	Car	**3m**	**PLANT_DRY_parrot-sarah**	
180	**Washing Machine**		**YES → 59 min**	**NO → 1h**
19394	Dog	**1.5m**	**WASHING_MACHINE_NOT_IN_USE**	
190	**Ventilation**		**necessary? YES → prompt if opened and remind after 10min to close NO → 1day, also after execution**	
59425	Generic	**4m**	**WINDOW_NOT_OPENED_FOR_SOME_TIME**	
200	**Laundry (ask if low on fresh clothes)**		**YES → schedule prompt+1h NO → postpone 3days**	
17723	Bag	**2.5m**	**ask if laundry done YES → postpone 6days, NO → 10min**	

Appendix B Consent Form

The following two pages show the consent form used in the user study.

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Teilnehmer Information und Einverständniserklärung zur ZPAC Studie „Improving cooperation in smart homes using a location-aware wearable application"

Sehr geehrte/r Studienteilnehmer/in,

wir laden Sie ein an unserer Studie teilzunehmen, die sich mit dem Einfluss eines Prototyp-Systems beschäftigt, das die Übermittlung von Benachrichtigungen auf Smart Watches nützt. Dadurch werden die Auswirkungen auf die Zusammenarbeit zwischen den Bewohnern und einem Smart Home untersucht. Wir führen diese wissenschaftliche Studie durch, um die Bedürfnisse von Nutzern mit Gebäudetechnologien besser zu verstehen und einen Beitrag zur Verbesserung der Kooperation mit diesen Häusern zu leisten.

Um was werden wir Sie bitten?
Wenn Sie der Teilnahme zustimmen, werden Sie gebeten an zwei Interviews teilzunehmen: Eins vor der zweiwöchigen Feldstudie und eins nach dem Abschluss der Studie. Diese Feldstudie beginnt mit einer kurzen Einführung bei Ihnen zuhause, in dem wir Ihnen das System anhand von einigen Szenarien vorstellen werden und Ihre erste Meinung erheben werden. Danach werden Sie das System zwei Wochen in Ihrem Alltag verwenden.

Zeitplanung

Ein Termin im Zeitraum	21. Februar – 25. Februar für ein Vorstudieninterview
	05. März – 20. März für die Feldstudie
Ein Termin im Zeitraum	20. März – 22. März für ein Abschlussinterview

Welche persönlichen Daten werden im Interview aufgenommen?
Mit Ihrer Zustimmung wird eine Videoaufnahme der Gespräche gemacht, welche teilweise oder vollständig transkribiert werden können. Bei jeglichen Publikationen und Präsentationen basierend auf dieser Forschung werden Sie anonym bleiben. Eventuell verwendete Auszüge aus den Interviews werden ausschliesslich durch eine Teilnehmernummer oder ein Pseudonym referenziert, ebenso wird Ihre Identität auf eventuellen verwendeten Fotos unkenntlich gemacht. Bitte stimmen Sie der Verwendungsmodalität, mit der Sie einverstanden sind mittels Zeichnung mit Ihren Initialen zu.

___ Ich stimme der Videoaufnahme des Interviews unter der Bedingung der Anonymisierung bei öffentlicher Verwendung zu.

___ Ich stimme der Aufnahme von Fotografien unter der Bedingung der Anonymisierung bei öffentlicher Verwendung zu.

Gibt es Vorteile, Nachteile oder Risiken an dieser Studie teilzunehmen?
Die Teilnahme an dieser Studie ist für Sie mit keinerlei Kosten verbunden. Es gibt keine besonderen Risiken ausser solchen, die mit normalen Alltagstätigkeiten verbunden sind. Bei Interesse, werden wir Ihnen gerne die resultierenden Forschungspublikationen zukommen lassen.
Bei technischen Problemen während der Feldstudie wird natürlich so umfassend wie möglich Hilfe geleistet.

Nutzung des Interviewinhalts
Die Ergebnisse der Studie werden primär in der Masterarbeit und innerhalb der Forschungsgruppe, sowie eventuell extern in Präsentationen und Veröffentlichungen, sowie wissenschaftlichen Journalen und Konferenzbänden verwendet.

