Design of an Integrated Robotic Reminder System for People with Dementia

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by

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Preface

When I started studying computer science in 2018, I knew that I wanted to learn how to solve complex technical problems, use logic to create the best algorithms, make great software, and maybe prove that $p \neq np$ while I was at it. Looking back now, nearly six years later, I can say that most of these were successful (the last one was always a long shot, but for a million dollars it was worth a try). But while these technical challenges originally grabbed my interest in computer science, the human aspects of it clutched it and cemented my love of the field. Still, the term “human aspect” encompasses a lot. It ranges from using computers to analyze human behavior, to emulating it well, to thinking about the consequences of unleashing systems into the world. But my favorite part became designing systems that can help people with real, tangible, problems they have — from start to finish. From coming up with the first ideas, to creating an intuitive interaction, to designing the software architecture, to writing and testing code in a way that makes it easy to make changes later, I fell in love with the whole process.

The thesis before you now describes such a process. It discusses the design of an integrated robotic reminder system for people with dementia. It should be easy to see why I would like a topic like this. The target audience comes with interesting and unique problems, the potential impact on their lives is clear, and it allowed me to touch upon many aspects of designing a technology system. There is one important aspect I did not have the time for, however. That is actually *making* the software. Of course, there is the robot prototype, but if only I had a team of interaction designers, front- and back-end software engineers, software architects, computer vision engineers, embedded software engineers, artificial intelligence engineers, network engineers, cybersecurity and privacy experts, and — last but not least — a few years to fully realize this project. For now, this thesis will have to do.

There’s some people I would like to thank. First and foremost, there are the participants of the two workshops, the caregivers and residents of the care home, and the experts who took the time to talk to me about the software architecture. Your feedback was invaluable, thank you. Thanks also goes out to all the caregivers and researchers from many fields I have had the chance of speaking with during the past few months, who welcomed me into their spaces and shared their experiences and views with me. I would also like to thank my two supervisors, Mark Neerincx and Frank Broz. Thank you for your feedback, our weekly meetings, and for challenging me. I’d also like to thank my third thesis committee member, Dave Murray-Rust, for joining the committee. I hope you enjoy my thesis. Thanks and love go out to my parents, brother, grandparents, and other family members. Thank you for your continued love and support, and thank you for listening to me try to explain complex algorithms to you — I hope this thesis will be more accessible. Finally, I want to thank all the wonderful friends, fellow students, fellow teaching assistants, and teachers I have had the privilege of meeting over the course of my studies. The human aspects of computer science may be what cemented my love for the field, but you are what cemented my love for my time here.

Ricardo Vogel
Delft, April 2024

Summary

Dementia is a cognitive condition that impacts millions worldwide. It causes a decline in memory, attention, and executive function, and also other non-cognitive symptoms, like depression, anxiety, and trouble sleeping. Seventy percent of people with dementia live at home, and often receive care from an informal caregiver, like their partner or child. These caregivers often spend a lot of time providing care, and cannot always be present. This can cause them stress and can cause them to feel overtaxed.

A useful technology to alleviate negative symptoms of people with dementia is robotic pets. Most robotic pets, however, only have pet-like functionality. This is useful on its own, but adding additional care functionality would be helpful. A different useful tool for people with dementia is reminder systems. These systems can help them remember to do important daily tasks, like eating meals and taking medicine. These systems, however, usually use a phone as a medium. The user might leave their phone in another room, and if they do not take it to the location where the task is to be completed, they cannot check what the reminder was for.

This thesis aims to combine these two systems, and presents the design of an integrated robot reminder system for people with dementia who live at home. It aims to address the problem of people with dementia forgetting important things, improve their quality of life, and reduce the stress experienced by their informal caregivers. The system consists of an animal-like robotic pet, which delivers reminders for important activities of daily living directly to the user with dementia. It guides them to a location in the house, where a screen tells them what the reminder is for. Through sensors placed in the house, the system can automatically detect whether some reminders have been completed, and can use contextual clues to send reminders at the best time. The research question for this thesis is “How can an integrated robotic reminder system effectively support people with dementia living at home in completing daily tasks while alleviating stress of their informal caregiver?”

To alleviate the stress experienced by informal caregivers, a phone app is used. Using this app, they can add reminders, check up on their loved ones, and see an overview of recurring reminders, which allows them to (re)schedule reminders for the most appropriate time.

Three research topics are explored in the thesis. The first topic is that of value-sensitive design. The two main user groups, people with dementia and caregivers, both have values they want to see reflected in the system. Sometimes, these values may clash. The conflict between these values is explored in this thesis. Secondly, the interaction between the robot and the person in the context of a reminder system is researched. It should be clear to a user that the robot is trying to convey a reminder. The third topic relates to the software architecture and software engineering requirements. Private data should be stored securely, and the requirements should be written to make future development easy. Recommendations are made regarding the ideal setup of the system, ensuring proper security and usefulness.

To evaluate the system and the interaction with multiple stakeholders, a high-fidelity robot prototype was made. This prototype shows the core interaction of receiving a reminder. Besides the robot, a semi-functional user interface prototype was made to show the functionality of the app that caregivers can use to create reminders, see if they were completed, and get insights into what reminders should be changed.

The system was designed through an iterative process. In order to improve the system and validate its acceptability, two design workshops were held, one with professional caregivers and one with people with dementia living in a care home. We showed them the robot, and showed the caregivers the user interface prototype. These workshops showed that the combination of the robot and the reminder functionality was appealing, though not everyone was as interested. To validate and improve the system architecture choices, two interviews with experts in the field of privacy were held.

Contents

1 Introduction

Dementia presents a significant challenge globally, impacting millions of people and their caregivers. Dementia is a cognitive condition that causes decline in memory, attention, and executive function, among other symptoms [1]. Over 55 million people have dementia worldwide [2], with nearly 10 million new diagnoses per year. People with dementia often forget to perform important daily tasks and have problems with executive function [1]. They may also experience other negative symptoms, like anxiety and depression [1, 3–5], and many feel lonely [6].

Seventy percent of people with dementia in the Netherlands live at home [7, 8]. The current healthcare system cannot provide all the care they may need, so many also receive informal care, by for example their partner or children [8]. These informal caregivers spend, on average, 39 hours per week providing care [9], many of them besides their regular job [8]. With the amount of time they spend, and the concern they may feel when not being able to provide care at a given moment, it is understandable that many caregivers suffer from anxiety and feel overtaxed [9, 10].

One useful technology to alleviate negative symptoms of people with dementia is robotic pets [11–13]. These robotic pets aim to imitate the behavior of real pets, the user can play with them and pet them. This alone provides value, but the functionality is quite limited. Additional care functionality would be a useful addition to these pets.

A different useful technology for people with dementia is reminder systems [14–16]. The benefits are clear: reminding people with dementia to perform important tasks, like taking their medicine or having a meal, can help them with remembering these tasks. Most reminder systems found in literature use smartphones as their medium. This may not be the ideal choice for people with dementia, as they may not get reminders if they leave their phone in another room, and as they cannot easily check what reminder they got last if they do not take their phone with them. Some reminder systems found in literature make use of the context to provide reminders at an appropriate time, which increases the chances of the user completing the task, and reduces annoyance of getting reminders at inappropriate times or when doing something else [15, 17, 18].

This thesis aims to combine the functionality of robotic pets and reminder systems through the design of an integrated robotic reminder system, which aims to alleviate the problems of people with dementia forgetting daily tasks, their sometimes low quality of life, and the stress experienced by their informal caregivers. The system does this by making use of a robotic pet, which comes to the user with dementia to remind them to do important activities of daily living, like eating, drinking water, showering, and taking medicine. It keeps the caregiver in the loop by sending them updates when some tasks were completed. The system makes use of sensors and other technology integrations to detect whether the reminder was completed, to gather contextual information in order to send the reminder at an appropriate time, and to make completing reminders easier. The main research question of this thesis is “How can an integrated robotic reminder system effectively support people with dementia living at home in completing daily tasks while alleviating stress of their informal caregiver?" This is a multi-faceted research question, which will be answered from the angles of the design of the whole system, the interaction between the human and robot, and software engineering. These three themes will be discussed now.

The system has two types of users: the people with dementia and the informal caregivers. These users want several things out of the system, such as the level of care, safety, and privacy. These different values may sometimes clash. Decisions have to be made where one value has to be compromised in order to guarantee another. For example, placing cameras and sensors around the house may increase the level of care and the safety, but decrease the privacy. Several of such trade-offs will have to be considered during the design process. The research sub-question related to the design is "How can the design of an integrated robotic reminder system balance the conflicting values of individuals with dementia and their informal caregivers?" (SRQ1)

As discussed before, most robotic pets only have pet-like functionality, and most reminder systems use a phone as their medium. Delivering reminder information through the medium of an animal-like robot is still an open research topic. Several aspects will be explored, like the act of interrupting, how to make clear that the user should follow the robot, and the way the reminder is communicated. The research sub-question for the interaction with the robot is "How can a robotic pet effectively give reminders to people with dementia in a more interactive manner compared to traditional reminder systems?" (SRQ2)

The final research theme is that of software engineering. If this system were to be implemented in a real-world setting, there are certain things that should be paid close attention to. The first is the software architecture. The use of sensors and cameras raises privacy and security concerns, if these data leak, it would be a major breach of privacy. Designing the software architecture in a way that minimizes these risks is paramount. Besides the software architecture, this thesis also presents user stories and formal software requirements that can be used for future development. The research sub-question for this part is "What are the recommended system architectures and requirements for implementing the integrated robotic reminder system in a real-world setting, ensuring easy development and high security, privacy, and usability for both the users with dementia and their caregivers?" (SRQ3)

Engaging people of the target audience in the design process is an effective way to understand their needs and to ensure these needs are met. To this end, two design workshops are held, one with professional caregivers, and one with people with dementia living in a care home. These workshops aim to gather feedback on the design and to gauge the acceptability of the system. Additionally, two interviews with experts are held to validate and improve the software architecture choices.

To evaluate the system and interaction, a high-fidelity robotic prototype is made. It makes use of the animal-like MiRo robot, and makes use of the MiRo's built-in cameras to find the user and screen. Additionally, a medium-fidelity user interface prototype is made for the caregiver app. This shows how a caregiver can set reminders, see which reminders were completed, and get insights in recurring reminders and context rules. These prototypes are used in the two workshops.

This thesis is structured as follows: first, in Chapter 2, I discuss useful background information regarding dementia, reminder systems, robotic pets, and participatory design. Chapter 3 presents the design of the integrated robotic reminder system, describing the design process, going over major design decisions, and specifying certain features. Chapter 4 talks about technical details of the robot prototype, and Chapter 5 shows the UI prototypes of the screen on which reminders are shown and the app used by caregivers to set reminders. Then, in Chapter 6, the procedure and outcomes of the two design workshops are presented. Chapter 7 talks about the proposed system architecture and the expert interviews held to validate them, and Chapter 8 presents the final requirements of the system. In the discussion in Chapter 9, I present points of improvement and useful areas for future work. Finally, Chapter 10 wraps up the thesis.

2
Background

Before getting into the design of the system, let us talk about some important background information. This chapter will discuss four areas of research relevant for this thesis. First, we will discuss symptoms and other effects of dementia on the people themselves, on their informal caregivers, and on society as a whole. This is done in Section 2.1. We will then discuss reminders systems and their features in Section 2.2. Robotic pets used for people with dementia, and their benefits and potential ethical concerns, will be discussed in Section 2.3. Finally, we will discuss participatory design methods for people with dementia in Section 2.4.

2.1. Dementia

According to the World Health Organization [2], over 55 million people have dementia worldwide. There are nearly 10 million new cases each year. It is currently the seventh leading cause of death worldwide, and is seen as one of the major causes of disability and dependency among older adults [2]. In the Netherlands specifically, 290,000 people are estimated to have dementia, of which only about two thirds have received a formal diagnosis [8]. Projections suggest that by 2040, the number of people with dementia will rise to half a million [8]. Dementia is more common in women, who account for 61% of those affected [7]. While dementia is more prevalent among older adults, approximately six percent of individuals with dementia in the Netherlands are under the age of 65 [7]. As for the living arrangements, around seventy percent of those with dementia in the Netherlands reside in their own homes, leaving approximately thirty percent who live in care homes [7, 8].

2.1.1. Symptoms of Dementia

The ICD-11 [1], the International Classification of Diseases, 11th Revision, describes dementia as a decline in cognitive abilities outside what you could normally expect given an individual's age. In order to be diagnosed with dementia, impairments should be present in at least two cognitive domains[1] [1]. Memory is perhaps the most well-known cognitive domain when it comes to dementia, but problems with memory are not necessary symptoms for a diagnosis.

There are six cognitive domains in which people's cognitive abilities may decline [1, 19]. The first of these is complex attention — the ability to sustain and divide your attention. Examples of symptoms for dementia include difficulty holding new information in mind and getting easily distracted by competing events in the environment. The second is executive function, which relates to planning, decision-making, error correction, and mental flexibility. This relates to short-, medium-, and long-term planning and decisions. The third domain is learning and memory. This domain relates to immediate

[1]According to the ICD-11 [1]. In the American DSM-5 [19], Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, just one domain is enough.

memory, recent memory, and very-long-term memory. Symptoms include people repeating themselves in conversation and not keeping track of short lists like grocery lists, but also forgetting memories from far in the past. Then there is the language domain. People showing decline in this area speak less fluently, often use general-use phrases such as “that thing”, make more grammatical mistakes, and in severe cases may not be able to recall the names of close friends and family members. The fifth domain is the perceptual-motor domain, related to hand-eye coordination. For example, people with decline in this area may not be able to use some tools anymore, even if this used to be second nature. This domain also relates to navigating in familiar environments and general perception, like recognizing colors or faces. The final domain is that of social cognition. This would be a decline in social and emotional capabilities, like considering others’ emotional and mental states and showing sensitivity on potentially harmful topics.

Dementia can be caused by a variety of diseases and injuries that affect the brain [2]. Alzheimer’s disease is the most prevalent form of dementia, and is estimated to be responsible for sixty to seventy percent of dementia cases [2]. Other forms of dementia include vascular dementia, Lewy bodies, and frontotemporal dementia. Other causes include Parkinson’s disease, HIV, or traumatic brain injury [1, 19].

2.1.2. Other Effects on People with Dementia

Besides the cognitive symptoms, people with dementia also often experience a number of behavioral and psychological symptoms. These symptoms include apathy, depression, anxiety, psychosis, agitation, wandering, irritability, hallucinations, and delusions [1, 3–5]. People with dementia can also experience problems with sleep or sudden changes in appetite. These symptoms are experienced by the majority of people with dementia. They can be used in diagnosis, and are, of course, important factors in the care of people with dementia [3–5].

The effects of dementia do not end at these symptoms. Kane & Cook [6] conducted a survey among people with dementia about their feelings of loneliness. 38% of respondents said they are lonely, and twelve percent state they do not know if they are lonely. Balouch et al. [20] found that having more friends could have a positive influence on cognition in people with dementia. They also note, however, that the effect could be reverse: instead showing that greater dementia severity may lead to fewer friends.

2.1.3. Effects on Informal Caregivers and Other Parties

People with dementia living at home, which make up seventy percent of all people with dementia in the Netherlands [7, 8], may not be able to receive all the necessary care through the healthcare system, and thus often require informal care provided by, for example, partners, children, other close family members, friends, or neighbors [8]. It is estimated that around 800,000 people in the Netherlands — which is nearly five percent of the population — provide informal care for a loved one with dementia [8]. Just under half of these provide care for their partner with dementia, closely followed by those who care for their parent or parent-in-law.

Dutch informal caregivers spend on average 39 hours per week providing care [9], around as much as a full-time job. It is easy to see how this can be quite taxing, especially if the caregiver also has a day job — which is the case for around forty percent of them [8]. Just over half of people surveyed by Bijnsdorp et al. [9] reported feeling at least heavily taxed, with 13% feeling overtaxed. A quarter of caregivers suffer from more significant anxiety than an average person [10].

Besides the effects on individual informal caregivers, the increase of the number of people with dementia also causes problems on a larger scale. There are long waiting lists for dementia healthcare, which often lead to waiting times outside the acceptable time frame, especially for less urgent cases [21]. The Dutch government reports staff shortages [22], which can, according to an investigation by journalist and the trade union, lead to dangerous situations in care homes [23]. The shortages in the healthcare system are not something that will be solved easily. It would be useful if people with dementia were able to safely and comfortably live at their own home for a longer time.

2.2. Reminders for People with Dementia

The type of memory related to remembering things to do in the future is called prospective memory [16]. There are a variety of prospective memory tasks a person runs into in everyday life. One way to distinguish between tasks is to split them into time-based and event-based tasks [16]. Event-based tasks can be helped by external cues. For example, if you need to remember to take medicine after lunch, having lunch might trigger your memory of having to take your medicine. For time-based tasks, you cannot rely on such an external trigger. Having to call your doctor at two in the afternoon has no external trigger.

Reminders can be a useful aid to help with prospective memory [16]. Reminders can come in many forms, they can range from sticky notes placed around the house, to a calendar app that sends mobile notifications, to voice assistants, to integrated systems. Zhou et al. [17] make a distinction between four different types of reminders: they use time-based reminders, like the prospective memory tasks discussed previously, and split up event-based prospective memory tasks into location-based, activity-based, and complex context-based reminders. Time-based reminders can be set for a specific time, or in a time range for some reminder systems [24]. Location-based reminder systems, as described by Zhou et al. [17], seem to focus on outside locations (e.g., the grocery store), but specific locations in the house could also be possible. Activity-based reminders take the user's current activity into account, and are useful to ensure they do not get interrupted unnecessarily when doing something else. Hartin et al. [15] make use of mobile phone sensors to detect the user's current activity. Complex context-based systems take multiple aspects into account, for example the aforementioned time, location, and activity, but you could also think about the usual time the user performs the activity. Dey & Abowd [18] allow users to set the context through rules.

2.2.1. Reminding People with Dementia of Activities of Daily Living

When looking at the symptoms of dementia described in Section 2.1.1, it is easy to see the impact this has on people's everyday lives. Difficulties in sustaining attention, executive function, learning, and memory can make it difficult to perform important activities of daily living like taking medication, eating, moving around, and making important calls. It logically follows that reminding people with dementia of important tasks can be very helpful. Hackett et al. [25] confirm this intuition through an experiment where people with dementia were tasked to drink four glasses of water at predetermined times. Participants who were given reminders through smartphone notifications drank more glasses and had to check the list of times less often than those who only had access to the list.

Extending this to a whole day, reminders can help people with dementia perform activities of daily living [14], sometimes referred to as ADLs. Hartin et al. [15] define six types of activities of daily living: Meal, Drink, Medication, Hygiene, Appointment, and simply Other.

2.2.2. Contextual Reminders

Badly planned reminders can cause anxiety [26] and interfere with task performance [27]. That's why it is important that reminders are sent at the right time. Both the time and other contextual clues can be used to change the reminder time.

Dey & Abowd's [18] amusingly named CybreMinder allows users to describe contextual situations in which the reminder should be delivered. This includes time, locations of people, activity, free time available, whether or not a door is open, and even things like stock price (as you can probably guess, this system was not made for people with dementia). This manual rule-based approach is also used by Du et al.'s [24] HYCARE. This system is more relevant to this thesis, as it is designed for people with dementia, not for people that care about stock prices. Their rules include time-based reminders aided by contextual clues, both fixed (e.g., the system tells the user that their favorite TV show started; but it only sends it if the user is in their home) and in a window (e.g., the system reminds the user to take their medicine at some point in the afternoon; but only if they are home and not asleep), urgent context-based reminders (e.g., reminding the user to take their keys if they are leaving without them), and "event-relevant" reminders (e.g., turning on the dishwasher if it's loaded enough and the user is going to bed soon). To schedule these reminders, the system uses three priority levels. Event-urgent reminders have the highest priority, followed by fixed-time reminders, followed finally by the time-window and event-relevant reminders. These are sorted based on their expiration time, working on the intuition that if the deadline is far in the future, the system will have more chances to try to remind the user.