Was passiert mit den Ihren Daten?
Die Teilnahme an der Studie ist freiwillig und vertraulich. Sie können die Studie zu jedem Zeitpunkt und ohne Angabe von Gründen unterbrechen oder abbrechen. Die von Ihnen bis zu diesem Zeitpunkt gegebenen Informationen (die Kommentarzettel sowie das begonnene Interview) können – ausser auf Ihren expliziten Wunsch hin – im Rahmen der Studie verwendet werden. Ihre Daten (Kommentarzettel, Videodateien und/oder Transkripte) werden auf passwort-geschützten Geräten oder in abschliessbaren

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Schränken und Räumen der Universität Zürich bis zu fünf Jahren aufbewahrt und dann permanent gelöscht bzw. sicher vernichtet. Die Daten können zur Anwendung von wissenschaftlichen Methoden durch die an diesem Projekt beteiligten Forscher eingesehen werden. Mit Ihrem expliziten Einverständnis dürfen weitere Personen Ihre Daten für Ausbildungszwecke oder wissenschaftliche Zwecke einsehen. Bitte mit Ihren Initialen der jeweiligen Verwendung zustimmen.

__ Ich stimme der Verwendung der anonymisierten Daten zur Ausbildungszwecken im Rahmen der von ZPAC für Bachelor-/Masterstudenten angebotenen Kurse zu.

__ Ich stimme der Verwendung der anonymisierten Daten durch externe Forscher zur Anwendung von wissenschaftlichen Methoden durch zu.

Einverständniserklärung

Wir werden Sie bitten diese Einverständniserklärung beim persönlichen Interview zu unterschreiben und dem ausführenden Forscher mitzugeben.

Mit Ihrer Unterschrift bestätigen Sie folgendes:

- Ich wurde von der verantwortlichen Person über die Studie und die oben aufgelisteten Bedingungen aufgeklärt.
- Ich hatte die Möglichkeit Fragen zu stellen.
- Ich habe die Antworten verstanden und akzeptiere sie.
- Ich bin mindestens 18 Jahre alt.
- Ich hatte ausreichend Zeit, mich zur Teilnahme an der Studie zu entscheiden und stimme der Teilnahme zu.

Diese Einverständniserklärung beeinflusst in keinerlei Weise Ihre gesetzlichen Rechte oder entbindet die Forscher und beteiligten Institutionen Ihrer gesetzlichen oder beruflichen Verantwortung. Es steht Ihnen jederzeit frei Ihre Teilnahme zu widerrufen. Wenn Sie weitere Verständnisfragen haben oder gerne weitere Informationen hätten, können Sie sich zu jeder Zeit Ihrer Teilnahme an uns wenden.

____
Name der Teilnehmerin/des Teilnehmers

____________________ ____________________
Ort, Datum Unterschrift der Teilnehmerin/des Teilnehmers

____
Name der Forscherin/des Forschers

____________________ ____________________
Ort, Datum Unterschrift der Forscherin/des Forschers

Sollten Sie noch weitere Fragen bezüglich dieser Forschung und/oder Ihrer Teilnahme haben, können Sie sich an folgende Ansprechpartner wenden:

Student Master Jonas Hofer	Dipl.-Inform. Sarah Mennicken	Prof. Dr. Elaine M. Huang
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Appendix C Pre-Deployment Questionnaire

The questionnaire used for the pre-deployment interviews can be found on the next six pages.

Jonas Hofer auteamate 31.03.2016

Fragen für Vorstudien-Interview

Einleitung

Beschreibung des Interviewablaufs und Zwecks (Grundlegende Infos & demografische Daten, Informationen über euren Haushalt und die Erledigung / Aufteilung der Aufgaben, Wissen und Erwartungen bezüglich Smart Homes), Zeitplanung (Termine für Deployment und Post-Deployment Interview) übergeben, Consent Form erklären und unterschreiben lassen, Videokamera starten.

Vielen Dank für die Teilnahme an der Studie zur Evaluierung des Studienprototyps „auteamate".

Die Applikation „auteamate" habe ich im Rahmen meiner Masterarbeit an der Uni Zürich entwickelt und stellt ein Beispiel einer Smart-Home Lösung dar, die sich auf Benutzer-Interaktion und Zusammenarbeit zwischen den Bewohnern und dem Smart-Home-System fokussiert. Dabei werden Anfragen auf Smartwatches angezeigt, die dem Smart-Home-System dazu dienen Informationen von Bewohnern anzufordern.

Persönliche Hintergrundinfos

Alter, Beruf (Teilzeit, 9bis5, Arbeitsort und Pendler-Verhalten), Haus/Wohnung, Mitbewohner…

Was ist einzigartig an eurem Wohn-Arrangement?

Welche elektronischen Geräte benützt du und wie häufig?
Pc? Smartphone? Gibt es andere Geräte (zB Küchengeräte oder anderes?)

Hattest du in der letzten Zeit Probleme? Bitte erzähle?

Wie sehr beeinflussen dich Probleme mit diesem Gerät / mit anderen Geräten?

Was machst du bei Problemen?
(Neustarten, Support anrufen, etwas probieren, Googlen was man in dieser Situation machen könnte)?

Jonas Hofer auteamate 31.03.2016

Haushaltsaufgaben

Gibt es eine Aufgabenteilung? (Wie ist sie organisiert?)

Wie koordiniert ihr diese Tätigkeiten? Habt ihr einen Plan?
Ist dieser Plan auf Papier, oder digital?
Benützt ihr Erinnerungen einer Art zur Koordination?

(Wer führt beispielsweise welche Tätigkeiten aus?) Wie habt ihr dies so aufgeteilt? → Tab ergänzen falls weitere Nennungen erfolgen

Gibt es bestimmte Aufgaben, die problematisch sind? Wieso?

Ist die Zusammenarbeit zwischen den Bewohnern im Zusammenhang mit diesen Tätigkeiten ein Thema? Werden manchmal Sachen vergessen?

Fragen über konkrete Aufgaben – Szenario Liste

Jonas Hofer auteamate 31.03.2016

Szenario Liste

Wie gerne erledigst du die folgenden Tätigkeiten?	1 gar nicht	2	3	4	5	6	7 sehr gerne
Pflanzen tränken							
Staubsaugen							
Lüften (Fenster öffnen/schliessen)							
Lichter ein/ausschalten							
Wäsche waschen							
Abwaschmaschine ein/ausräumen							
Abfall entsorgen							

Jonas Hofer auteamate 31.03.2016

Wie entscheidest / weisst du ob du einen Task erledigen solltest?

Erfasst du ob du einen Task ausgeführt hast? Oder wann du ihn wieder machen solltest?

Ist das hilfreich? Glaubst du, dass das eine Hilfe sein könnte? Warum?

Weisst du was die anderen Bewohner im Haushalt erledigen? Wie weisst du ob / wann etwas bereits erledigt wurde von jemand anderem?

Unterscheidest du zwischen Haushaltsaufgaben für dich selbst und für den ganzen Haushalt?

Kannst du mir ein Beispiel geben für eine Aufgabe, die jeder für sich erledigt?

Kannst du mir ein Beispiel geben für eine Aufgabe, die eine Person für alle erledigt?

Erledigt ihr gewisse Aufgaben zusammen? Ist jemand für die Ausführung verantwortlich?

Welche Aufgaben würdest du dir wünschen, dass sie sich von selbst erledigen würden?

Gibt es Aufgaben bei denen du denkst, dass eine Maschine oder ein Gerät im Haushalt einen besseren Job machen kann als ein Mensch?

Gibt es Aufgaben bei welchen der Mensch einen viel besseren Job macht als das eine Maschine könnte?

Jonas Hofer auteamate 31.03.2016

Wie hilfreich würdest du die folgenden Unterstützungen finden?	1 gar nicht	2	3	4	5	6	7 sehr hilfreich
Daran erinnert werden, wenn Pflanzen getränkt werden müssen							
Gefragt werden ob der Boden dreckig ist, falls einige Tage der Roomba nicht eingeschaltet wurde							
Lüften (Fenster öffnen/schliessen)							
Lichter ein/ausschalten falls man sich im Raum aufhält							
Daran erinnert werden, wenn ein Waschgang abgeschlossen ist							
Ans Ein/Ausräumen der Abwaschmaschine erinnert werden							
Daran erinnert werden den Abfall bereit zu machen für die Abholtour am Dienstagmorgen							

Können diese Szenarien bei euch umgesetzt werden?