One major downside of both CybreMinder [18] and HYCARE [24] is that setting up the reminder rules can get quite complicated. Rules have to be manually set, and a small mistake in logic could turn a useful reminder like "turn off the gas stove when it's on *and* the user isn't cooking" into a continuous stream of notifications if it is accidentally entered as "turn off the gas stove when it's on *or* the user isn't cooking." This is not a problem if the rules are entered by experts or developers, as they can test the rules, but is certainly not ideal for a system where people with dementia and their caretakers are meant to create these rules, who will not have the time to test them properly.

On the complete other end of the automation spectrum, Hartin et al. [15] use mobile phone sensor data in their reminder system designed for people with dementia to completely automate the timing of reminders. They use motion, positional, and environmental data like the accelerometer, temperature sensor, proximity sensor, and GPS receiver. They record this data three minutes before a reminder is sent, trying to see if it is possible to associate certain sensor states with acknowledged or missed reminders. The sensor data is a way to capture what the user is doing, if they are busy doing a certain task where they like not to be interrupted, they are doing a certain motion, and this might translate to certain values in the sensors. They aim to utilize this association to build a model that can be used to select a context where the user is likely to acknowledge the reminder. They build several models using four different supervised machine learning techniques, namely a C4.5 decision tree, Bayesian network, random forest, and K*. They get a 76% accuracy (precision=0.78, recall=0.76) in their Bayesian network trained on data from people with dementia. Adding data from people without dementia into the training data decreased the accuracy of this model by three percent, showing that a non-generalized model for people with dementia may be beneficial.

In their time-based reminder system, Fikry et al. [28] use reinforcement learning to select how long before a deadline a reminder is sent. The system uses smartphone notifications and is designed specifically for people with dementia or other cognitive impairments. By trying out different options, the system learns the preferences of each user, and automatically adapts to them. Reminders can be sent from two hours before the deadline time, with fifteen minute intervals between possibilities. Users can confirm that the reminder was completed or dismiss it. The system rewards accepted reminders, and punishes rejected reminders.

Zhou et al. [17] model their reminder system as a fuzzy linguistics problem. They define two aspects that guide their decision-making. First, there is urgency. As less urgent tasks can be delayed for a longer time, they use the acceptable delay time as a proxy for urgency. Anything that has to be completed within five minutes has an urgency value of one, anything that can be delayed for two hours or more has an urgency value of zero, the rest is linearly scaled between those two. The acceptable delay is gathered through input from participants of their pilot study. The second aspect is interruptibility, the extent to which people are willing to be interrupted for a given thing at a given moment. Ho & Intille [29] describe eleven factors that contribute to a person's interruptibility, like for example activity of the user, utility of the message, emotional state, frequency of interruptions, social engagement, and the history of responses. Zhou et al. [17] argue that the user's current activity is the most important contributing factor to interruptibility. They gather interruptibility for different user activities through questionnaires.

Besides contextual clues, one interesting aspect to consider could be personalization. Ho & Intille [29] mention history of responses as a factor in interruptibility. Fikry et al.'s [28] reinforcement learning method is originally trained on existing data, but the model could be changed based on specific users. Another possible way of personalizing is by categorizing users into groups, where people in the same group generally have similar preferences. One useful categorization could be the user's stage of dementia. People in a later stage may benefit from different type of help, but this is just speculative.

2.2.3. Interaction Media for Reminders

Many previous related works in this section use smartphones as their medium, but this may not always be the most appropriate choice for a reminder system. After all, users with dementia may not have a smartphone, and if they do, they might leave it in another room, or it might become tedious for them to take it out of their pocket often. Additionally, they cannot easily check what reminder they got last unless they take the phone with them to the location where the task is to be completed.

To solve this problem, Fixl et al. [30] created a spatial reminder system that uses “electronic sticky notes” that can be placed on displays around the house. These e-ink displays have a touchscreen, so the user can confirm that they have completed the task. Placing multiple screens has the added benefit that reminders can be set on locations that make sense with the given task. This way, the time between giving the reminder and executing it is minimized, decreasing the chance that the user forgets it on the way. The locations of the displays and on which screen a reminder shows up are chosen by caregivers.

To add a more personal touch to the reminders, one system allows caretakers to record video reminders for people with dementia, which would then be shown on a mobile phone at specified times [31]. This system was generally reviewed positively by both the people with dementia and their caregivers in an experiment by O’Neill et al. [31].

Another concept that can be helpful for reminders, is that of Internet of Things (IoT) smart homes. IoT devices are often used in residential settings, for use cases ranging from smart energy consumption [32] to medical sensors [33]. Some reminder systems make use of IoT sensors to aid their reminders. Giroux & Guertin [34] and Ramljak [35] present implementations of such a system, for cognitively impaired users and for medication reminders, respectively. Many context-aware reminder systems, discussed earlier, also make use of sensors to detect certain contextual clues.

2.3. Robotic Pets for People with Dementia

The use of robotic pets has often been used for the care of people with dementia [11–13, 36, 37]. While results vary from study to study, several literature reviews [11–13] show significant decreases in behavioral and psychological symptoms, especially agitation and depression. The results hold for both group settings and individual time with the robot.

Ghafurian et al. [37] present an extensive literature review, which shows that different experiments have shown different areas of improvement, such as improving quality of life, reducing depression, anxiety, agitation, and sleeping problems. Assistive robots have also been shown to improve task performance and cognitive attention, mood, and physical activity. They can also help improve social engagement with others, for example by being the topic of a conversation.

2.3.1. Examples of Robotic Pets

In this section, I will highlight a few examples of robotic pets, both those designed by researchers and commercially available robots. Not all these use cases will be directly applicable to the design made in this thesis, but they still serve as inspiration. The target audience for these robots is (or at least is for a large part made up of) people with dementia, unless specified otherwise.

First, let’s discuss the Joy for All companion cat [38], shown in Figure 2.1a. This is a commercially available and affordable robotic cat which the user can cuddle. It cannot walk around, and seems to have no smart technology inside. Pike et al. [39] tested it on a small group of people with dementia. Overall, the experiment showed positive results for both the people with dementia themselves and for their family. They found that one of the main benefits of the robot is that it stimulated conversations between the person with dementia and others. The participants of the study talked to the cat, the cat was a common conversation topic, and the cat brought back memories for a participant that used to have cats. Another benefit is that the cat calms people down. Family members also found that the cat helped with the mood of the person with dementia. This experiment highlights that even a simple and relatively inexpensive robot (around €120 as of the time of writing [38]) can have benefits for people with dementia and their caregivers.

Perhaps the most well-researched [37] robotic pet is PARO [43], a robot seal, shown in Figure 2.1b. Similarly to the Joy for All cat, PARO's primary goal is to act as a cuddlable companion. Where it differs, however, is in its more advanced functionality. It actively seeks eye contact, responds to touch, can remember faces, and learns actions that generate a favorable reaction. PARO also responds to sounds and can learn names, including its own. It can show emotions such as surprise, happiness, and anger, and will cry if it is not receiving sufficient attention.

Sony's aibo [44], shown in Figure 2.1c, is a robot dog that can walk and play with toys. It is designed for a general audience. By default, it reacts to human behavior, and can react to names and detect people's faces. Odetti et al. [45] performed an experiment with an altered version of aibo with people with early stages of dementia, focussing on acceptability. While participants were generally positive, especially in those who have a good relation with technology, they did find that some participants were not able to recognize the robot as a dog. They believe this might be due to people's cognitive impairments. In Naganuma et al.'s [46] experiments show similar things to other robots: the aibo was a useful conversation starter, in their case between different residents of a care home.

Consequential Robotic's MiRo [47] is a robot designed to incorporate aspects of different animals. Figure 2.1d shows a picture of the robot. The robot has several sensors, movable parts, can make sounds, and is programmable. This is the robot I will be using in this thesis. Its programmable nature, camera input, and precise motion outputs make it a suitable choice for creating prototypes.

(a) Joy for All companion cat. Source: [40]

(b) PARO robot seal. Source: [41]

(c) aibo robot dog. Source: [42]

(d) MiRo robot. Photo my own.

Figure 2.1: Several robot pets

In order to have the MiRo be able to show emotions better, Ghafurian et al. [48] created a series of behaviors drawing inspiration from emotional expressions from several animals, focussing mostly on dogs and rabbits. For example, the ears follow the behavior of a rabbit, while the tail wags like that of a dog. They also use the MiRo's colored lights, but they do not use any sound. They present a table with different emotions the robot should convey, and a description of how the eyes, neck, head, ears, and tail should move, along with the color and MiRo's movement. The design was evaluated using videos. The expressions of happy, sad, excited, surprised, and tired were correctly identified, but participants had difficulty recognizing more complex emotional expressions.

2.3.2. Long-Term Effects of Robotic Pets

The social robots discussed earlier are not designed to be used just once. Looking at the long-term effects of these robots can be useful, as the interaction and effects may change over time. Novelty could play a big role in the effects, suggesting that future interactions with the robot may not be as fruitful [37]. Unfortunately, long-term studies are not very common. This is likely due to challenges when setting up an experiment that takes time over multiple sessions, such as participant availability, time constraints, and costs. This section will go over a few papers that do look into the long-term effects of social robotic pets.

Moyle et al. [49] use the PARO [43] robot and bring people with dementia in contact with it several times, with five weeks between sessions. While not being an experiment, their insights are useful as a case study. They found that different people have different responses to the robot in general. One participant was very happy to be around PARO, but another became quite agitated. This agitation did not reduce over time, though there was a single brief moment in the hallway where they petted PARO. The authors suggest to not see the robot as a solution for all people, but to apply it when useful. Besides the differences between people, there were also cases where the same person would have different responses at different times. One participant seemed neutral in the first session, agitated in the second, but reacted positively in their third session. The authors recommend researchers to do more frequent assessment. They also suggest doing a baseline assessment of the participant's mood before each session.

Ostrowski et al. [50] looked into the effects of a social robot on social connectedness in a care home for older adults, focusing on their community. Participants engaged with the Jibo robot [51], a tabletop robot that mildly resembles a humanoid without facial features, and with other participants over a three-week period. Their results show a higher community engagement and more social connectedness. The robot often served as a conversation starter. They also found a statistically significant increase in number of residents present in the common spaces. One of the functionalities of the robot was giving reminders and alerts. This was received with mixed positivity. Participants initially open to the use of robots remained positive on their use, participants initially not very open remained skeptical, but participants with an initial middle openness improved their opinion on the reminder functionality.

Šabanović et al. [52] use the PARO robot in group sessions with people with dementia for seven consecutive weeks. Their experiments show that PARO has positive effects when it comes to social and physical activity, mostly with people around them. They also show that these positive effects grow over time, suggesting the positive effects are not just due to the novelty of using a new robot. It is worth noting, however, that all participants had memory impairments, and that some did not remember PARO from session to session.

Looking beyond a few sessions to very-long-term applications, Wada et al. [53] present a case study for a five-year use of the PARO robot in an elderly care home. All but one of the fourteen participants had dementia. The authors found that the robot increased residents' moods, and continued doing so over the five-year period. In particular, they mention a very touching story about a woman with mild dementia, who formed a real connection with the PAROs. She would ask about one of them when it was taken in temporarily for "surgery" (repairs), and was very thrilled on its return. She always joined activities with PARO, even if her health did not allow her to join many activities. The researchers note that she always seemed happier after playing with her robot friends.

2.3.3. Robot Interruptions

When giving reminders, a system may have to interrupt someone while they are busy doing something else. While contextual methods like those in Section 2.2.2 aim to pick an appropriate time to remind someone, sometimes an interruption is inevitable. If it is, what is the best way to interrupt someone? And does the ideal solution change depending on context or person?

An interruption presented through a robot will differ from a traditional notification on a phone. While the latter uses only sound, a robot can move around in space and can move its body parts to communicate to a person that it would like to interrupt them. Saulnier et al. [54] created a set of composable physical non-verbal cues that can be used by a robot to interrupt someone. This set was created through observing the behavior of interruption between two humans, only having access to non-verbal behaviors. They then created a robot that exhibited similar social cues, and tested it in several interruption scenarios. They found that motion and proximity were the most important components of an interruption. Some motions, however, should be used sparingly. Fast and frantic movements were found annoying, but were found to be useful in emergency situations. The experiment did not show statistical significance in the degree of interruption for head movement and eye gaze, but that does not mean these features are completely useless. They could be used to add extra information to the interruption, such as who is being addressed.

As different people may have different tolerances to be interrupted, Chiang et al. [55] present a system that can individualize the behavior the robot uses to get someone's attention. Because a robot cannot easily make the distinction between a user who did not notice it and a user who did notice it but who has decided to ignore it, they model the problem using a "Human-Aware Markov Decision Process". They split up the robot's beliefs about the human's *awareness* of the robot and the belief about the human's *engagement* with the robot. The robot can take actions, like for example waving, which may affect the person's awareness towards the robot, which in turn could influence their engagement. The robot can also use social cues and behaviors observed from the person, which are utilized to infer the awareness as well. In addition, someone's interruptibility also depends on the current activity they are engaged in, as also suggested by Ho & Intille [29]. They use the current tasks the user is engaged in and how urgent the incoming interruption is, similar to how Zhou et al. [17] model their reminder system.

2.3.4. Ethical Concerns

Preuß & Legal [56] compare real pets with robotic pets. While robotic pets remove some ethical concerns compared to real pets, like animal welfare issues that could arise when someone with dementia forgets to feed the pet enough, there are some issues that arise when it comes to robotic pets. First, they argue that sharing a connection with a real pet is different from a robotic pet, it would be a deception that could appear questionable, affect the dignity of the user, and fosters a readiness to treat people with dementia in a child-like fashion [56]. When it comes to robots that monitor the person with dementia, concerns arise related to data security and privacy, but also on an emotional level, as the relationship between the person and the robot becomes one-sided, which they argue changes the quality of the relationship. While I agree with the points made about possible social stigma, dignity, and infantilization, I think the last argument is more nuanced than they make it out to be. I agree that a pet monitoring you to provide care to you changes the nature of the relationship between you and the pet, but this does not necessarily reduce the quality of said relationship. I would argue this is similar to a guide dog or other service animals. That being said, service animals are not the same as robotic pets meant for monitoring. Robotic pets may send their data to other people, including the person's own caregiver. This data sharing may alter the quality relationship between the person with dementia and the robotic pet after all.

In interviews with people with dementia and their caregivers, Wang et al. [57] found some concerns people had when it comes to assistive robots. Some people were concerned that having the robot would lead to less contact with the caregiver, one person with dementia even mentioned they were concerned about neglect.

Moyle et al. [49] talk about the ethics of giving and taking away a robotic pet. One of their participants became very attached to the robot, a PARO, during a session with it. She did not allow the other care home residents to play with it, and when the caretaker tried to take PARO away, she became agitated. Another participant was not very engaged, but kept PARO on the table anyways, while barely interacting with it. While this did not seem to be a negative experience for the resident, it also was not a very enjoyable one. The same resident did enjoy their session with the robot on a different occasion. The authors suggest researching what a useful time to give the robot would be, so that people can enjoy the robot the most. They also suggest looking at cheaper alternatives, such as a simple stuffed animal. This way, it would not have to be taken away if the resident wants to keep playing with it, as the care home can buy multiple stuffed animals for the same price as a single robot.

2.3.5. Future Areas of Research

Ghafurian et al. [37] propose a few potential directions for future work. Firstly, although the different studies discussed in their literature review were written by researchers from 16 different countries, cross-cultural differences should be studied further. They could change the effects of the robot, and may also influence the design. Culture may affect expectations of a robot, preference about the shape, and the preferred way of interaction.

The next important future development is an implementation of better emotional intelligence. Having the robot show and understand emotions and affective expressions may boost the positive effects. They also argue that expressing proper emotions may help to persuade people with dementia to perform activities, as emotions remain an important part of people with dementia's lives.

Long-term effects of robotic pets is another area of research that has not received enough attention. While some studies have been performed, see Section 2.3.2, many of them are case studies and not controlled experiments. This could likely be due to the difficulties in setting up long-term experiments. It is however important to see whether the positive effects will persist if the robots are deployed for longer, as novelty could be an important contributor to the benefits. The authors also suggest more work to be done in the ideal shape of robots for a specific task. An example they give is that an animal-like shape might be more appropriate when assisting people with private activities of daily living, as being watched by a humanoid robot might be inappropriate, while a humanoid robot might be more appropriate for other, non-private, activities of daily living.

The final area of research that is mentioned is that of robots that can help people with activities of daily living. Most robots so far seem to focus on therapeutic care, often limited to imitating normal pet behavior. But robots that can assist in tasks, for example by providing a step-by-step guide, performing some tasks automatically, or by reminding, may allow caregivers to spend their time more on meaningful activities with the person with dementia or on their own activities. This area of research aligns closely with the goals of this thesis. Reminder systems are a useful form of care-functionality that are currently missing in robotic pets.

2.4. Participatory Design for People with Dementia

When designing a system, it is essential to design for the needs and wants of the target audience. After all, if the system is not useful or usable for them, it will probably not be adopted. To ensure the needs and wants of the audience are met, it is invaluable to involve these people in the design process. A broad term for this approach is participatory design or co-design. While exact definitions of this term vary, Spinuzzi [58] argues it is just as much a research and design methodology, rather than only a research orientation more focussed on users. He characterizes the method as three stages: initial exploration, discovery, and prototyping. These three stages are iterative, making a prototype is not the end, it is just as much the start of the next cycle. The discovery phase should be done with participation of the stakeholders. They should not just be asked to verify whether the work is correct, they should be a part of the design process. This can be achieved through design workshops.

The rest of this section will go over a few of these workshops performed with people with dementia and older adults, and their main takeaways that can be used during our workshop.

Dosso et al. [59] used MiRo [47] and T-Top [60], a tabletop robot with a humanoid avatar on a screen, in workshops with older adults and their caregivers. Twenty-seven people participated, of which two had dementia. The participants filled in the Multi-Dimensional Robot Attitude Scale [61] before the workshop, to capture the participants' baseline attitudes towards social robots. After an introduction, an icebreaker activity, and a video and demonstration of the MiRo robot of one minute each, participants filled in the Psychosocial Impact of Assistive Devices Scale [62] survey based on their first impressions. This scale captures the user's perceived impact of assistive devices based on competence, adaptability, and self-esteem.

After conducting the surveys, the researchers showed a short video of the T-Top robot [60]. The discussion period followed, which was used to gather qualitative insights. There were three important discussion topics: (1) social robot application areas and design elements, (2) emotion functionalities, and (3) the potential stigma around social robot use. The discussion phase consisted of a mix of talking, anonymous polls, and chat functionality.

Rodgers [63] uses a design workshop to show that co-design can be beneficial and enjoyable for people with dementia, and that people with dementia can still participate in design activities. The participants designed a tartan, a Scottish cloth pattern. This is, of course, quite different from a social robot, but his insights are still useful. He gives several recommendations for co-design in research. First, it is important for people with dementia to be able to choose which part of the research they want to be involved with. Second, people with dementia should be involved when setting research priorities. Third, physical and emotional safety are paramount. Fourth, researchers should use language that is supportive and not offensive. Fifth, researchers should be aware of the struggles of people with dementia, but not become patronizing. Finally, researchers should try to schedule the session at a time that make sense for the participants and should consider how their participants keep track of time. While some of these guidelines may seem straightforward, they are still worth keeping in mind explicitly in the design of our evaluation and participatory design.

Hsu et al. [64] performed a series of design workshops for the design of a humanoid social robot for people with dementia. The goal of the first workshop was to provide insights and gather challenges people with dementia face. They found that the workshop group dynamic was better when the participants were there with friends or their spouse. The workshop consisted of one-on-one activities and one-on-two focus group discussions. The focus of the discussions was the people with dementia's purpose in life. They also showed a robot and discussed how they might use it to support their purpose in life. They then asked them to draw a storyboard of at least three frames based on their suggestion. Unfortunately, the workshops were challenging for the participants. They often felt confused and told the researcher they did not understand the session or what the robot was saying, or what the purpose of the robot was. The researchers also noticed that the experience did not seem enjoyable for the participants.