Entsprechen die Szenarien den Aufgaben, die bei euch erledigt werden müssen?

Was steht auf der Liste, das für euch nicht zentral ist?

Gibt es weitere Unterstützungen, die für euren Haushalt Sinn machen würden?

Was steht nicht auf der Liste, das ihr gerne haben möchtet?

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Smart Home

In einem Satz: Was denkst du was ein Smart-Home ist?

Was wären deine Erwartungen an ein Smart Home?

Hast du bereits Dinge, die man als „smart“ bezeichnen könnte (evtl. auch nicht elektronisch)?

Was war dein Gedanke, als du es gekauft hast? Wofür wolltest du es einsetzen?

Hat es deine Erwartungen erfüllt?

Abschluss

Vielen Dank für deine Mitarbeit an der Evaluation meiner Masterarbeit!

Hast du Fragen zur Studie, der Forschungsarbeit oder zum Interview?

Denkst du, dass du selbst von dieser Studie in einer Form profitieren kannst?

Appendix D Post-Deployment Questionnaire

An exemplary questionnaire used for the post-deployment interview for household 1 can be found on the next four pages.

Jonas Hofer auteamate 31.03.2016

Fragen für Abschlussinterview

Einleitung

Danke für die Bereitschaft zur Mitarbeit an der Pilotstudie meiner Masterarbeit!
Dieses Abschlussinterview stellt für dich den Abschluss der Studie dar.
Falls du gerne über die Ergebnisse informiert werden möchtest, werde ich dir die fertige Arbeit und die darin gezogenen Schlussfolgerungen gerne mitteilen.

Die Szenario-Liste des Haushalts hervornehmen, falls sich ein Bewohner darauf beziehen möchte.
Video starten

Benützung des Systems

Du hast das System für 2 Wochen benützt, hatte das eine Auswirkung auf euren Haushalt? Wie?
Gibt es spezielle Situationen in denen das System eine Auswirkung hatte auf dich? und andere?
Hat sich die Benützung des Systems auf die Zusammenarbeit in eurem Haushalt ausgewirkt? Bitte erzähle.
Kannst du dazu ein Beispiel nennen?

Dir sind ja Prompts angezeigt worden die letzten zwei Wochen, hast du das Gefühl, dass das einen Einfluss hatte wie du Haushaltsarbeiten wahrgenommen hast?
Hat sich die Wahrnehmung bezüglich der Haushaltsarbeiten geändert?

Hast du den Überblick mit den Haushaltstätigkeiten auf dem Phone angeschaut?
Kannst du ein Beispiel geben wann du es benützt hast? Was hast du gerade gemacht?
Ist die Übersicht wichtig für dich? Hilfreich? Hat sich das Bewusstsein was zu tun ist verändert?

Bei den Einleitungsinterviews wurde öfter genannt, dass Hausarbeiten möglichst effizient und mit möglichst kleinem Zeitaufwand erledigt werden sollen.
War das System diesbezüglich hilfreich? Kannst du ein Beispiel nennen?

Jonas Hofer auteamate 31.03.2016

Unterstützungen

Wie hilfreich hast du die folgenden Unterstützungen gefunden?	1 gar nicht	2	3	4	5	6	7 sehr hilfreich
Gefragt werden, ob die Pflanzen (ohne Sensor) getränkt werden müssen und ans tränken erinnert werden							
Daran erinnert werden, wenn die Pflanze beim Esstisch (mit Sensor) getränkt werden muss							
Daran erinnert werden, wenn die Palme in der Stube (mit Sensor) getränkt werden muss							
Gefragt werden ob der Boden dreckig ist, falls einige Tage der Staubsauger Roboter nicht eingeschaltet wurde, falls ja den Roboter starten							
Gefragt werden ob es nötig ist die kleinen Abfallkübel zu leeren und daran erinnert werden es zu erledigen							
Daran erinnert werden den Abfall bereit zu stellen für die Abholtour am Dienstagmorgen							
Gefragt werden, ob das Licht eingeschaltet werden soll, wenn man sich auf beim Sofa vor dem Fernseher aufhält							
Gefragt werden, ob das Licht auf dem Balkon eingeschaltet werden soll, wenn man auf dem Balkon ist							
Gefragt werden, ob das farbige Licht eingeschaltet werden soll, wenn man sich in der Stube vorne aufhält							
Daran erinnert werden, wenn ein Waschgang abgeschlossen ist							

Jonas Hofer auteamate 31.03.2016

Angaben zu Prompts

Nach dem allgemeinen Teil geht es jetzt um die Prompts, die auf der Uhr angezeigt wurden.