They went back to the drawing board and coming up with a workshop method that fixes some problems with their previous iteration, which they believe are a lack of identity as an expert, connectedness to the robot and researcher, feeling of security while participating, and feeling they lacked autonomy to share their opinions about the robot, following a dementia well-being framework developed by Eden Alternative [65]. The second iteration focused more on the participants' well-being and autonomy. They chose to hold the workshop at the place where their participants spent most of their time. They performed five workshops. There were five design objectives for the workshop design: the participants should feel like experts of their own needs, should feel connected to the robot and researcher, should feel security with the group and environment, should feel autonomy and the freedom to say what they want, and finally should elevate overall well-being with active support from the researchers. In the end, they chose to have five sessions, one week apart, focussing on discovering through storytelling, building a robot through hearing, dressing up the robot, dancing, and reflective storytelling.

From their experience, they specify guidelines for each of the design goals. To improve participants' feelings of identity, they recommend focussing on familiar and simple activities at first. To help participants feel a connection to the researcher and robot, they recommend repeated interaction. To create a safe space, workshops should focus on peer support and group dynamics, for example by getting together a group that already knows each other. They also suggest showing peoples' decisions in the design of the robot. For example, if users express that they like certain dance moves in the robot, the robot show this immediately and in subsequent sessions. The researchers found this helped people feel like experts, and increased their autonomy. Finally, they recommend that well-being should be a primary decision-making factor. For the second set of workshops, the authors consulted the director of the care home. They also highlight the importance of seeing the participants as people instead of merely as participants. The activity should bring them joy or meaning in addition to generating useful research output.

3
Design of the Integrated Robotic Reminder System

To help people with dementia remember to do important tasks, improve their quality of life, and reduce informal caregiver stress, an integrated robotic reminder system will be presented here. Let's go over the term "integrated robotic reminder system" in reverse order: the *reminder system* allows caregivers to set reminders for the user with dementia to receive within a specified time frame, if certain specified conditions are met. The system will be aided by a *robot*. In particular, the animal-like MiRo robot is used. This robot allows for additional interactions with the person with dementia, like guiding them to certain places in the house. It also may have inherent benefits, as described in Section 2.3. Finally, the system will be *integrated* with other technology in the house. Sensors will be placed in the house to, for example, see where the user is, whether there are other people there, whether the fridge is open or closed, whether medicine was taken from a medicine dispenser, or whether the person's house keys are in the house. These sensors are used to detect whether tasks are completed, whether the current context is right to send reminders, and to make task completion easier.

The core interaction looks as follows. When a reminder needs to be given, the MiRo robot drives towards the person with dementia, trying to get their attention. It will then guide them to a screen. Several of these screens will be placed around the house, to make the distance between getting the reminder and performing it smaller. After the user performs the task, its completion can be noted in two ways. If possible, sensors should detect whether a reminder was completed. When this is not possible, the reminder should be confirmed by the user through the screen.

This chapter is about the *design* of the system. Chapter 4 will talk about the creation and design of the robotic prototype, and Chapter 5 shows the user interface prototype. Chapter 7 is about the proposed system architecture of the system, and finally, Chapter 8 presents the formal software requirements.

The research sub-questions relevant for this chapter are "How can the design of an integrated robotic reminder system balance the conflicting values of individuals with dementia and their informal caregivers?" (SRQ1) and "How can a robotic pet effectively give reminders to people with dementia in a more interactive manner compared to traditional reminder systems?" (SRQ2).

3.1. Problem Statement

The problem statement consists of three parts:

Problem 1: People with dementia often struggle with **remembering important daily tasks**. The focus will be on activities of daily living, like Hartin et al.'s [15] list of having meals, drinking, taking medication, keeping up with hygiene, going to appointments, and the wildcard other category. In Section 2.2, I talked about reminder systems for people with dementia, and concluded that these types of systems can be useful to help people with dementia remember to do important daily tasks.

Problem 2: The **quality of life of people with dementia** is sadly not always as high as it could be. Section 2.1.2 talks about some of the problems experienced by people with dementia. These include depression, anxiety, agitation, irritability, and loneliness. Section 2.3 shows how robotic pets can inherently help people with dementia with these non-cognitive symptoms.

Problem 3: **Informal caregivers** of people with dementia spend a lot of time caring for their loved one with dementia. They also do not know if the person with dementia is taking care of themselves properly while they themselves are away. For many informal caregivers, providing care can lead to **high stress**. The system should provide informal caregivers with some peace of mind while they are away, and should aim to reduce the workload and stress of informal caregivers — or at least not *increase* it.

3.2. Design Process

The system was designed using an iterative process, drawing mostly from the socio-cognitive engineering method [66, 67]. Figure 3.1 shows a diagram of the main iterations of the design process. Contact with stakeholders was an important method to ensure the system fits their needs. The two largest iterations came after the two design workshops hosted, one with professional caregivers, and one with people with dementia living in a care home. This chapter mostly shows the final iteration of the design. The setup of the workshop, and the changes made because of them, are described in Chapter 6.

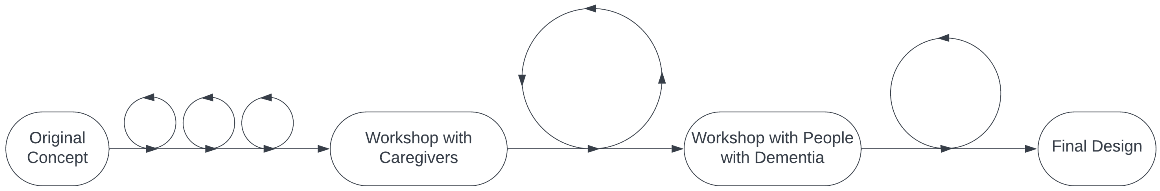


Figure 3.1: Main iterations in the design process.

To help keep the final users in mind during the whole design process, two personas were made. Personas are representations of people that could use the system you are designing [68, 69]. Creating personas serves two main purposes. Firstly, they enable designers to explore diverse user profiles. For instance, one of the personas is someone with dementia who is supported by their spouse, while the other portrays a person receiving care from a busy, working adult child. While user diversity could be outlined without personas, the second benefit lies in personifying these abstract user groups. By giving personas names, stories, and personalities, designers can better retain and consider their needs throughout the design process. It enhances the empathy and engagement during design, compared to merely listing the user groups. Appendix A shows the personas made for this thesis.

In crafting a system for people with dementia, a thoughtful and empathetic approach is paramount. For a system to be used, the needs and values of the different stakeholders need to be respected and reinforced. This is where value-sensitive design comes in useful. Broadly, value-sensitive design is a design approach that systematically accounts for human values [70]. The first step of value-sensitive design is determining who the stakeholders of the system are [70]. This follows in Section 3.3. The values these stakeholders hold are discussed in Section 3.4. Occasions where these stakeholder values clash will be discussed in different points in this thesis.

3.3. Important Stakeholders of the Reminder System

This section will go over important stakeholders involved in the system or its effects, and discuss their benefits of using the system, and some important things to keep in mind for them. I will first go over the primary stakeholders, those who use the system directly, followed by the secondary stakeholders, those who are only affected indirectly.

3.3.1. Primary Stakeholders

The first, and most obvious, primary stakeholder is the people with dementia who live at home and use the system. As discussed in Section 2.1.1 and Section 2.1.2, these users struggle with the cognitive, psychological, and behavioral symptoms of dementia. The goal of the system is to help them remember to do important tasks, and to improve their quality of life.

People with dementia are not the same as the general population. Extra care should be taken to take their symptoms into account. Jiancaro et al. [71] also recommend focusing more on learnability and self-confidence when compared to designing for a general audience. Finally, the values that are important to them, and their priority compared to each other, are different. This will be discussed further in Section 3.4.

The other primary stakeholder is the informal caregivers of users. They are also able to receive updates on how the person with dementia they are caring for is doing. Informal caregivers are often busy and stressed, as discussed in Section 2.1.3, so an important design goal is alleviating their stress and giving them more time for themselves. It is also important to keep the connection with the person with dementia. This positive effect is also beneficial for the person with dementia.

Just under half of informal caregivers in the Netherlands provide care for their partner [8]. This means they are, most likely, older adults themselves, and may thus not have that much experience with technology. This is useful to take into account.

3.3.2. Secondary Stakeholders

Another important group to consider are visitors, like other loved ones, friends, or tradespeople like plumbers. These people will come in contact with the system and, more specifically, with the robot. Their presence serves as an important contextual clue for the system to consider: reminding someone to go shower is unlikely to be accepted if there is someone else in the house. The robot could also serve as a conversation starter between the person with dementia and the visitor, as discussed as one of the benefits in Section 2.3. Some of these visitors may occasionally provide some care, for example by bringing a meal.

Medical and healthcare professionals do not interact with the system directly, but they will still be able to see any benefits of the system. They could also recommend the system to their clients or patients. They could instruct the caregivers on what reminders might be useful for their client or patient, think for example about physical recovery exercises prescribed by a physiotherapist or of taking a kind of medicine at a specified time (e.g., after lunch).

Finally, let's briefly touch upon some societal-level effects of the system. The system could potentially increase the time a person with dementia is able to live in their own home, alleviating the capacity issues experienced by care homes. Reducing the workload of home care professionals has a similar effect, if they can forgo a visit sometimes, it would allow them to service more clients per day. Finally, by reducing the stress and workload of informal caregivers, they may be able to spend more time in their community and keep working for longer. For wide-scale adoption, the system should be affordable, scalable, and easy to set up, use, and troubleshoot.

3.4. Important Values of The Primary Stakeholders

The systems goals and design should align with the values of the previously discussed stakeholders. Köhler et al. [72] derived a set of sixteen values from interviews with people with dementia, their caregivers, and healthcare professionals. Five values are of particular importance to this thesis. These are *caring & empathy* (one value), *autonomy*, *safety*, *privacy*, and *participation*. These values are sometimes at odds with each other. This section explains these conflicts. Future sections explain design decisions and compromises based on these conflicts in more detail.

Some of these values reinforce each other. Take *caring & empathy* and *safety*, for example. By creating a caring and empathetic environment, the person with dementia likely feels and is and be more safe (both physically and emotionally). *Caring & empathy* also shares a reinforcing connection with *participation*. Involving the person with dementia makes it easier for the caregivers to understand them and to empathize with them. However, other values have some conflict. The reinforcing and conflicting relationships between values are shown in Figure 3.2.

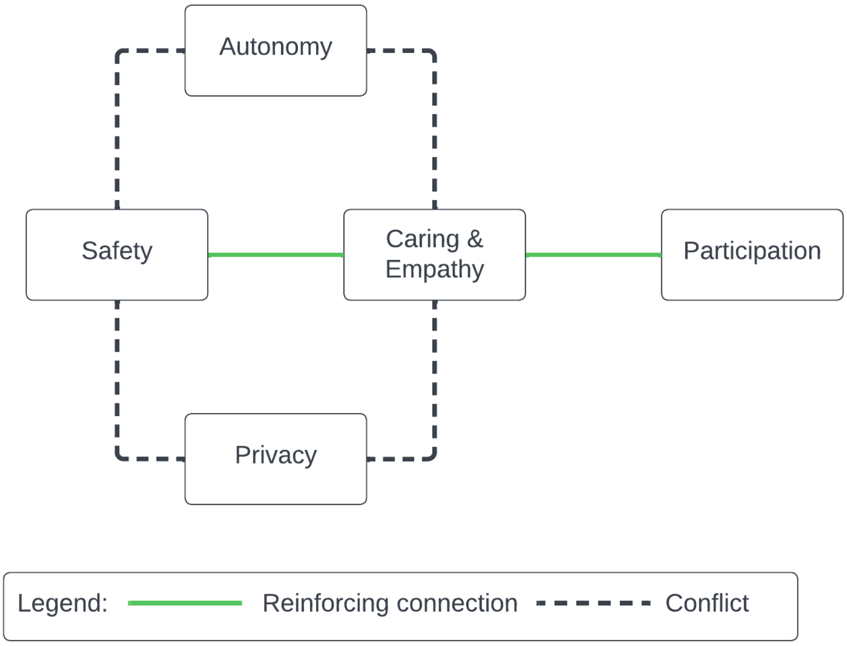


Figure 3.2: Relevant values and their reinforcements and conflicts. Values and relations from Köhler et al.'s [72] values for systems designed for people with dementia, image is my own.

I will now go over some potential conflicts that are important when making design decisions. The first of which is the conflict between *autonomy* and *caring & empathy*. As the system is designed for people with dementia living at home, a certain level of autonomy can be expected. The conflict arises when, for example, the person with dementia wants to schedule their own day (*autonomy*), while the caregiver and the system wants to give more reminders to make sure they do the activities of daily living (*caring*).

The second conflict is that between *privacy* on one side, and *safety* and *caring & empathy* on the other. The *privacy*-*safety* conflict is one that is relevant for many systems. Placing many sensors, cameras, and other tracking methods in peoples' houses may increase their safety, but it could also be seen as a violation of their privacy. One way to ensure a good level of care and safety provided by the system, while maintaining the user's privacy, is by keeping private data safe, and deleting it after use. If cameras are to be placed in the house, their data should not be processed or saved unencrypted in the cloud, where it could be seen by others or hacked, but should be kept only while needed, and be kept on a device in the house. Details on the software architecture used to achieve these goals can be found in Chapter 7. While these technical decisions try to ensure private data cannot be seen (or easily hacked) by external parties, it does not fully solve the issue of privacy. Having cameras and sensors in the house may still make the person with dementia, their caregiver, and visitors *feel* like their privacy is being violated. Explaining to the users that the data are kept securely may not be enough to alleviate their concerns. It should thus only be done with care.

3.5. Use Cases

This section goes over the nine use cases of the robotic reminder system. The descriptions already include some design decisions. These will be elaborated on later.

Setting Reminders

The caregiver can set reminders to be sent to the person with dementia later. Reminders have multiple settings, such as the acceptable start and end time (and an option to have it trigger at one specified time no matter what), prerequisite reminders, urgency, and whether or not the caregiver will be notified when the task is completed. The person setting the reminder will also be able to set how the reminder can be completed. Some common reminders could be pre-programmed, so that the user only has to select them.

Receiving Reminders

The robot will prompt the person with dementia to perform the predetermined activities. This can be done in multiple ways, depending on the type of reminder, settings, user, and context. First, the robot could guide the person to a specific place. In some cases, this could already prompt the user to perform the action. For example, for lunchtime, the robot could guide the person to the fridge. For other reminders, the robot will instead guide the user to a screen. This is a screen somewhere in the house that can show the user what to do. It could also show a video or play a sound. There will be multiple screens in the house, so that the robot can guide the person to a location close to where the reminder needs to be performed. This way, the user may be less likely to forget what it was they were supposed to do, and can check what the reminder was in case they do. Some reminders can be integrated with other technologies. For example, if the person with dementia should call their cardiologist, their phone number could be preselected on the user's phone, so that they only have to press call. Finally, some common tasks could have a specific interaction with the robot. To get the user to perform some physical exercise, for example, the robot could dance with the user.

Completing Reminders

After a task is completed, the system should be notified about this. This can be done in two ways. Some tasks can be detected, through sensors in the robot or elsewhere in the house. A smart pill dispenser will detect when the pills have been taken, and will notify the reminder system. Other reminders will require explicit confirmation. This can be done through the screens. On the screen, there will also be an option for when the user does not want to do it right now, but wants to be reminded later. This should only be possible for lower-priority reminders where the time slot still has enough time left. A reminder to call your doctor sent at one p.m. can be sent again later in the day, while a reminder to have lunch sent at one p.m. should be completed now, and an urgent reminder, like turning off the stove when it is not in use, should not be postponed.

Contextual and Personalized Reminders

At reminder creation, specific rules can be set regarding context, such as location, whether or not there are guests, and data from different sensors (e.g., is the person sitting down? Has the fridge opened in the last hour? Is the gas stove on?). These rules are then taken into account when giving reminders. Besides these manually inputted rules, the system will automatically plan in reminders within their designated time slot in a way that maximizes how many reminders can be completed.

Feedback to Caregiver

If selected when the reminder was created, the caregiver will be notified on their phone when a reminder was completed or when an important reminder was not completed within a certain time frame. This gives the caregivers peace of mind, and allows them to intervene if something goes wrong. For less urgent matters, the caregiver could, instead of being notified, check up on task completion on their phone.

Safety
With all the sensors already placed in the user's house, it is possible to detect emergency situations, like falling down the stairs. In these situations, the caregiver (or even the emergency services) will be notified. The system will also tell the user with dementia that help is on its way, to prevent the user hurting themselves trying to get up after a fall.

Reminder Insights
Sometimes reminders are set up in ways that do not work well. Maybe a weekly reminder was accidentally placed at the same day and time the user's granddaughter regularly comes to visit. This reminder would then usually not be completed. It is important that the caregiver is able to find these unfortunately timed reminders, in order to change them to a better time.

Information and Help
At first use, the robot tells the user with dementia what it is, and what they should do. It explains that it can help the user with reminders, and that it sometimes comes to the user, that they should follow it, and that it will tell them what they should do next. If at a later time the user gets confused about what the robot is for, they can tap the question mark button on one of the screens, which will show a video explaining the system. The system will, of course, also come with detailed instructions for the caregivers.

Besides information about the robot, the screen should also show the time, both when a reminder is active and when no reminder is active. Additionally, it should show the next upcoming reminder, so that the person with dementia can choose to already complete it earlier, should they want to.

Play
When not giving reminders, the robot should behave like an animal pet, so that the person with dementia can play with it. It should react to touch and make animal sounds. It could also react to its own name, and play with toys.

3.6. Setting Reminders

The reminders in the system are set by the informal caregiver of the person with dementia. This is done through a phone application, as this gives the caregiver the option to set reminders even when they are away. This also allows them to later check up on the person with dementia to see if they have completed the reminders. The caregiver has several options when creating a reminder. A prototype of the user interface of this application is presented in Chapter 5.

To clear up the concept of a reminder, an ontology was made. This ontology encapsulates different components of a reminder within this system, including the connection between these components. The ontology can be seen in Figure 3.3. Components with a gray background are explicitly set by the caregiver during creation, while components with a white background change while the system is in use. Some of these white components can be estimated by the system, and are used to schedule future reminders at an appropriate time in within the time window. The context conditions are both set manually and learned by the system. This will be explained further in Section 3.10.

Some important aspects of the reminder are, first and foremost, the task that the reminder is for. Besides this, there are a few general settings. These are the location, urgency, and category. The reminder comes with a time window, defined by its start and end. The reminder should be given somewhere within this time. For example, a call to the doctor could be done anywhere between nine and five, and lunch should be somewhere between twelve and one. Of course, calling the doctor does not actually take the full eight hours. The caregiver gives an estimate of the duration of the task, which is used for scheduling when within the timeframe the reminder should be sent. This estimate can also be changed by the system, if the caregivers estimate proves not very accurate.