Kannst du dich an eine Situation erinnern, wo der Prompt besonders hilfreich war, was hast du gerade gemacht?
Zu welcher Tageszeit hat dies stattgefunden? Warst du alleine?
Solche die du gemocht hast?
War es etwas Wiederkehrendes? Immer der gleiche?
Achten auf: Unterscheidet User zwischen Fragen auf der Uhr, die eine Aktion des Benutzers erforderlich machen und solche, die durch das System ausgeführt werden.

Gab es eine Situation wo dich die Frage auf der Uhr unterbrochen oder gestört hat?
Welche Fragen waren das? / Bei welchen Szenarien ist dies aufgetreten?
Wurde dir eine Frage mehrere Male gestellt, obwohl es eigentlich klar war, dass dies nicht nötig ist?
Fragen ob dies durch eine suboptimale Konfiguration oder eine technische Limitierung aufgetreten ist oder eigentlich richtig konfiguriert war, es die Benutzer aber trotzdem nervt.
Gab es noch mehr Beispiele? Häufiger vorgekommen oder nur einmal?

Es sind ja einfach formulierte Fragen, haben die Fragen Sinn gemacht wenn sie angezeigt wurden, oder haben sie nicht in die Situation gepasst?
War es manchmal unklar, für was das System eine Frage stellt?
Hat es einmal die Situation gegeben, dass du nicht wusstest was das System von dir will? / Wieso es dir eine Frage stellt?

Jonas Hofer auteamate 31.03.2016

Smart Home Anwendungen

Konntest du durch das 2-wöchige Benützen des Systems einen Einblick in das Thema Smart Home erhalten? Gibt es etwas, das dich daran erstaunt oder verblüfft hat?

Du hast das System jetzt 2 Wochen im Kontext von deinem Haushalt benützt, hast du andere Ideen was man noch tun könnte in eurem Haushalt oder im Allgemeinen?
Kannst du ein Beispiel nennen?

Gibt es Teile des Systems, die du gerne behalten möchtest? Welche wären das?

Gibt es Teile, die du nicht behalten möchtest?
Gibt es sonst Sachen, die dir nicht gefallen haben an diesem System?

Wovon hängt dies ab? Aufwand vs. Ertrag, Wie kamst du mit der Hardware klar?

Hatte die Benützung des Systems es einen Einfluss auf die Zusammenarbeit im Haushalt?
Wie hat sich dies ausgewirkt? Kannst du ein Beispiel nennen?
Achten auf Präferenz: Entweder, Arbeit komplett abnehmen, oder helfen bei der Koordination & Zusammenarbeit zwischen den Bewohnern und dem Haus.

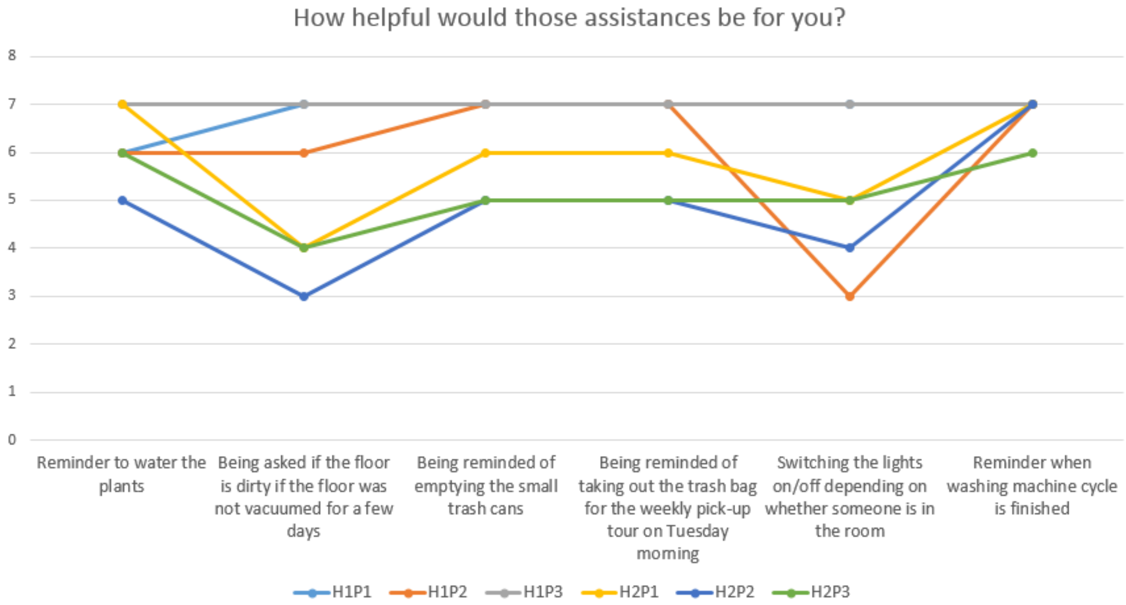
Abschluss

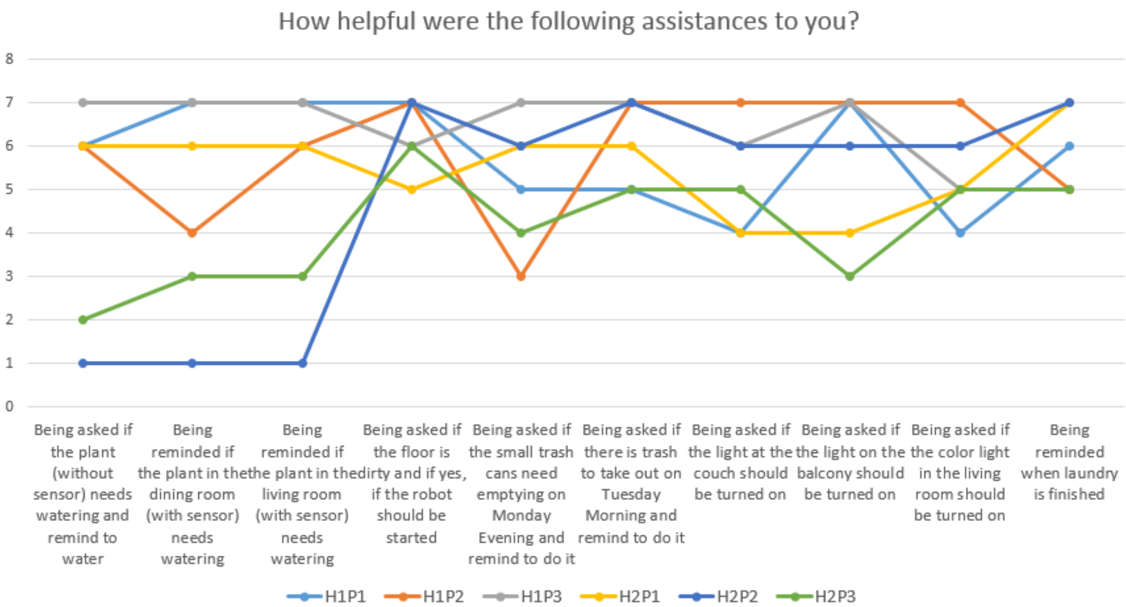
Vielen Dank für deine Mitarbeit an der Evaluation meiner Masterarbeit!