Besides reminders with a given timeframe, the system also supports event-based reminders, like those discussed in Section 2.2. These reminders do not have a time element, but rely only on context

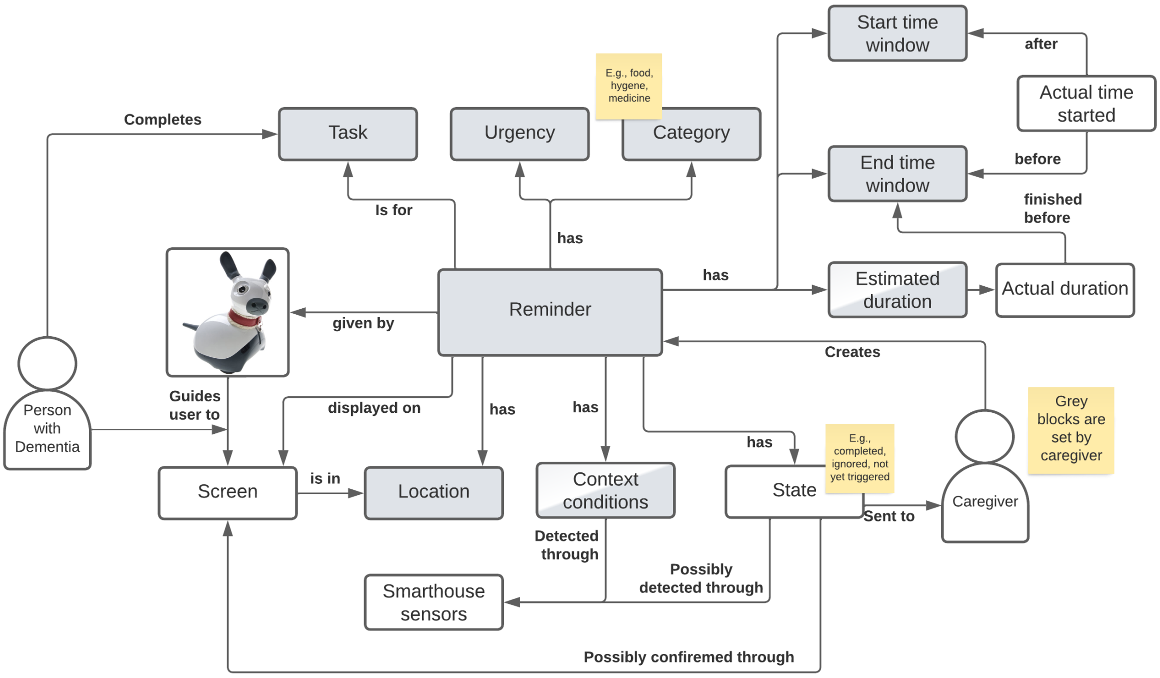


Figure 3.3: Ontology for Time-Based Reminders.

rules. Useful examples are a reminder to turn the stove off when it was accidentally left on, and a reminder to take your keys when leaving the house. The ontology of these types of reminders is simpler, and can be found in Figure 3.4.

While of course every user is different, many activities of daily living are useful for everyone. That is why I propose using a set of predetermined reminders that can be chosen by the caregiver. This allows caregivers to spend less time setting up basic reminders, reduces the chance of errors in reminder creation, and allows for us to create custom interactions for some common reminders.

Finally, let's discuss the possibility of the people with dementia adding reminders themselves. Ideally, this is something that should be possible. It would allow for a greater degree of *autonomy* and *participation*, two important values for the system. However, the users with dementia may set reminders for themselves that have little use, may set the same reminder on multiple times in the same day, or may set a time frame and context conditions that are not in line with the reminder. These potentially lower-quality reminders may decrease the level of *care* and could, in some circumstances, lead to lower *safety*. It may be possible for these reminders to be verified by the caregivers through the phone application, but this could lead to an increased workload again.

Even if we ignore the issue of low-quality reminders, the implementation of this idea is easier said than done. Even without some of the advanced options in reminder creation, it is difficult to conceive of a good way for the users with dementia to enter reminders. A simplified version of the creation screen, perhaps placed on one of the screens in the house, may be an option, but this still expects a level of computer literacy that people with dementia sadly may not have. Using voice controls instead would not make it much better, as there would have to be a multistep process where the different aspects of a reminder are asked.

For now, I believe it is best if the users with dementia cannot set reminders themselves. Of course, it is still possible for the caregiver and the person with dementia to create reminders together. This should still increase the users' sense of *autonomy* and *participation*.

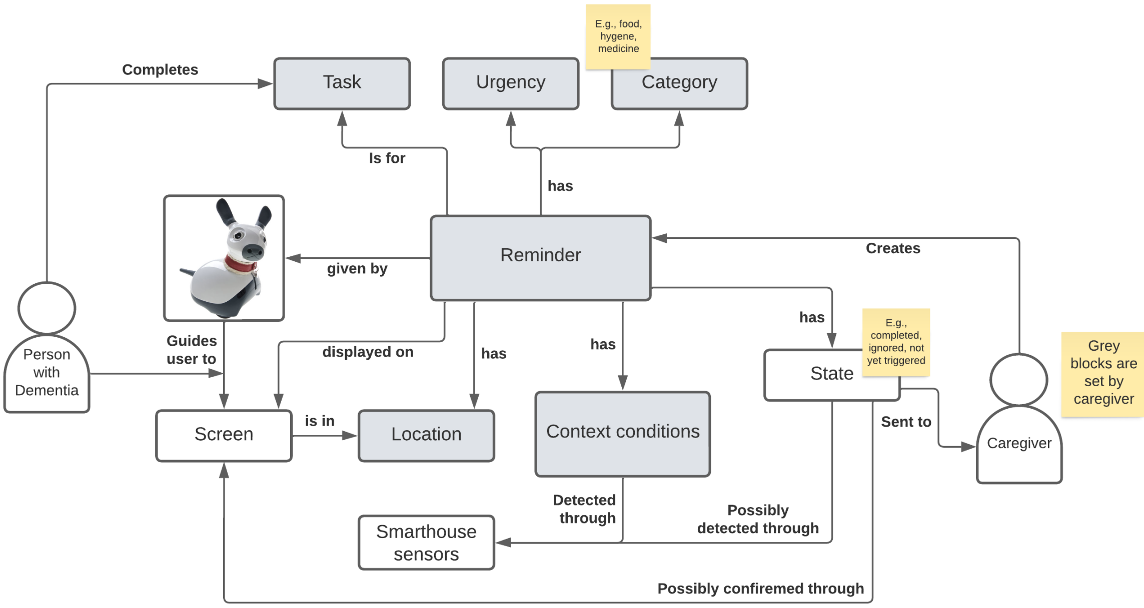


Figure 3.4: Ontology for Event-Based Reminders.

3.7. Receiving Reminders

To convey the reminder to the person with dementia, several options have been explored. For example, the robot could speak, either by text-to-speech or by using recordings of caretakers, similar to the video recordings used by O'Neill et al. [31]. Benefits here include the fact that the user does not have to read and the fact that the system is contained to the robot. A possible drawback would be that talking may not be expected behavior from an animal-like robot like the MiRo, and could thus seem unnatural. Furthermore, text-to-speech might not be heard correctly, and it is difficult to go back and check what the reminder was for, the robot would have to say the reminder again.

Another option could be to incorporate a secondary reminder system, like a screen, similar to the e-ink sticky notes used by Fixl et al. [30]. Here, the robot would prompt the user to read the text on screen. This screen could also be used to confirm the reminder if this cannot be done differently. This would, however, make the system not contained to the single device. Finally, a connected Internet of Things (IoT) solution could work for some types of reminders. If, for example, the user needs to call their doctor, this solution would preselect the doctor on the phone when the robot reminds the user. This could also have the benefit of automatically determining whether this reminder was completed. However, this would require extra development time, would require the user to own certain smart devices, and would put an extra burden on the caregiver of inputting what exactly the reminder should do in the system.

Considering the benefits and drawbacks discussed before, screens provide the clearest way of showing information that is most certain to be understood, and can be viewed again later. It also grants the option of additional functionality, like showing the current time or even a calendar, which may be able to help the user even when no reminder is being shown. The use of IoT devices is also a worthy addition. It would cost extra development and setup time, but adds clear benefits in the ease in which some tasks can be completed. IoT solutions are also used in detecting whether tasks are completed, discussed in Section 3.8, and in the use of context to give reminders at an appropriate time, discussed in Section 3.10.

At first, I conceived the system working without any speaking, as I found the added benefit of easier information not worth it compared to the unnaturalness of an animal-like robot speaking, the chance of not hearing the robot, and missing the option to go back to read the reminder again. However, in the first design workshop (see Chapter 6), the participants, who were professional caregivers, did not find the unnaturalness a concern. In the final version of the system, the robot does speak. The problems of not hearing the robot and not being able to go back remain relevant, however. For this reason, the screens are still used, and the robot verbally tells the user to follow it and to look at the screen. This has all the benefits of the screen-based system, while also making the interactions of following the robot and looking at the screen more clear. More on the interaction with the robot can be seen in Section 3.9.

3.8. Completing Reminders

When a certain task is completed, the system should know about this, and mark the reminder as completed. If a task was completed *before* the reminder was given, the system should ideally know this, so that it can forgo giving this reminder. When a reminder *is* given, the system should know whether the related task was completed. If it was, it can notify the caregiver if they selected this option. If it was not completed, the system could try to give a reminder again, depending on the situation.

I envision two ways the completion could be registered. It could either be detected automatically, or be inputted by the person with dementia. The automatic approach is achievable using sensors and other technology integrations. The manual confirmation could be done through the robot, but I believe the screen is a more appropriate choice. Asking the user with dementia to speak to the robot could cause problems with the speech not being heard or understood by one party. Asking the user to touch the robot on a certain spot on the robot is not an intuitive way of telling it you have completed the task.

Manual confirmation has some major drawbacks when it comes to reliability. Someone with dementia may forget to confirm the reminder on the screen after having done it. When a reminder is given but the task was never completed, the system should try to give the reminder again at a later time. This could lead to a reminder being completed twice, which could lead to dangerous situations when it comes to some reminders, like taking medicine. Alternatively, the user may have completed the task before the reminder was given. The screen shows an option for “already completed”, but the user may forget they have already completed it before. This could also lead to a reminder being completed twice. Having the “already completed” option comes with another problem: the user may mistakenly believe they have already completed the task, while this is not true. This would cause the system to believe it was done.

Perhaps the automatic approach is more fitting, then? With sensors and technology integrations around the house, the system can detect whether some reminders were completed. Placing cameras would further increase the possibilities of completion detection. Still, the automatic approach comes with drawbacks too. Not every detection method will be equally reliable. While detecting whether someone has showered can be done reliably with a water flow sensor in the shower, the same cannot be said about a similar sensor in the sink for detecting whether someone drank water: they might have turned on the faucet to wash their hands. Table 3.1 shows a few reminders with possible detection methods, along with an estimate of the reliability of these detection methods. The detection may differ depending on whether the task was completed before or after the reminder. The user may open the fridge door several times during the day, so this information is not enough to know whether they have had a meal. However, if they open the fridge shortly after receiving a reminder to have a meal, it is more reasonable to assume they opened the fridge for the purpose of completing this task.

Besides the reliability, the automatic approach has another clear drawback. All these different sensors need to be installed in the house and be linked up to the correct reminder. This would cost extra time for the caregiver, and can lead to human errors. This problem is mitigated by the fact that many reminders should happen more than once, and that many sensors have a simple setup. Setting up the shower sensor and related reminder only needs to be done once, and consists of simply screwing on the water flow sensor and telling the system this is for the “take shower” reminder. Because many activities of daily living are common between many or all users, some sensor-reminder links can be presented as presets. The reliability of these can be determined by the developers. This would mean that a water flow sensor placed on the sink would not automatically mark the reminder to drink water as completed when the sink is used without a reminder, while a similar sensor in the shower is

Table 3.1: Different reminders with a possible detection method and an estimate of the reliability of these detection methods, both for before and after a reminder was given.

Reminder	Detection	Reliability (before)	Reliability (after)
Take shower	Sensor in shower	High	High
Call person	Connection with phone	High	High
Take medicine	Connection with smart pill dispenser	Medium-High[1]	Medium-High
Have meal	RFID tags on food containers	Medium-High	Medium-High
”	Sensor on fridge door	Low[2]	Medium[3]
Drink water	Sensor at sink	None	Medium

enough evidence of completion.

Both the manual and automatic methods suffer from reliability issues in their own way. For this reason, I have chosen a hybrid approach. Whenever sensors are available and reliable, they should be used for completion detection. When sensors are unreliable or not available, the screen should have buttons to manually confirm the completion of reminders, with an option for “done”, “already done”, and “not now”, which would send the reminder later. It cannot always be certain whether a certain task was completed or not. This is a significant drawback of the system, but one I believe cannot be solved completely. One way to mitigate this problem is to keep the caregiver in the loop. They could, when needed, check up on the person with dementia if an important task, like eating a meal or taking medicine, remains uncompleted. Feedback to the caregiver will be discussed in Section 3.11.

The goal of a reminder is to make sure important tasks are not forgotten. The decision of whether or not to actually complete the task, is up to the person with dementia. To this end, I propose the using the priority of the reminder to see if reminders should be sent again. First, reminders of high priority should always be attempted again until completion. Tasks like taking medicine and turning the stove off could be high priority reminders. For safety reasons, it is important these are always completed. Medium priority reminders should be retried again. The user may not feel like eating now, but perhaps some time later they may. However, unlike high priority reminders, it is acceptable to stop trying if it is clear the user does not want to complete the task. This could be after one to a few attempts. Low priority reminders are the least important. For example, it is fine if the user does not exercise if they do not feel like it, attempting to give the reminder again is not necessary. The caregiver can see which reminders were completed, and can get insights on which reminders are usually ignored. They can use this to change the timing of the reminder, and to talk to their loved one with dementia to ask why they usually ignore it. This will be discussed further in Section 3.11.

3.9. Robot Interaction

As discussed in Section 2.3.3, an effective way to show that a robot is trying to interrupt you is by moving and stopping at an appropriate place [54]. However, this should be done non-erratically, as that was found to be associated with emergencies. The robot should move towards the user, and stop at an appropriate distance. While not the main components for interruption, sound can still be a useful addition [54]. MiRo has built-in sounds, to which an emotion can be set. These sounds could help get the user’s attention during the approach. To make it clear what the user should do, the robot will verbally ask the user to follow it after it has been noticed. This was added after advice from caregivers participating in the workshop (See Chapter 6). They thought that, while the approach would likely get the user’s attention, it may not be clear what to do next. Asking the user to follow them adds this clarity.

The robot should then guide the user to a specified location. It should know whether the user is actually following it, so that it can go back to try to get their attention again if needed. This is easier

[1]It would be certain that a pill was taken from the pill dispenser, not necessarily that it has been taken.

[2]Opening the fridge at a arbitrary point in the day is not an indicator for having a meal. Opening the fridge at an appropriate time, e.g., lunchtime, may be a more reasonable indication.

[3]Opening the fridge right after a reminder to have a meal is likely to be related to this meal.

said than done, as MiRo does not have cameras on its back. Instead, it will have to occasionally look back to see if the user is following. If not, the user should be approached again similarly to the initial interruption. When the robot and user arrive at the screen together, the robot will verbally tell the user to look at the screen, for similar reasons as discussed in the previous paragraph.

This procedure works if the user is currently engaged with something else. If the user is currently already playing with the robot, in its role as a general robotic pet, the interaction works differently. The attention is already there, so all it has to do is verbally tell the user that it now has a reminder for them. The guiding works the same as before.

3.9.1. Interaction Design Patterns

While so far we have been talking about the pet-shaped MiRo robot, this section generalizes two important interactions to be appropriate for different types of robots. For this section, I am assuming the robot that could use these design patterns has access to movement and sound as mediums. I am also assuming that the robot has some way of facing certain directions.

Getting Attention

The first obvious way of getting someone's attention would be sound, if available. In the case of the MiRo robot, an animal sounds fits in its design language, and would likely grab someone's attention. A humanoid robot should interrupt similarly to a human, it could for example say “excuse me” to get a person's attention. Saulnier et al. [54] show that movement and proximity are the most important non-verbal factors when it comes to interrupting someone. Forgoing sound and using only movement and proximity would still get the idea of an interruption across, but it is possible the person does not notice the robot if it is behind them.

Drawing Attention to Something

The robot should look at the object it is trying to draw the user's attention to. Gaze is an important factor in communication. Mutlu et al. [73] show that gaze cues can help humans know which object a robot is referring to. It could also move closer to the direction, and perhaps make sounds at it. To show that the user should be the one paying attention, the robot could look at the user, and then look at the object. If the robot has arms, it could also point at a place. If the robot can speak, it could also tell the user where to look, in addition to gaze and direction.

3.10. Contextual and Personalized Reminders

Giving reminders at the wrong time can cause stress [26] and interfere with task performance [27]. For this reason, it is important that reminders are sent at the right time. What the “right time” means may differ per person. This section presents two ways reminders take context into account. The first is through rules set by caregivers, described in Section 3.10.1, and the second is the precise scheduling of a reminder within its specified time frame using a heuristic, described in Section 3.10.2.

3.10.1. Rule-Based Contextual Reminders

In Section 2.2.2, I discussed two main ways to handle the planning of contextual and personalized reminders. The first is through manually entered rules, where the caregiver would program in certain conditions that have to be met for the reminder to be triggered. While this allows for greater precision, setting up the rules can be quite complex and prone to human error. The second approach is automatic, for example using machine learning with sensor data as input. This is easier on the caregiver and less prone to human error, but allows for less precise control, requires a dataset, and could lead to strange situations.

For this system, the more precise control gained by a manual rule-based approach is valuable. The imprecise nature of the automatic approach could lead to confusing situations, like asking a user to shower when a visitor is in the building, and would require either a dataset to start with, or would require learning about the user, which would mean the system does not work well when it is first used.

When using a manual rule-based approach, the next question becomes: who sets the rules? Here, we find another clash of values of the caregivers. While the developers of the system creating rules that the caregivers could choose from would be the safe, as they have time and knowledge to test the rules extensively, it takes away some autonomy from the caregivers. Giving them more control allows them to tailor the rules more to the specific needs of the person with dementia they are caring for. While giving more freedom to the informal caregivers to create their own complex rules would be ideal, giving them full freedom to create complex rules seems too risky. Instead, the system allows them to select multiple rules, like “no visitors” or “not busy”, which all have to hold before the reminder can be sent. They will also be able to select whether the rule is strict or a preference. Strict rules will never be broken, while preference rules may be dropped if it is otherwise unlikely the reminder will ever be completed.

3.10.2. Precise Scheduling of Reminders Using a Heuristic

While the rule-based approach discussed in the previous section determines whether a reminder can be sent or not, it says nothing about when *exactly* within a certain timeframe it is sent. There may be situations where two reminders could both be sent, which one should then be sent first? If the reminder is high-priority, the answer is clear, but what about medium- and low-priority reminders?

Du et al. [24] sort their reminders based first on priority, then on distance to the deadline. This is a good heuristic: the most important reminders are more certain to be completed, and reminders with a deadline further in the future have a higher chance of their prerequisites to be satisfied again at a later time. This approach, however, is not perfect — it is just a heuristic, after all. Take Figure 3.5 for example. There are two tasks with an equal priority, one with a close deadline, and one with a far deadline. The task with a close deadline has very lax prerequisite rules, but the one with the further deadline has strict rules. Du et al.’s [24] method would schedule the task with the earlier deadline first. In this situation, however, it would be beneficial to schedule the later task first. The strict prerequisites of the later task may not all align perfectly anymore in the future — this could be the last chance of completing it!

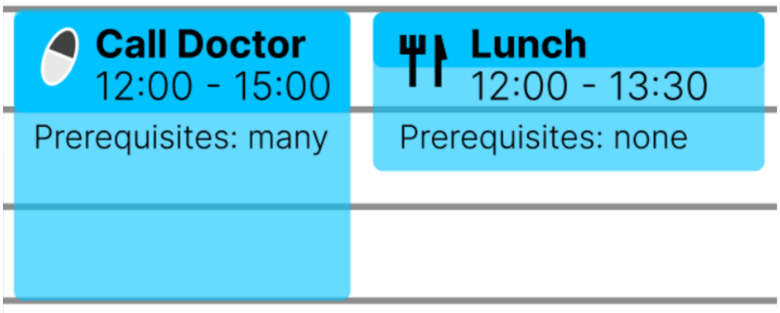


Figure 3.5: An example of two tasks where deciding which one to choose may be difficult.