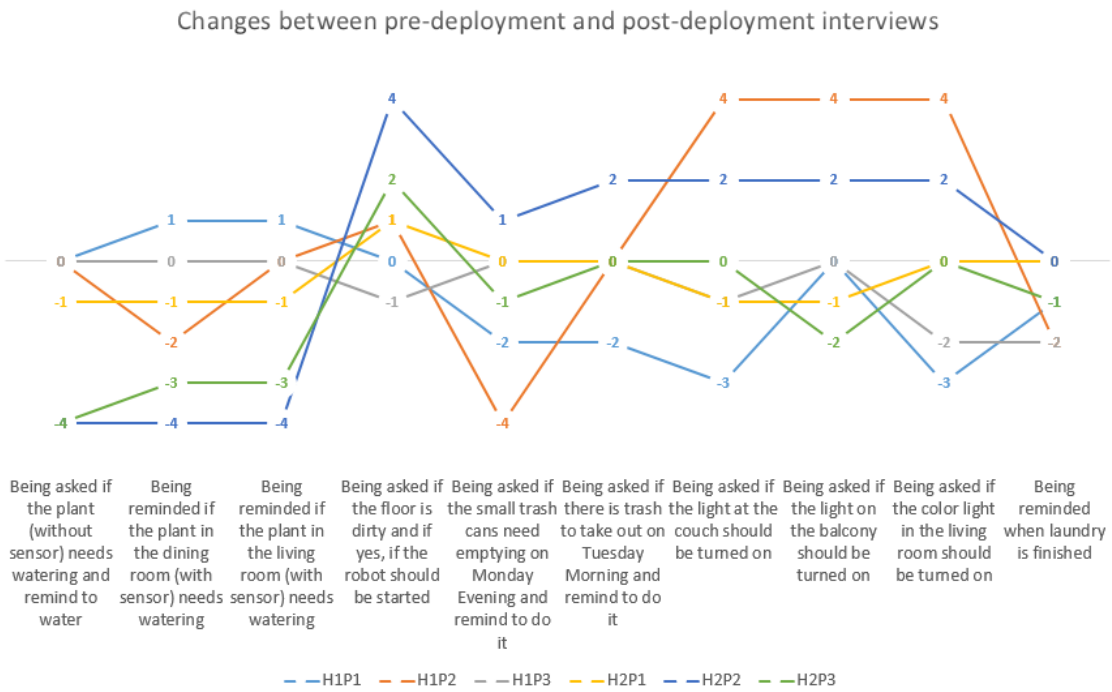
Hast du Fragen zur Studie, der Forschungsarbeit oder zum Interview?

Ich hatte beim ersten Interview gefragt, ob du dir vorstellen kannst, dass du selbst von dieser Studie in einer Form profitieren kannst. Sind deine Erwartungen erfüllt worden?
P1: System kann mich an Sachen erinnern für die zwei Wochen und gewisse Sachen von selbst erledigen.
P2: Ich hoffe auf einen positiven Effekt auf die anderen Haushaltsmitglieder, dass sie ihre Aufgaben zugunsten des Haushalts erledigen. P3 – P4 – P5 –
P6: Es ist interessant über Haushaltsarbeiten und mögliche Unterstützung durch ein System nachzudenken und es wird sicherlich interessant eine Implementation eines solchen Systems im Einsatz zu erleben.

Appendix E Likert Scale Visualizations






Changes between pre-deployment and post-deployment interviews
Being asked if the plant (without sensor) needs watering and remind to water
Being reminded if the plant in the dining room (with sensor) needs watering
Being reminded if the plant in the living room (with sensor) needs watering
Being asked if the floor is dirty and if yes, if the robot should be started
Being asked if the small trash cans need emptying on Monday Evening and remind to do it
Being asked if there is trash to take out on Tuesday Morning and remind to do it
Being asked if the light at the couch should be turned on
Being asked if the light on the balcony should be turned on
Being asked if the color light in the living room should be turned on
Being reminded when laundry is finished
H1P1
H1P2
H1P3
H2P1
H2P2
H2P3

Appendix F Content of the Enclosed CD-ROM

Abstract.txt	Abstract of the thesis.
Zusfsg.txt	German summary of the thesis.
Master Thesis.pdf	This document.
Auteamate.zip	Zip-File containing the source code.

Eidesstattliche Erklärung

Der/Die Verfasser/in erklärt an Eides statt, dass er/sie die vorliegende Arbeit selbständig, ohne fremde Hilfe und ohne Benutzung anderer als die angegebenen Hilfsmittel angefertigt hat. Die aus fremden Quellen (einschliesslich elektronischer Quellen) direkt oder indirekt übernommenen Gedanken sind ausnahmslos als solche kenntlich gemacht. Die Arbeit ist in gleicher oder ähnlicher Form oder auszugsweise im Rahmen einer anderen Prüfung noch nicht vorgelegt worden.

Ort, Datum Unterschrift des Verfassers