Should we want to make this decision in a smarter way, there are a few things the system should know. The ontology in Figure 3.3 shows which aspects go into a reminder. Some of these will be defined by the caregiver, but some can be learned. First, there is the duration of tasks. It might be beneficial to squeeze in a quick task before a long one, to make sure both are completed if any unexpected delays happen. As many tasks will be performed often, some even daily, the average time one particular user takes can be derived over time. Then, as mentioned before, there is the possibility of some sets of prerequisites triggering only rarely, while others may be true almost the whole day. This information, too, can be learned. The system should store at which time of day which rules hold. Finally, task completion can be used as a useful scheduling tool. If someone usually ignores a reminder around a specific time of day or when doing a specific different activity, it may be useful to postpone the reminder, as it has a higher chance of not being ignored in the future.

After storing the aggregate data of the duration, prerequisite satisfaction, and acceptance context, the system should decide on a specific time. This part of the system still requires experimentation, as it is difficult to test without real data or without having people use the system for multiple days. As a first version of the system, I propose a heuristic approach. Du et al. [24] have the right idea sorting on priority first. A high priority reminder should be sent out as soon as possible, as there is a chance they may not be able to be sent anymore later. Medium priority reminders should be sent before low priority reminders, all else being equal. However, if a low priority reminder has a deadline coming up soon, while the medium priority reminder still has plenty of time left, perhaps the low one should be sent first.

My proposal is to give each reminder a *priority score*. This will be a weighted sum of the aspects previously mentioned, namely time away from the deadline (minus the duration, it should be finished before the deadline), whether the reminder is low or medium priority, whether there are any contextual preference rules active, the probability that the prerequisites will be active again in the future, and the probability that the reminder will be completed now given the current time and the user's current activity and context. The first three aspects require no calculation, but the two probabilities do. I would try a simple probability calculation using past data, but for the first few days and weeks a certain user uses the system, there may not be enough data yet to calculate the probability accurately. In that case, relying on only the priority and distance to the deadline, like Du et al. [24] do, still provides a useful heuristic, which can be applied while the system learns more about the preferences of this specific user. The exact weights in this function should be decided after experimentation, and could even be altered per user.

Some users may have particularly strong preferences about some times they do not want to be interrupted. If someone always watches a certain TV show at a certain time, and always ignore reminders during that time, the weighted heuristic function will automatically take this into consideration, but that may not be enough. If the probability of reminders being ignored in a given context or a certain time is consistently high, it will be added automatically as a preference rule (so not a strict rule). This is also communicated to the caregiver, if they see that the user often ignores reminders while watching a certain TV show, they can decide to reschedule reminders around the show's time, or can decide to add the rule as a manual rule, meaning they can apply it — as a strict or a preference rule — to reminders of their choice. Reminders with a high priority ignore this system.

3.11. Feedback to Caregiver

Keeping the informal caregiver in the loop is an important aspect of helping them with their stress. When they are out of the house, they can rest assured knowing that their loved one is doing the important things they need to do. There are three ways in which the caregiver is notified. First, they have access to an overview page at any time. This allows them to see which reminders of the day have been completed. On reminder creation, they also have the option to get notified when a task is completed. This is done through their phones' push notifications, and is the second way they can get notified. The third and final way is through notifications when selected reminders were *not* completed within their time frame. This allows them to check up themselves.

The second important way the caregivers are kept in the loop is triggered when an emergency is detected. For example, if the person with dementia might have a bad fall. The caregiver, and perhaps the emergency services, will be notified. Ideally, this is done through a phone call instead of a push notification, as this is more noticeable, and less likely to get blocked by any do-not-disturb features on the caregiver's phone. This would also allow the caregiver to talk to the person with dementia, for example through the speakers of the robot. This would allow them to confirm the emergency, and ascertain how bad it is. During an emergency, it is important that the person with dementia knows that help is on its way. This way, they are less likely to hurt themselves when trying to get out of the situation.

The final way caregivers are kept in the loop, is through information about recurring reminders and contextual rules. This information can be used to get insights about the reminders, which would allow them to reschedule them in a way that would improve their effectiveness. This is done in two ways, for recurring reminders and for smart contextual rules. The recurring reminder view shows a list of all reminders that occur on a repeating schedule. It shows the caregiver whether these reminders are usually completed or not, and whether the reminder is usually necessary. Per recurring reminder, it is visible which days tasks were completed before the reminder, when they were completed after the reminder, when they were not completed, and when the reminder was unable to be sent. Reminder that are consistently missed can be rescheduled, and reminders that are consistently completed before the reminder was given could be removed.

The caregiver also has access to an overview of the contextual rules. Rules that often cause reminders to not be sent or cause major delays are highlighted, as they may be too strictly applied. It may be worth removing the rule from some reminders, or rescheduling the reminder to a different time. Per contextual rules, a calendar overview is shown, which shows on which days the rule caused no problems, major delays, and on which days a rule caused a reminder to not be sent. It also shows per reminder how often it caused delays or caused it to not be sent. This way, it is possible to narrow down which rule and which reminder is causing problems.

3.12. Storyboards

In order to show several features of the concept to the participants of the workshop, storyboards have been made. These storyboards show the interaction and the flow of these features. These storyboards were also used during the workshop.

Figure 3.6 shows a storyboard of one of the main features: the completing of reminders. It shows one of the personas, Robert, getting a reminder to drink water. He completes this task, and confirms it as completed on the screen. It also shows two other scenarios: one where Robert did not mark the reminder as completed, so he is prompted again to confirm, and one where sensors are used to detect the completion of reminders.

Storyboards for contextual reminders, personalized reminders, rule-based reminders, feedback to caregivers, and help and information can be found in Appendix B. The storyboards used in the workshop were presented in Dutch. These versions can be found in appendix C.2.

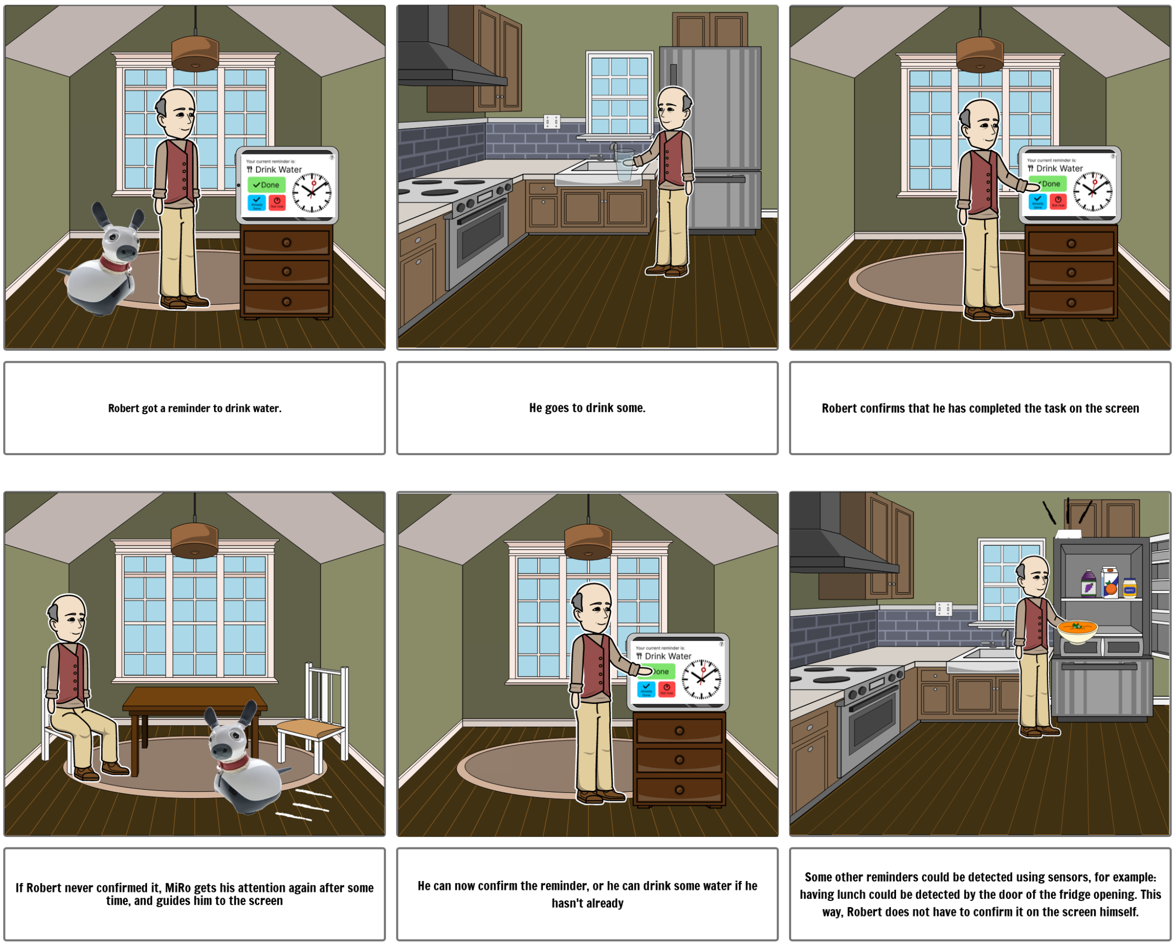


Figure 3.6: Storyboard for completing reminders

4 Robot Prototype

To show people with dementia and caregivers the ideas and interaction described in the previous chapter, a high-fidelity prototype was made. This prototype uses the MiRo-E robot, and will be used in both the workshop with caregivers and the workshop with people with dementia. Broadly, the prototype does the following: it first drives towards the participant, prompts them to follow, guides them to a screen, and occasionally checks if they are following. The robot can also introduce itself. During the workshop, this will be done before the main part of the prototype is demonstrated.

The prototype was developed using an iterative technique. Because the lab in which the robot could be used was not always available, and because other thesis work unrelated to the prototype were done in parallel to development, a sprint-based system like Scrum [74] would not be an appropriate choice (besides, Scrum is aimed at development teams while the prototype was made by myself only). Instead, I used a kanban board, a method inspired by a process in the Japanese car manufacturing industry [75], to keep track of open issues, both features still to be implemented and bugs or improvements that should be fixed or added to the code. This allowed me to easily add features to the backlog for later implementation, and allowed me to program at times most suitable for me, without having the strictness of sprint deadlines.

The prototype is high-fidelity, showing the core interaction. This was done in order to give the participants of the workshop a clear feeling of what the robot would behave like. This way, their feedback could be more specific than the feedback they might have given with a lower fidelity prototype. The prototype is not a fully functional system, however. While more advanced features, like better spatial awareness for pathfinding, could have been added, this would not have achieved much additional feedback in the workshop. Further development would not have been worth it, as the extra development time would result in diminishing returns.

As I wanted to show complete interaction with the robot at the workshop, the whole interaction should not take more than a couple of minutes. Because of this short interaction, testing the robot manually after each added feature was feasible. I wrote down a set of test cases to perform manually every time a new feature was implemented, to try to ensure the additions did not break anything.

The final code of the prototype can be found on the EEMCS GitLab instance here: `https://gitlab.ewi.tudelft.nl/in5000/ii/robotic-reminder-system-for-people-with-dementia`.

4.1. The MiRo-E Robot

This section will go over the built-in features of the MiRo-E robot. Both its input and output methods will be described, and the different ways of programming for the robot are explained.

MiRo has two cameras available, one in each eye. The cameras have a large depth of field and auto-exposure. The possible resolutions are 180, 240, 360, and 720 in height, with both a 4:3 and 16:9

aspect ratio available. The two cameras have an overlap of 60 degrees, which means that 60 degrees of vision is seen in both eyes. The robot has two main microphones, one in each ear for spatial sound, and two additional microphones in its head and tail to filter out sounds made by the robot itself. MiRo has a single sonar sensor in its nose with a range of approximately thirty centimeters, allowing it to tell whether an object is in front of it. MiRo also has two cliff sensors, one on each corner at the front, which are on by default. If MiRo gets a command to drive forward off a cliff, it will refuse. It has four light sensors, one on each corner, that can aid in navigation further. Finally, it has 28 touch sensors spread around its head and body.

Not all these sensors are equally reliable. When testing the robot myself, I found that MiRo refused to drive on some surfaces, like carpets and glossy tabletops, because they set off the cliff sensors. The robot also does not have cliff sensors on the back or sides, meaning that when the robot drives backwards or spins while on a table, it might still fall off. I found that since it wrongly detects some surfaces as cliffs, and since it needs supervision anyway when near a real cliff to make sure it does not drive off backwards, it made sense to disable the cliff sensors. The final prototype also does not make use of the sonar sensor, microphones, light sensors, and touch sensors, either because they seemed not reliable enough, or because they were simply not needed.

The MiRo has several ways to express itself. First, there is movement. It can drive and rotate, move its head up and down, angle its head in two directions, turn its ears, close its eyelids, and wag its tail in four directions. It can also make sounds in two ways. Firstly, it can play audio files. Secondly, it has a built-in emotional sound system. It allows you to set the emotions through the level of valence (displeasure-pleasure) and arousal (deactivation-activation), based on Russell's circumplex model of emotions [76]. This model models emotion on these two axes. For example excited and angry both have a high arousal, while having opposite valence values (excited is pleasure, angry is displeasure), while depressed and relaxed are both low arousal emotions, again with opposite valence values. The robot will then make sounds based on these values that, in my opinion, can be best described as "robotic generic animal sounds," sounding not quite like any specific animal. The emotion settings seem to be conveyed through the pitch and speed of the sounds, with positive emotions (high valence) being higher pitched than negative ones, and high arousal values being faster than low arousal emotions.

Programming MiRo can be done in several ways: on-board, off-board, in the simulator, and using block code. The first three are all programmed using the ROS (robot operating system) software framework, while the block code uses Consequential Robotics's, MiRo's creators, own system. The block code style does not offer the full capabilities provided the ROS interface, using it for a complex prototype like this one is outside the scope of its capabilities. As the MiRo's cameras play an important role in the prototype, using the simulator during development was not possible, as the simulated cameras provide an image of a rendered 3D environment while the system should be usable in a real situation. Then there was the question of whether to run the code on the robot itself (on-board) or on a computer (off-board). The system needs to perform complex calculations to detect where people are standing. Having the larger computation power and dedicated graphics card of the computer will speed things up significantly. For this reason, the code is executed on an external computer, and commands are sent to the MiRo robot using ROS.

4.2. Detection Through Cameras

To be able to interact with the user, the robot has to be able to find them. Several options have been tried. The first was face recognition, implemented using a Python library [77]. While the system was able to detect the faces well, it did not work when the person was far away, as the face would be too small, and it obviously did not work when the person's face was out of frame. Instead, the system detects the whole body of a person. To achieve this, I used the YOLO (You Only Look Once) [78] framework, a real-time object detection machine learning model. The name You Only Look Once comes from the fact that instead of training one model that detects objects and one model that classifies objects, YOLO uses a unified convolutional neural network that performs both steps in one pass, greatly improving its speed [78]. More specifically, I make use of YOLOv8 [79], created by different people than the original.

If MiRo cannot see anyone, it starts spinning until it sees a person in frame. I also use the fact that the robot has two cameras, if a person is only detected in the left eye, the robot spins counter-clockwise, so towards the person, until the person also appears in the right eye. You might remember from the previous section that the overlap of the two eyes is 60 degrees, That means that when the robot stops spinning because the person is now also seen in the right eye, they are not yet perfectly centered. Luckily, YOLO is not just able to detect if people are in frame, it also gives you the position of several limbs and other body parts, as seen in Figure 4.1. By taking the average x-position of all points, we are able to see where in the frame the person is standing. This is used to center the robots' rotation on the person more precisely. This information is also used to make the robot look at the person's head, by taking the position of the person's nose and moving the robot's head so that the nose is as close to the center of the frame as possible.

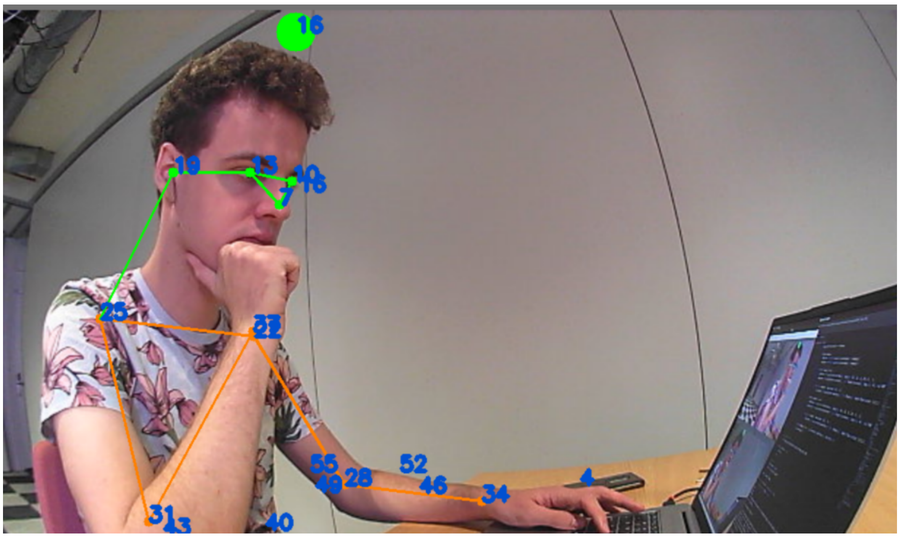


Figure 4.1: Pose Detection

One useful feature of YOLOv8 [79] is that it still gives a position of certain body parts even if they are out of the frame of the camera. If the camera is looking only at the person's legs and lower torso, it will still give a position for the head, namely the (around) the highest point in the picture. This way, the robot's head still moves up to look at the person's face, even if their face is not visible (yet).

The robot should also detect how close the person is, to see if it should drive forward or stop. This is done by calculating the size of the bounding box around the person's torso. While this is not an exact distance measure, I determined a size at which the robot is a reasonable distance away from the person. While this is sensitive to the person and how exactly they are standing, in my testing I found that the distance was always reasonable.

All of this assumes there is only one person visible, while during the workshops, there will be more people in the room. To solve this problem, the system needs to know who is the actual user and who are not relevant. While a tracking or detection system would solve this well, there is a simpler solution: disregarding people that are sitting down. By asking all other people in the room to sit, the system will know that the one standing person should be the one to pay attention to. It detects who is sitting and standing by checking the relative positions of the knees and the hips. While not a flawless way to determine this, it does work well enough for the purposes of the prototype.

Besides detecting and driving towards people, the robot also needs to be able to drive towards certain locations. In a perfect world, I would use a complex navigation system, for example using depth cameras [80, 81] or stereo cameras [82, 83]. While the MiRo does come with stereo cameras, a quick look at these papers reveals their complexity and a lot of challenging math[1]. While implementing this may be possible, it would be very time-consuming, and given the scope of this project and single-room setting the workshop will take place in, I decided a simpler approach would be better suited, being faster to implement but just as valuable for the purposes of getting feedback during the workshop. Instead, the robot navigates using a QR code. This QR code is placed at the robot's eye level, directly below the reminder screen. The robot finds the QR code and drives towards it, similarly to how it finds and drives towards the person. Once again, YOLOv8 is used, this time with a Python library specifically designed for QR codes, QReader [84]. The library finds any QR code and gives the location and bounding box. Centering the QR code and determining its distance is done in the same way as it was done for humans, described earlier. To make detection easier, a micro QR code [85] is used instead of a regular QR code. While QReader used [84] cannot *decode* the micro QR codes, it does *detect* them and can give their location in the frame. For this prototype, knowing that there is a QR code and knowing where it is located is enough, the information encoded in it is irrelevant.

One major problem arose with the QR code system. When the robot was spinning to try to find the QR code, it was often unable to detect it due to the motion blur of spinning. This was not a problem for finding people, likely due to the fact that humans are larger[2] and the fact that a slightly blurry human is still detectable as a human, while a slightly blurry QR code might also be some other dots that are not arranged in the actual shape of a QR code. Reducing the spinning speed solved the problem, but this made the motion of finding the QR code very slow, taking about 12 seconds to rotate 180 degrees at a speed where detection was possible. I tried several image processing techniques, such as changing the contrast, printing the QR code in a certain color and only using that channel, and reducing motion blur using a Wiener filter, as done by for example Zhang et al. [86]. Sadly, none of these seemed to solve the problem. In the end, I decided on a work-around. The QR code is printed on a piece of paper in a very bright pink color. The robot spins around at its regular (fast) speed, but when it sees a lot of this specific hue of pink, its speed is reduced. At this reduced speed, the motion blur is reduced, and the QR code can be properly centered at the slower speed. This method requires some tweaking when moving the robot to a new location, as the lighting conditions of the room affect the perceived hue of the QR code. It also relies on the hope that there are no other bright pink objects in the room. A different color could be chosen if that is the case, but in the worst-case scenario where the color detection does not work for any reason, the system can easily be set up to turn slowly.

4.3. Robot Behavior and Movement

This section will go over the behavior of the robot, more specifically the different states the robot can be in, the way movement is handled, and the ways the robot expresses emotion.

The robot makes use of a simple state machine to determine its behavior. There are three states, approaching the user, guiding them to a location, and checking if they are following[3]. The system starts with approaching the user. After the robot is close to the user for two seconds, it switches to guiding the user. After guiding them for eight seconds, the robot switches to checking if the user is following them. It spins around, and if it still sees the person, it goes back to guiding. Getting the attention of the user is done mostly through proximity and movement towards the user, with the addition of sound, following Saulnier et al.'s [54] recommendations for robot interruptions.

The different detection systems, like detecting the pose and QR codes, are not perfect. They occasionally fail to detect something, or think they detected something that was not actually there. This usually happens for a single frame, and is often solved again the next frame. In the first implementation of the system, the robot would come to a complete stop for a few milliseconds the moment it lost the person, and would continue driving at full speed when it saw them again. This made the robot's movement jerky and jittery. To solve this, most movement operations are "smoothed." Instead of setting the

[1] A long look reveals even more complexity and even more math…

[2] Of course, this depends on how far away the human is, but given that the system is used indoors, there's only so far away the person can reasonably go without ending up outside.

[3] During the workshops, this state was never active, as the distance the user had to walk with the robot was quite small.

driving speed to the maximum or to zero whenever a person is seen or not seen retrospectively, it increases or decreases the speed slightly, capped between the maximum speed and zero. The same is done with spinning, capped between the maximum speed clockwise and counter-clockwise, and with the head movement towards the face of the user, where the robot's head moves towards the target height of the user's head position, or to the middle if the user is not seen. It is also done to make the tail movement more smooth. A small decrease in speed for a few milliseconds is not noticeable, removing the jerky movement.

When you tell MiRo to drive forward, it does not always drive in a perfect line, it might end up a bit to the right or left as well. Additionally, if the user moves while the robot is driving towards them, the robot needs to both spin and drive forward. Doing both at the same time is problematic, as it does not always do what you would want it to do. To solve both these issues, the robot "hones in" on the target (which could be the user or the QR code). The robot first spins to put the target in the center. It then drives forward for two seconds. Even if in this time the target shifts (slightly) out of the center, it keeps driving forward. After the two seconds, it spins again to center the target, and hones in for another two seconds. This ensures that the robot does not spin and drive at the same time and that it does not deviate from its path to the target. If during the honing, the robot is close enough to the target, it stops driving as to not run into the target.

Besides the behaviors related to driving and head movement, the robot also has other ways of expressing itself. If the robot sees the person when approaching or if it is guiding them to the screen, the robot wags its tail to show excitement. The robot also has two ways of making sound. Firstly, it can say things. It says "follow me"[4] when starting the guiding, to make its purpose more understandable, and says "look at the screen"[5] when it arrives at the location, to tell the user what to do next. It also introduces itself with the line "Hello, I am MiRo. I am a robot that can help you remember important daily things, like eating, taking your medicine, or drinking water. Sometimes I will come to you, please follow me and I will show you what to do."[6] The second way the robot can make sound is by using the emotional sound system from the MiRo, as described in Section 4.1. It makes excited sounds (high valence, high arousal, see [76]) if it is close to the person or QR code, to help get attention. It also makes sad sounds (low valence, medium arousal) when it lost the person and has not seen them in a while, and makes a short excited sound when it is done honing in, as described before, and is turning to face the target again. This last sound was added to help the user notice the robot earlier if they are currently engaged in something else.

4.4. Robot System Architecture

The MiRo robot makes use of the ROS (robot operating system) [87] software framework. This framework allows for easy communication between the robot and a computer. The robot *publishes* the data it gathers, such as the cameras and other sensors, to *topics*. The computer running the code can *subscribe* to these data streams, and then process the data. Conversely, the software running on the computer can publish commands to the robot, such as giving the driving speed, the position of the tail, or a stream of audio to play.

One potential problem with this system is that some complex operations, such as processing the position of the body as described in Section 4.2, take a lot of time. Running these operations in the same program as controlling the movement would make the robot's motions jittery and unpredictable. Take for example wagging the tail, if the robot wants to show that it is happy or excited, it should wag it smoothly by sending the angle of the tail (from negative thirty to thirty degrees, zero degrees being straight ahead). Processing the camera data will stop the software from sending the data as often. The tail might then jump from a ten degrees to twenty degrees immediately, without ever going through eleven, twelve, etc.

[4] Dutch:"volg mij"
[5] Dutch: "kijk op het scherm"
[6] Dutch: "Hallo, ik ben MiRo. Ik ben een robot die u kan helpen met het onthouden van belangrijke dagelijkse dingen, zoals eten, uw medicijnen innemen of water drinken. Soms kom ik naar u toe, volg mij dan, dan zal ik u laten zien wat u moet doen."

To solve this problem, I make use of a microservice architecture. Microservices are pieces of software that work autonomously on a small task, which work together to create a complex system [88]. By splitting the complex tasks off into separate programs, the main system can run smoothly. In total, I split off three tasks into separate microservices: Pose detection, QR detection, both because of their computational complexity, and playing audio through the MiRo speakers, because large files require a constant stream with precise timing, and because this can be computationally complex if the file still needs to be processed[7]. Figure 4.2 shows a schematic overview of the robot's system architecture.

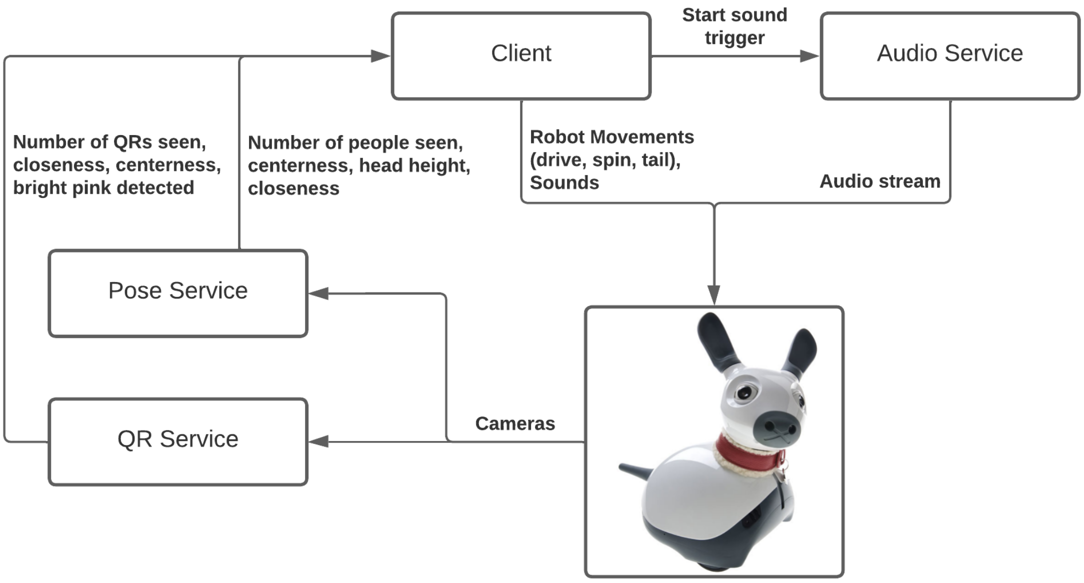


Figure 4.2: The robot's system architecture. Arrows represent publications and subscriptions to ROS topics, and move from the publisher to the subscriber.

Now, there would have been other ways to solve the before mentioned problem. For example, the computationally intensive parts could have been performed in separate threads. There are however other benefits to the microservice method. Firstly, it makes the code more understandable. Instead of having one large program taking care of everything, there are several smaller programs, each cohesive in its functionality and easier to understand. The modular approach also helps with extensibility. If a future developer, or even myself, wants to make changes in the code, they only have to change one part and can rest assured that their changes will not break other parts of the codebase. Finally, microservices can easily be reused. If someone wants to make a different system using the MiRo robot that also relies on detecting people, they can reuse (large parts of) the pose detection service[8].

Within the client code, which takes care of all the robot's output except playing audio files, the code can be structured in two ways: based on state and based on function. Originally, I structured it based on state. This caused a lot of code duplication, as some behavior, like driving or wagging the tail, is shared between several states. The code is thus structured by function. If you want to, say, add sad sounds whenever the robot is checking if the user is following, but cannot find them and has been looking for at least two seconds, you can add a single if-statement to the part of the code that takes care of sound, which on its own is easy to understand without familiarity of the rest of the codebase, consisting of only around fifteen lines of code.

[7] Fortunately, this processing only needs to be done once, as the processed data are cached for later use.
[8] In fact, I have already sent the code to colleagues at Eindhoven University of Technology for an initial prototype.

5
User Interface Prototypes

This chapter will show the user interface prototypes used during the workshops. There are two prototypes: the tablet screen on which the reminders are shown, and the phone application that informal caregivers use to create and edit reminders, and to see which reminders have been completed.

The prototypes were made in several stages. First, I determined core design goals for each of the two prototypes. I then drew low-fidelity prototypes on a drawing tablet. This was done to find a good structure for the screens, and to be able to quickly create several alternatives. The final medium-fidelity prototype was made using the prototyping tool Figma[1]. These prototypes were made using quick iterations: changes were made often, for example after feedback from caregivers in the first workshop. The medium-fidelity prototypes are semi-interactive, the user is able to switch between screens and open pop-ups. In most cases, the functionality inside one screen is unavailable.

As the design workshops will be in Dutch, the prototypes shown during the sessions should be Dutch too. The ones presented here in this thesis will be the English version. The Dutch versions of the storyboards can be found in appendix C.1. The English version was created first and the translation to Dutch was done by myself.

5.1. Tablet Screen Prototype

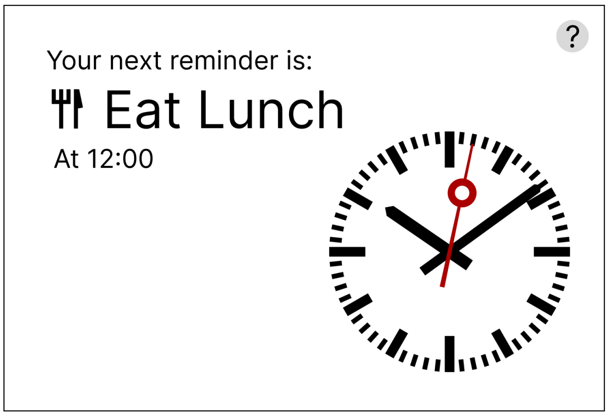
The tablet screens will be placed around the house. The user with dementia will use them to see what their current reminder is and use them to confirm reminders that cannot be confirmed automatically. When a reminder is active, it should show this reminder. When no reminder is active, it simply shows the current time and the next upcoming reminder. A version showing a full calendar was considered too, but in the end I decided this might be too complicated for people with dementia. Sticking to simply the current time and the next reminder still shows useful information, without the possibly overwhelming amount of information and buttons to press a calendar would provide.

Because the design is made for people with dementia, it should be simple, have large enough text to make reading easier, use both text and icons whenever possible, and have only a few possible actions and pieces of information presented at the same time.

Two screens were made to show off the functionality of the tablet screen: the idle and reminder screen. Both show the current time as an analog clock. The idle screen shows the next reminder, the reminder screen the current reminder with three buttons: done, already done, and not now. The prototype can be seen in Figure C.1. For the workshop with people with dementia, a simplified version of the screen that shows the reminder was used. Because the workshop consisted of a single reminder, in a context different from the real-world setting with several reminders over the course of a day, the "Already Done" and "Not Now" buttons were omitted, as can be seen in Figure C.1c.

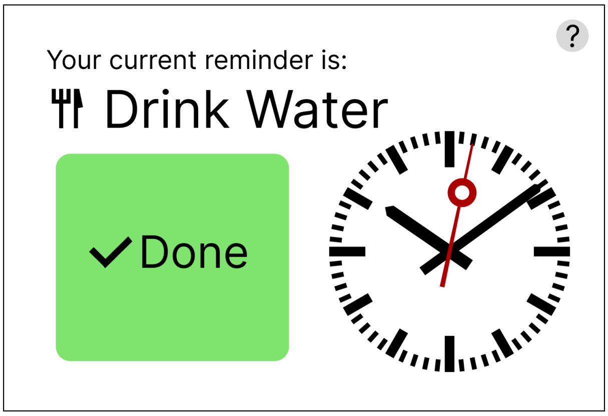
[1] `https://www.figma.com/`

An earlier version of this prototype had the clock only on the idle screen, with it disappearing when a reminder was shown. In the end, however, I chose to include the clock in the reminder state too. This not only creates more consistency between the two screens, it also provides the time when showing the reminder. This could help the user understand why the reminder is shown, showing a lunch reminder next to a clock which shows a time around noon contextualizes the reminder.



(a) Idle screen shown when no reminder is active.

(b) Reminder screen shown when a reminder is being given.



(c) Reminder screen used during the workshop with people with dementia, with only the “Done” button visible.

Figure 5.1: The two screens of the tablet prototype.

In all different states of the screen, a question mark button is shown in the top right. This will show a short video explaining what the robot is, what it does, and what the user should do. Note that this video is not implemented in the prototype.

5.2. Caregiver App Prototype

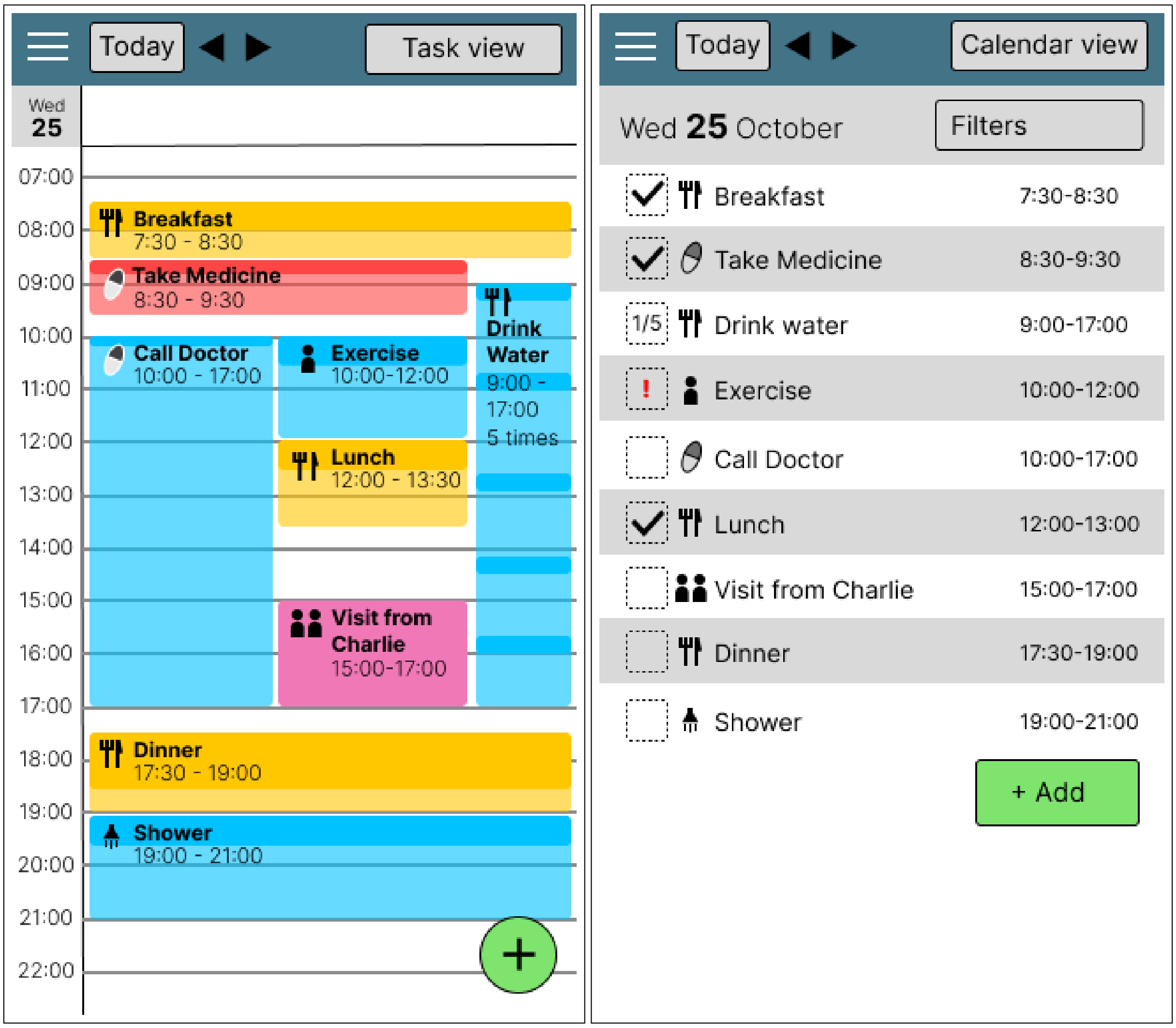
The caregiver app is a phone application that informal caregivers have access to in order to add reminders and to keep them updated on what the person with dementia is doing. It should give the caregiver an overview of current reminders, allow them to add or edit reminders, show them which of today’s reminders have been completed, and give them information about recurring reminders and contextual rules.

While this app will not be used by people with dementia, just under half of informal caregivers in the Netherlands provide care for their partner [8], who are themselves likely older adults too. This means that they may not have a lot of experience using technology, so the app should stay simple, follow a consistent design, and to accommodate mobility problems, should have buttons that are large enough. While not implemented in the current prototype, the app should also have an option to increase the text size, increase the contrast, and should be developed in a way friendly to screen-reading services.

There are two ways the caregiver can view a day's reminders. First, there is the calendar view, shown in Figure 5.2a. This view is inspired by calendar applications like Google Calendar (which of course is in turn inspired by real calendars). Unlike normal calendar apps, this system needs to show both an estimated duration and the timeframe it can be performed in. While calling a doctor, for example, only takes a few minutes, it can be done at any time between nine and five, where a half an hour lunch can be scheduled only around lunchtime. To show this, a somewhat transparent color is used to denote the time range, while a fully opaque block of the same color is used to denote the estimated duration. Color is used to denote priority, and non-reminder events (like people visiting) get a special color. The screen has a floating plus button to add reminders in the bottom right. A real application should also allow for adding reminders by dragging, though this is not possible in the prototype software used[2].

The second way to show all reminders is the task view, as seen in Figure 5.2b. This view is inspired by to-do lists and to-do list applications. This is a list of all reminders on a given day, with time ranges shown too. This view also shows whether tasks have been completed, missed, or not given yet. Completed reminders are marked with a check, missed reminders with a red exclamation mark, and reminders that occur multiple times in one day show how many have been completed (e.g., 1/5). Reminders that have not been sent out yet are simply an empty checkbox. The checkboxes use dotted lines to denote that the user cannot click them to complete them themselves. A pop-up could be added to make it possible for caregivers to mark reminders as completed. If a reminder is completed with the caregiver in the same room, it is reasonable for the caregiver to mark the reminder as completed.

[2] In fact, one of the caregivers in the workshop, discussed in Chapter 6, tried to add a reminder this way.

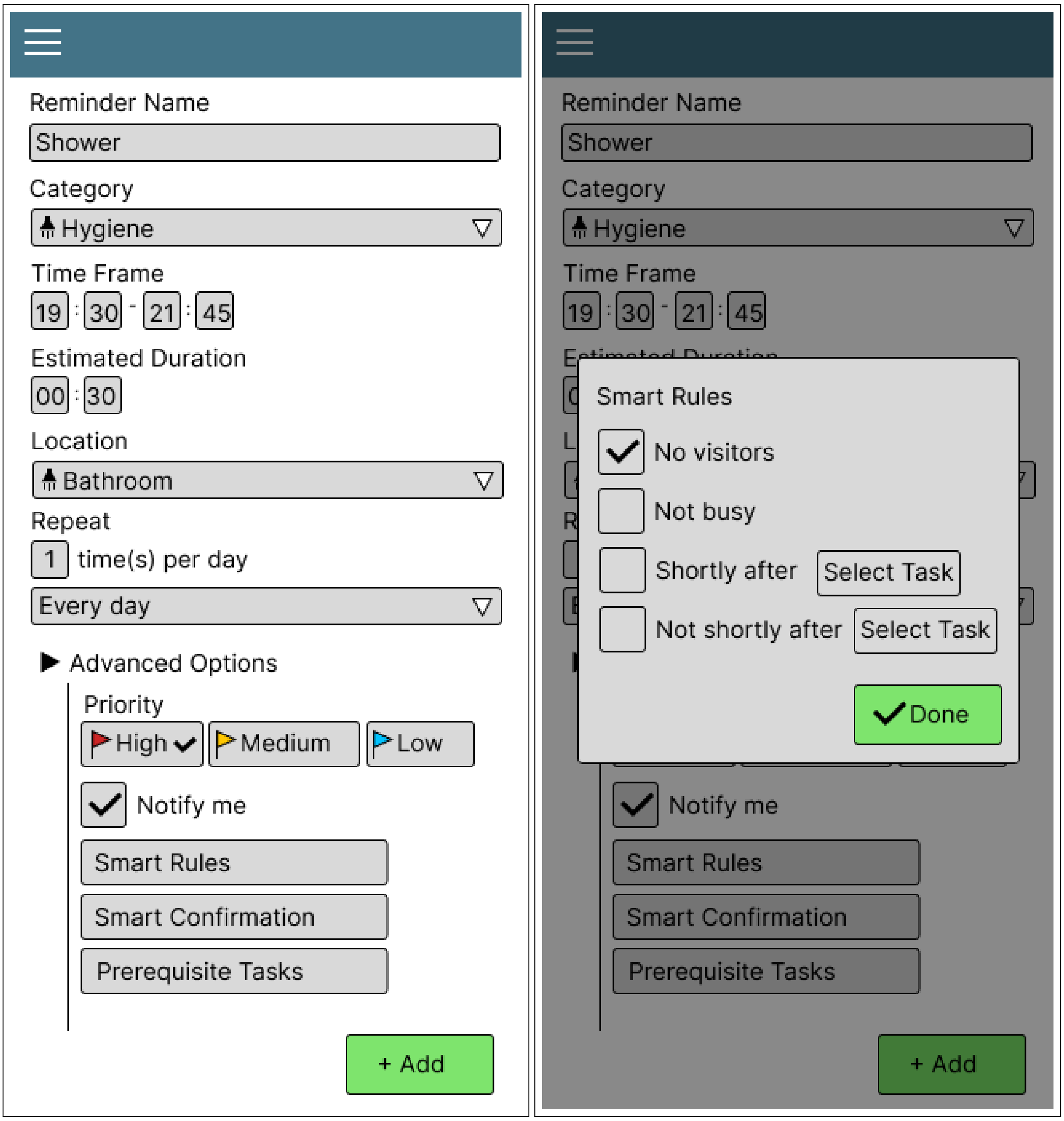


(a) The calendar view of today's reminders. **(b)** The task view of today's reminders.

Figure 5.2: The two ways to view today's reminders.

To add a reminder, the user can tap the green plus or add button. This moves them to the reminder creation screen, shown in Figure 5.3. Here they can choose the name of the reminder, the category (e.g., food or hygiene, see Hartin et al.'s [15] list of activities of daily living), the time frame, estimated duration, location, and how often to repeat the reminder (e.g., three times per day or every Tuesday and Friday). There are also some advanced options, like priority, whether or not to notify the caregiver, which smart rules to apply[3], which smart confirmation methods to use (e.g., fridge door opening), and which other tasks are prerequisites to this one (e.g., medicine only after food). These last three open up a pop-up screen, like the one seen in Figure 5.3b. These advanced options are collapsed by default, and can be opened by tapping on the text.

[3]Section 3.10.1 talks about being able to choose whether smart rules are applied as "strict" or "preference" rules. This feature is not shown in the prototype.

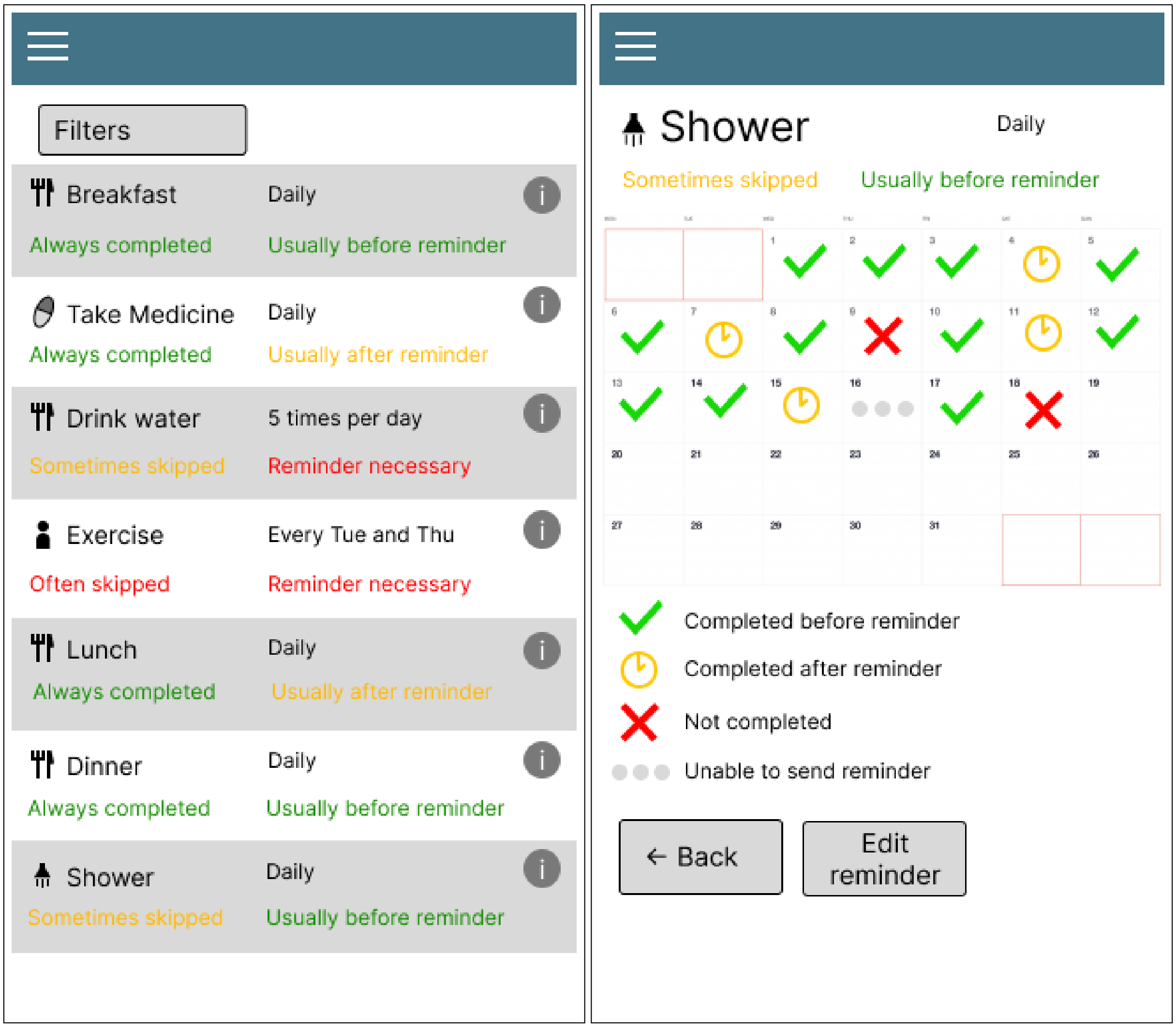


(a) The reminder creation screen. The “Advanced Options” can be expanded or hidden, and start out hidden.

(b) The reminder creation screen with an overlay to select which smart rules should be active.

Figure 5.3: The reminder creation screen.

In order to tailor the schedule to each user, it can be useful for the caregivers to have access to data regarding the recurring reminders. If their loved one with dementia often skips exercise, the caregiver can talk to them about it or reschedule it to a time where it may make more sense. Alternatively, if the user almost always eats breakfast before the reminder is given, the reminder may not be necessary (anymore). Figure 5.4a shows the overview of recurring reminders. Each reminder shows the name of the task, the category through the icon, how often and when it should be performed (e.g., daily, five times per day, every Tuesday), whether the reminder is usually completed, and whether the task is usually completed before or after the reminder. If the user wants more information on a specific reminder, they can use the detailed screen shown in Figure 5.4b. This shows a calendar overview with for any given day whether the reminder was completed before the reminder, after the reminder, not completed at all, or whether the system was unable to send the reminder (for example the shower reminder might not be possible if there were visitors in the house all day).



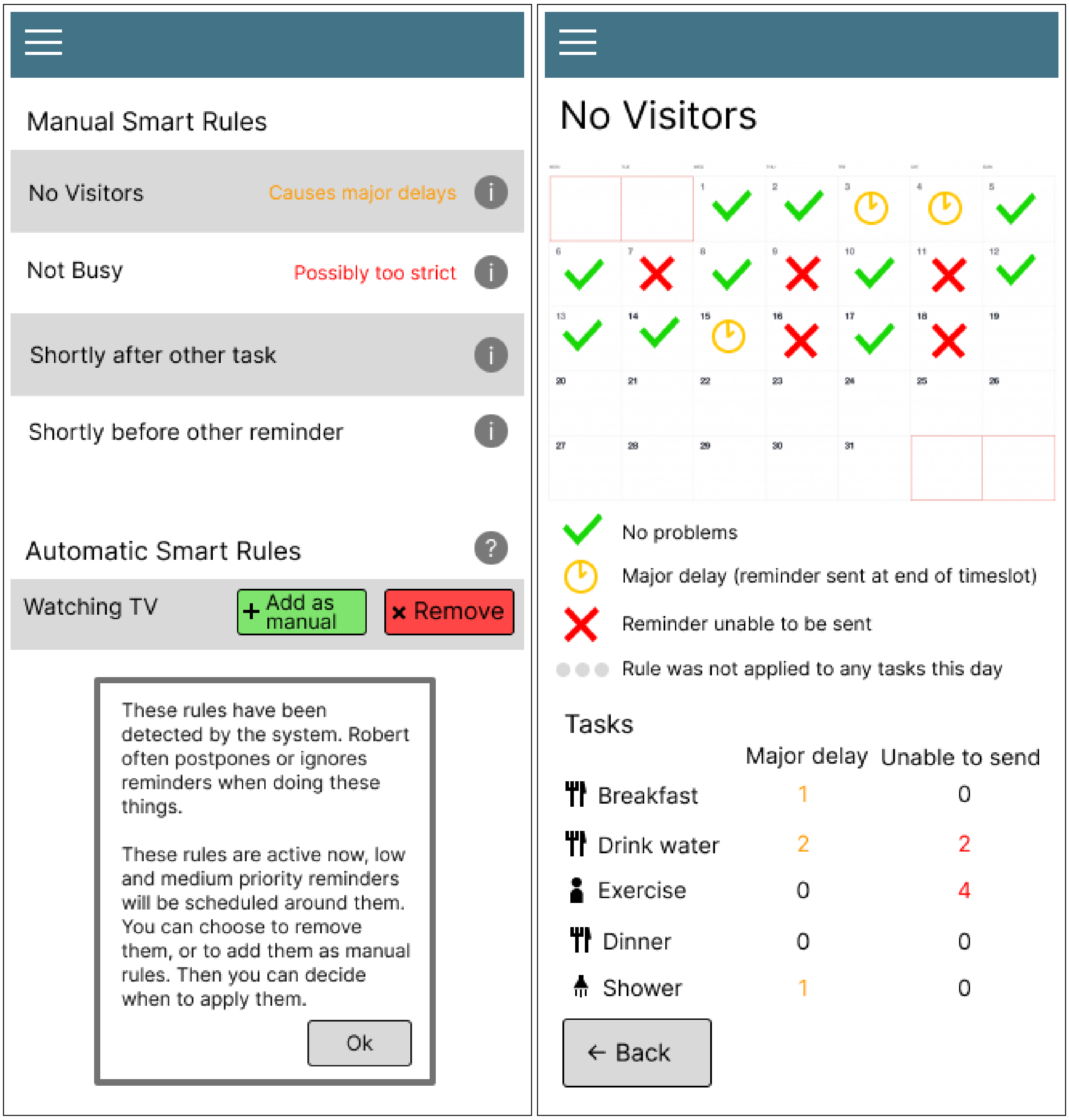
(a) Overview of all recurring reminders. **(b)** Detailed information on one recurring reminder.

Figure 5.4: The recurring reminder screens.

Similarly to the recurring reminders, the smart rules page comes with an overview and a details page. Figure 5.5a shows the overview, which has a list of all added smart rules. If the smart rules are too strict, for example if they often cause major delays in reminders or make it impossible to send reminders, a warning shows up. An earlier version of this page had the text “Causes reminder to not be sent [sometimes/often]” instead of the simpler “possibly too strict.” While the previous version showed more nuance, the text was a bit technical and not as descriptive of the actual problem: this rule is so strict, reminders are not sent because of it — you should consider applying it less strictly.

More details on major delays and inability to send reminders can be seen on Figure 5.5b through a similar calendar view as the recurring reminders. It also shows which reminders use this rule, and which suffer the most from the strictness. If a rule causes issues, it can be solved in two ways. You could either remove the rule from some reminders, or change the timing of some reminders. In the example of Figure 5.5b, the reminder to exercise often remains unsent because it cannot be performed when there are visitors. Perhaps the planned in exercise time of ten AM on a Thursday is the exact time the user’s granddaughter regularly comes over for a cup of coffee. By changing the exercise time, or allowing it across a larger time-frame, the problem could be solved. The reminder to drink water also gets delayed or remains unsent frequently, but it is worth reconsidering if the no visitors rule is relevant for this task, it can probably simply be removed.

The overview page of Figure 5.5a also shows automatic smart rules. These are rules that have been detected by the system. The user with dementia typically postpones or ignores reminders while doing the things or within the times mentioned in the smart rules. When the rules show up here, they are already active, meaning that low- and medium-priority reminders will be scheduled around them wherever possible. The caregiver can choose to remove them if they believe the rules are incorrect, or they can add them as manual rules, meaning they can decide when to apply them. The ? symbol explains this in a pop-up, shown at the bottom of the screen in Figure 5.5a.



(a) Overview of all manual and automatic smart rules. The pop-up shown under the screen appears when pressing the ? button.

(b) Detailed information on one smart rule.

Figure 5.5: The smart rule screens.

The final feature of the prototype worth mentioning is navigation. Each of the screens has a three-line hamburger menu icon in the upper-left corner, which opens the navigation menu shown in Figure 5.6. Here, the user can switch between the day overview, list of recurring reminders, adding a reminder, and the list of smart rules. It also shows an indicator that a new smart rule has been detected and added. The indicator will disappear when the user has seen it.

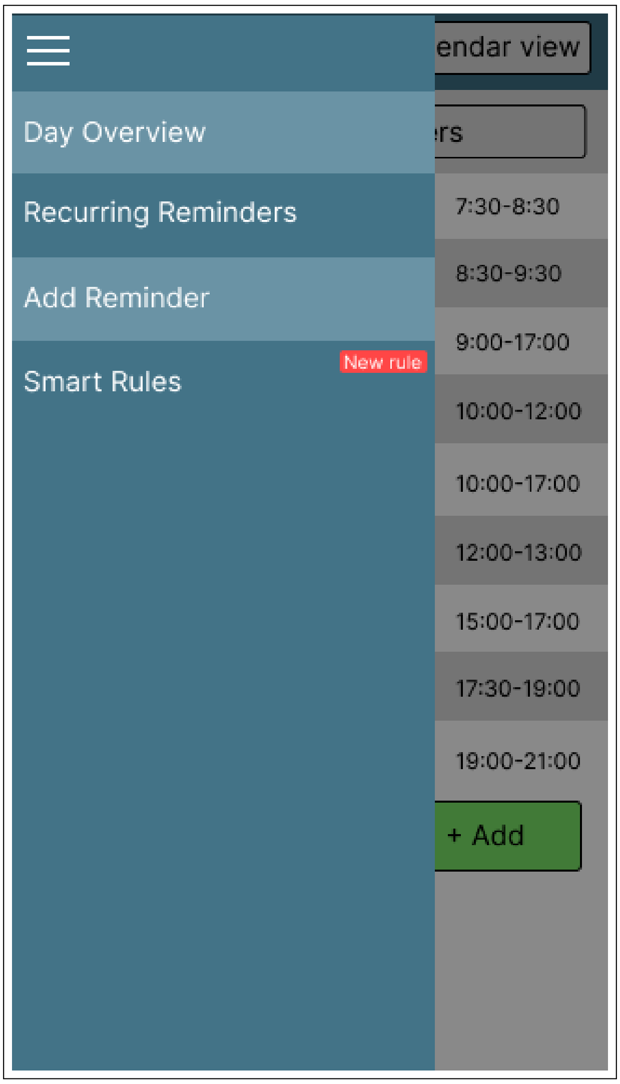


Figure 5.6: The menu opened over a different screen.

6 Design Workshop

In order to improve the design and prototypes and to assess the general acceptability of the system, two design workshops were held. The first was performed with a group of professional caregivers, the second with a group of people with dementia living in a care home. This chapter first describes the goals and research questions of these workshops, in Section 6.1. Following this, the structure of the workshops is discussed in Section 6.2. Section 6.3 describes how notes were taken, and Section 6.4 describes how they were analyzed. The ethics of human research and informed consent procedure are discussed in Section 6.5. The final two chapters describe the procedure, outcomes, and insights of the two workshops, the one with caregivers in Section 6.6, and the one with people with dementia in Section 6.7.

6.1. Workshop Goals

The goal of both workshops is to **improve the existing design and prototype** and to **assess the general acceptability in relation to the design goals**. During the workshops, we gather qualitative feedback to help further specify the next iteration. The changes made after the workshops will be mentioned in this chapter, but only the changes made after the first workshop with caregivers have been implemented into the robot prototype.

The research questions for the workshops are as follows:

- WRQ1: In what ways does the integration of the robot in the reminder system facilitate a more natural and intuitive interaction experience for people with dementia?
- WRQ2: How well received are some of the other features of the system, namely the completion of reminders, contextual reminders, personalized reminders, smart rules, feedback to the caregiver, and the help page?
- WRQ3: How good is the acceptability of the system, and how much would people with dementia integrate it into their lives?
- WRQ4: How well does the system solve the problems of people with dementia forgetting important tasks (problem 1), how well does it improve their quality of life (problem 2), and how well does it decrease the stress experienced by informal caregivers (problem 3)?

6.2. Workshop Structure

Both workshops are structured similarly. First, some general questions are asked. For the caregivers, I am interested in the daily structure of people with dementia, what kind of reminders would be most useful, and what technologies, like robots or reminder systems, are currently in use, and how ubiquitous they are. For the workshop with people with dementia, this stage is a bit shorter, asking about their familiarity with robots and technology in general, and asking their first impressions of the robot prototype before the interaction.

After this, we show the demo to the participants. Before showing the robot, we explain the concept and the situation in which it will be used. The prototype of the tablet screen is placed on one side of the room. One person is asked to participate in the interaction. The robot guides them to the screen. For the workshop with people with dementia, we also ask them to complete a reminder, by putting on the screen that they should drink a glass of water. For the caregiver workshop, we also show the caregiver app prototypes. This is done when the relevant questions come up.

The final stage of each workshop is the actual design workshop. Here, we go over some of the features of the robot and system, and ask the participants for thoughts, feedback, and possible improvements. Several topics were discussed. First and foremost, we talk about the core interaction with the robot, focusing on WRQ1. We ask whether it was clear the robot tried to tell the participants something, whether it was clear it is part of a system, what they thought of the screen, and whether the robot should talk. We also ask them to think of other ways the robot could accomplish these things.

After the initial discussion about the core interaction, we go over to WRQ2, asking the participants about some specific features of the system. We do this through the use of the storyboards, which are discussed in Section 3.12 and shown in Appendix B. For each of the storyboards, we first ask whether they think this is a good idea, and what they like and dislike about it. We also ask the participants some specific questions for each storyboard. For example, for contextual reminders and rules, we are interested in what rules they would like to see.

Finally, we ask the participants some general questions about the system, aimed at answering the higher level research questions WRQ3 and WRQ4. We discuss the three goals of the system, and to what extent the system solves them. We also ask whether they can envision using the system, and in what contexts it would work best. Finally, we ask what kind of reminders they would like to see in the system, and what other functionalities it could have.

For each of the question stages, participants are encouraged to talk about what parts of the system they like and dislike, and to provide other ideas that could be implemented in the system. We also ask follow-up questions to further specify how the participants envision the system.

Each workshop took around one hour to complete. This time includes the informed consent procedure and introduction. The full list of questions can be found in Appendix D.

6.3. Field Notes

The workshops have two researchers present, one to run the session, and one to take notes. The note taker is still active in asking questions. During the first workshop, with caregivers, we also took an audio recording, which we used later to improve and finish the notes. For privacy reasons, we decided to not take recordings during the workshop with people with dementia.

The note taker should not just write down the things the participants said. There are other important non-verbal behaviors and cues to take note of. Specifically, we are interested in whether the participants notice the screen, complete the task and confirm it on the screen (only for the second workshop), whether they talk to the robot, whether they follow the robot correctly or walk away, and whether they act friendly or annoyed towards the robot. We also write down notable non-verbal behaviors and cues, like looking at places for a long time and their tone of voice, whether they sound excited, calm, or agitated, for example.

6.4. Data Analysis

After cleaning up the notes, they had to be analyzed. Two analysis methods were considered, thematic analysis and the constant comparative method. The constant comparative method relies on first comparing data with previous data from the same category [89]. This is done multiple times, each time thinking of different and better ways the data can be categorized. Categories are then compared to each other. Finally, the categories and insights are compared with previous literature. Our dataset is quite small, consisting only of data from two focus groups, with little previous literature of the same type. Therefore, I believe the constant comparative method is not suitable for this use case. Thematic analysis, on the other hand, is a method for identifying, categorizing, and analyzing common themes and patterns in data [90]. After familiarizing themself with the data, the researcher goes over the data generating the initial codes, then categorized these codes into themes. In a small data set, these themes may have significant overlap with the codes [91]. Finally, the researcher reviews, defines, and names the themes, and creates a report. These codes and themes are created after the sessions, based on what was said in them. This means the approach uses inductive coding [92]. While the dataset is small, thematic analysis still seems like a valuable way to formalize the analysis done.

The thematic analysis done for the workshop with people with dementia is discussed in Section 6.7.

6.5. Human Research Ethics & Informed Consent

When performing a study with human participants, care should be taken when it comes to ethics, data privacy, and informed consent. This section talks about the risks when it comes to these areas.

First, there is the question of personally identifiable information (PII). While we do not aim to collect these data, participants may tell us personally identifiable information. The note taker should not write this down. For the first workshop and the expert evaluation we also take audio recordings, this is also PII. We deleted the audio recordings after finishing the notes, as to not store the information for too long. We also collected the participants' names through the informed consent form. We made sure to store the informed consent forms in a separate location, that the notes are pseudonymized, and that there is no way to reconnect the real names of the participants to the fake names (X, Y, and Z) used in the notes.

Another important risk for the second workshop is the fact that people with dementia belong to a vulnerable group. Due to their dementia, they may be unable to legally give informed consent themselves. To mitigate this risk, we explain to them, in simple terms, what the goal of the research is, what they will do, and that they can leave any time they want. We collect no PII of people with dementia, and do not take audio recordings. This minimizes the risks for the people with dementia. For their safety, we ask a caregiver to stay with us. Besides helping with the informed consent procedure and general communication, they are able to stop the workshop in case of problems. We hold the workshop at the care home where the participants live. They are familiar with the environment and the caregivers present.

6.6. Workshop with Caregivers

During the workshop with the caregivers, four caregivers joined us in the focus group, one of whom was an student intern. The general discussion about people with dementia and robots was useful, answering some of the questions I had about the daily structure of people with dementia, and pointing us towards interesting robotic solutions they had experience with. One caregiver participated in the demo, which went well. We discussed the physical shape of the robot, and then moved on to the workshop questions, first about the interaction, then about the different storyboards. When talking about the storyboards, I also showed the relevant screens of the caregiver application. Finally, we discussed the problem statement, and to what extent the system solves the problems, and they provided some tips for the next workshop with people with dementia.

The workshop was useful for learning more about the context in which the system will be used, and for specifying the requirements and deciding which features to add. First, the caregivers shared that when someone with dementia receives home care, the caregiver usually comes at most four times per day. They usually provide the planned healthcare, like taking pills, getting dressed, and going to bed, that can happen at specified times. If they are there, they may also help with unplanned care, like going to the bathroom. Of course, the home care caregivers are not always present to help with this. When it comes to informal care, when the informal caregiver lives with the person with dementia, the care is constant. However, when the caregiver does not live with the person with dementia, for example if they are their child, coming every day would be a lot, and is not very common.

When it comes to the interaction, perhaps the biggest insight was that the caregivers thought that people with dementia would like for the robot to talk. In my initial design, I decided against speaking, as speaking would not be in line with the animal-shape of the robot. The caregivers thought that because the concept of a robot would be new and strange to most people with dementia anyway, having it speak would not come as a surprise to them, as they already do not know what to expect. Adding speech is a good way to indicate what the person should do, therefore I added functionality for speaking to the system and prototype after the workshop. Regarding the other, emotional, sounds the robot makes, one participant initially thought it was speech, but after hearing it more closely, they liked the sounds it made.

When it comes to the rest of the interaction, the caregivers were not sure whether people with dementia would understand that they should follow the robot. They believed that some people may understand it, especially those with earlier stages of dementia. Adding speech to the robot may help, they believed. If speech is not an option, they suggested making it explicit in another way, such as putting a small sign on the robot, asking the user to follow it.

Another major concern the caregivers had was the reminder confirmation. They believed that users may press the done or already done button without having done it, or conversely may press forget to press the done button after completing the reminder, and then repeat the task when the robot comes to remind them again. The caregivers liked about the idea of using sensors to detect whether a reminder was completed. They also said that for some reminders, the problems of not doing it or doing it twice are not that great, forgetting to drink water or shower once or drinking more water or showering twice in a day is not dangerous. For other reminders, a more rigorous approach is preferred, forgetting medicine or taking it twice can have serious consequences. For this, using sensors or, in the case of medicine, a smart pill dispenser is important. After the workshop, the design was changed to further focus on automatic detection of task completion.

The participants liked the ideas presented in the storyboards, but had some comments about some of them. They thought the contextual reminder rules were useful, but found it hard to think of more than the examples given. Personalized timing for reminders also seemed good, but they did not understand what exactly the system would do. After explaining the concept further, they had two concerns. Firstly, they thought it may be unpractical to install this many sensors around the house. Secondly, they thought that while it is useful to not bother people while they are busy, for example watching TV, they questioned when the cutoff would be. Some people have the TV on almost the entire day. At some point, they need to be reminded. In a similar vein as the previous storyboards, participants thought it would be good to implement the fully rule-based reminders, like turning off the stove when it is no longer in use. They suggested locking the door when going to bed as another useful reminder.

When it comes to giving feedback to the caregivers, I unfortunately found that I had explained the idea of the caregiver application for too long, and did not ask enough questions to the participants. We did talk about the emergency system, where the caregiver, and perhaps the emergency number, is notified in case of an emergency. Something similar is already in use for home care, where the caregiver can talk to the person with dementia to ask what is wrong. They thought this would be useful. They also thought it would be very important for the robot to talk in this scenario. If, for example, the person fell, they argue, they should be told that help is on its way, so that they do not try to get up themselves and potentially hurt themselves in the process. They thought that if the robot speaks regularly, it would be easier on the person with dementia if the robot also spoke during an emergency, instead of that being the first time they hear the robot's voice. This feature was incorporated into the design.

Regarding the shape of the robot, the participants liked that it looked like a cross between a dog, rabbit, and donkey. They were concerned that it was quite small, however, believing that some people may kick it accidentally — or on purpose — or trip over it and fall. Staircases and rugs in the house are also a problem for the robot. They suggested a larger robot that can go over rugs would be ideal, but they also believe a static robot that asks the user to come towards it using speakers may be appropriate too. They also recommended making the robot louder so that people with hearing difficulties could hear it better, and keeping the robot cheap, so that more people are able to afford it. Of course, none of these suggestions could be implemented in the prototype, but they are still useful considerations for a future iteration using a different robot.

The caregivers were also wondering what the robot would do when it is not giving reminders. They thought that being active as a pet would be nice, meaning that the person with dementia can pet and play with them. They also thought this would be an ideal time to charge the robot, similar to how an automatic vacuum cleaner drives to a dock station.

Finally, let's discuss the system goals. The caregivers thought that the system could help solve the problems of people with dementia forgetting important things, low quality of life, and high caregiver stress. They were especially appreciative of the features for the caregivers, believing it could reduce their workload, while still keeping them connected to their loved one. They thought it would work especially well in home situations, as people living at home often have a less severe stage of dementia. Overall, they believed that the fact that most people with dementia do not have much experience with robots right now, could cause some problems with trying to teach them how to use it. It may still be possible, though. After all, they said, some residents of the care home know how to use video calling software quite well, so teaching new technology is possible. The system could work especially well with younger people with dementia, they argue, or in a few years when people that are old then are already used to using technology.

6.7. Workshop with People with Dementia

The second workshop took place in a room of a care home. The three participants with dementia, labeled X, Y, and Z, are residents of this home. One caregiver and one student intern were also present. The workshop was held in a working room, so a few caregivers entered and exited sometimes, but were not participating in the workshop. Unfortunately, one participant (Y) was not feeling well, and was unable to participate properly in the workshop.

The participants were not familiar with robots, though one participant (Z) had heard of them, describing them as “moving human-like art projects”. Z said they were somewhat familiar with computers, but had never used one themself. Z liked the robot when first seeing it, but another participant (X) did not like the look of it, citing their dislike of dogs as the reason.

We asked Z to participate in the demo. They used a walker to walk with the robot. Unfortunately, the robot did not detect the participant correctly, possibly because of the walker, possibly because of the light conditions. Z was still able to walk with the robot towards the screen. They did not seem to notice the screen, as their attention was focused on the robot. Even after pointing it out to them, they did not pay attention to the screen. They walked around the robot a couple of times, after which we asked them to sit back in their chair.

After the demo, Z said they liked the idea of the robot. They were open to robotic support, and said they would like it to act as a replacement of a notebook and calendar. They would want to be able to schedule a call with their niece[1], and would like it if this was planned in at a time when their niece was not at work. Z also suggested an alarm clock as a feature.

When first seeing the robot, Z thought it looked like a rabbit. They were immediately excited about the robot. Unfortunately, they were unable to hear the speech and sound of the robot, but when asked about the robot speaking, they thought it would be a great addition.

The other participant, X, was uninterested in the robot and the workshop. They had a visit planned later in the day, and thought they had to leave soon. Another reason they gave for not liking the robot was that they did not like dogs. They left halfway through the workshop, after giving their reasons for not liking it.

As discussed in Section 6.4, a thematic analysis was performed on the notes. In total, ten codes were created, both for verbal and non-verbal utterances and behaviors. These codes include interest in the robot, interest in the system as a whole, needing help, and talking about the context in which the

[1]or cousin, I do not know which one, as the word for these is the same in Dutch.

system would work. These codes were sorted into seven themes, interest, dislike/indifference, help needed, context, ideas, physical form, and interaction. The thematic analysis produced some valuable insights. It was useful to see a list of things the participants liked, disliked, and had ideas for. Separating ideas and feedback about the interaction and reminder system from that about the context and physical form was also useful.

Only few changes were made after the workshop. Participant Z was positive about the core concept, and some of their suggestions, like scheduling a call, are already possible in the design. Giving the people with dementia the option to add reminders to the system themselves was discussed in Section 3.6, but I made the choice to not include it. For now, I stand by this choice, as I believe the implementation of this could lead to low-quality reminders. That being said, after the workshop, I believe that researching a useful and reliable way for people with dementia to add reminders themselves should be one of the first steps for future work.

After the workshop, the caregivers who were present during the workshop wanted to share some thoughts. They thought the system would work better for people with an earlier phase or less severe case of dementia. They also thought it would be helpful in a different unit of their facility, where elderly people who are in physical rehabilitation live temporarily. Furthermore, they thought it would be especially helpful in contexts where people have control over their own medicine. In the dementia unit, all residents are given medication by the caregivers, but in other contexts, such as their physical rehabilitation unit or for people with early-stage dementia living at home, the system would be helpful. Finally, they mentioned a robot would be very helpful in playing music to bring people with dementia in a positive mood.

7

Proposed System Architecture

This chapter goes over the proposed system architecture for the entire system. This architecture was not implemented, as showing an implemented system would not have provided additional feedback during the workshop when compared to the high-fidelity robot prototype, the UI prototype, and the storyboards. To evaluate the proposed architecture, we asked two security and privacy experts to evaluate it. The research sub-question relevant for this chapter is “What are the recommended system architectures and requirements for implementing the integrated robotic reminder system in a real-world setting, ensuring easy development and high security, privacy, and usability for both the users with dementia and their caregivers?” (SRQ3).

7.1. Software Architecture

In Section 3.4, about value-sensitive design, I discuss the trade-offs between privacy, care, and safety. Having cameras and sensors around the house helps provide a higher level of care and safety, but it also raises privacy concerns. Mitigating these issues was one of the most important considerations when making the proposed system architecture, which will be discussed in this section.

One important step that can be taken to ensure privacy on the software architecture side is deciding which data are stored where. Data can either be stored within the house of the person with dementia, or be stored on a server elsewhere (the cloud). There are several types of sensitive data that need to be stored or processed in order to make the system work as intended. First, there is the most privacy-sensitive data: the raw camera and sensor data of the robot and of sensors placed around the house. There is no reason these data should be accessible outside the local environment, and there is no reason to store any of these data after processing. Then, there is the data gathered to help with contextual reminders, which are kept for a longer time. Examples include data on what the user is doing at what time and when they ignore or complete reminders. These examples have to be stored, but are still highly sensitive. Similarly to the raw camera data, they do not have to be accessible from outside the system. This is not true for all sensitive data, however. Information on which reminders are active, and whether they are completed, is also sensitive. However, this does have to be accessible by the caregiver device in order for them to be able to check up on their loved one. Besides the caregiver device, no one else needs access to these data. For the functionality, it does not matter where these data are stored. They can be stored on the cloud or at the user’s own house, the caregiver application just needs to be able to access them.

I envision three ways the software architecture could be designed. These are based on general architectures found in Internet of Things (IoT) solutions [93]. In the first version, shown in Figure 7.1, all relevant data are stored in the cloud. The cloud should store data that are relevant for long-term storage, or need to be accessible by the caregiver’s device. If local processing of a data source is possible, this should still be done. There is no reason, for example, to send the camera data to the cloud. This system is easier to set up and update, as the core server part is in control of the developers. It would also allow the developers to potentially use aggregated user data to improve the system for all users. This should be done with care, as collecting too much data may have privacy and legal concerns [94]. This cloud-based software architecture is also used in Fixl et al. [30] electronic sticky notes reminder system.

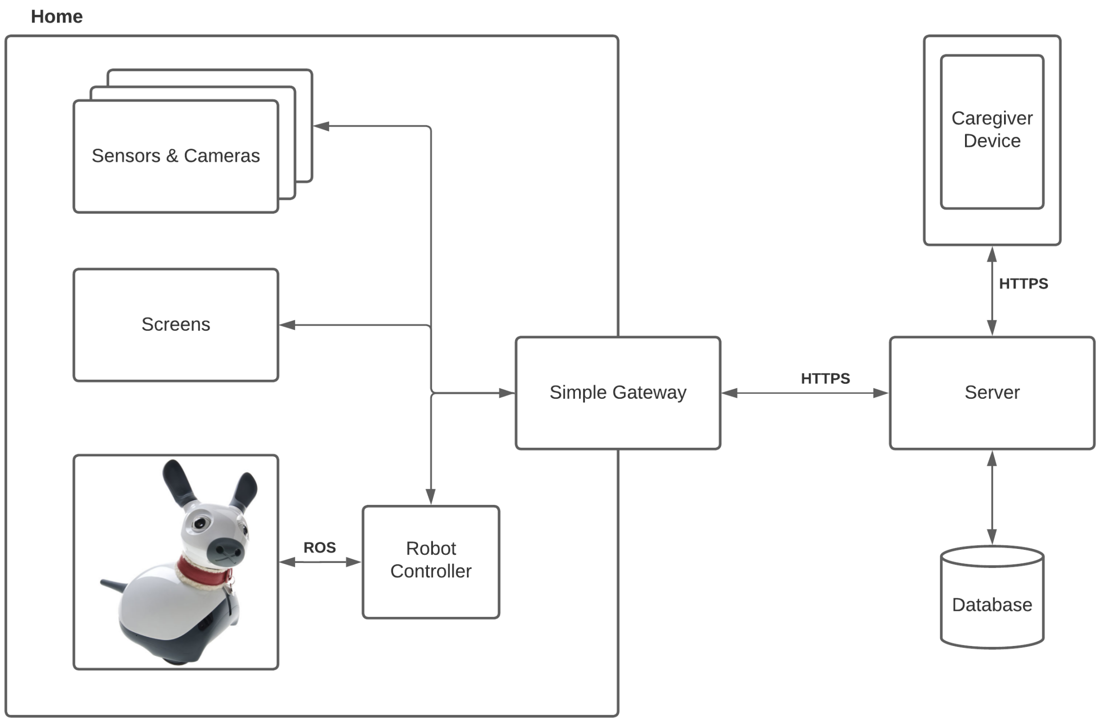


Figure 7.1: Cloud-based software architecture diagram.

On the other end of the spectrum, Figure 7.2 shows a version of the system architecture that keeps all data in the house. Instead of the system processing sensitive data and sending necessary information to a server afterward, it acts as a server itself. This is called on-device or on-premise edge computing [93]. The caregiver's phone connects to the system in the house directly. While this keeps all sensitive data local, it does come with problems of its own. It would be harder to set up, and when something goes wrong, it would be harder to provide technical support. If the system requires an update, it would be harder to immediately set this up. Finally, this system is more prone to downtime. If the electricity or Internet in the house goes down, the server becomes fully inaccessible, while the cloud-based solution would still allow partial access. This version is the most private system, all the data are kept in the house of the person with dementia, and the only person with access to it is the caregiver. This type of software architecture is also used by Zhou et al. [17] in their experiment.

In the third version, shown in Figure 7.3, the sensitive data that do not have to be accessed are stored and processed in the home. Task data, which are accessible to the caregiver devices, are stored on a local server in the user's house. This is in line with "fog computing" — where only a part of the data is in the cloud — solutions often found in some smart home IoT systems [95, 96]. This may be a nice middle ground, having benefits of both the cloud-based and local solutions. Unfortunately, it also inherits some of the drawbacks.

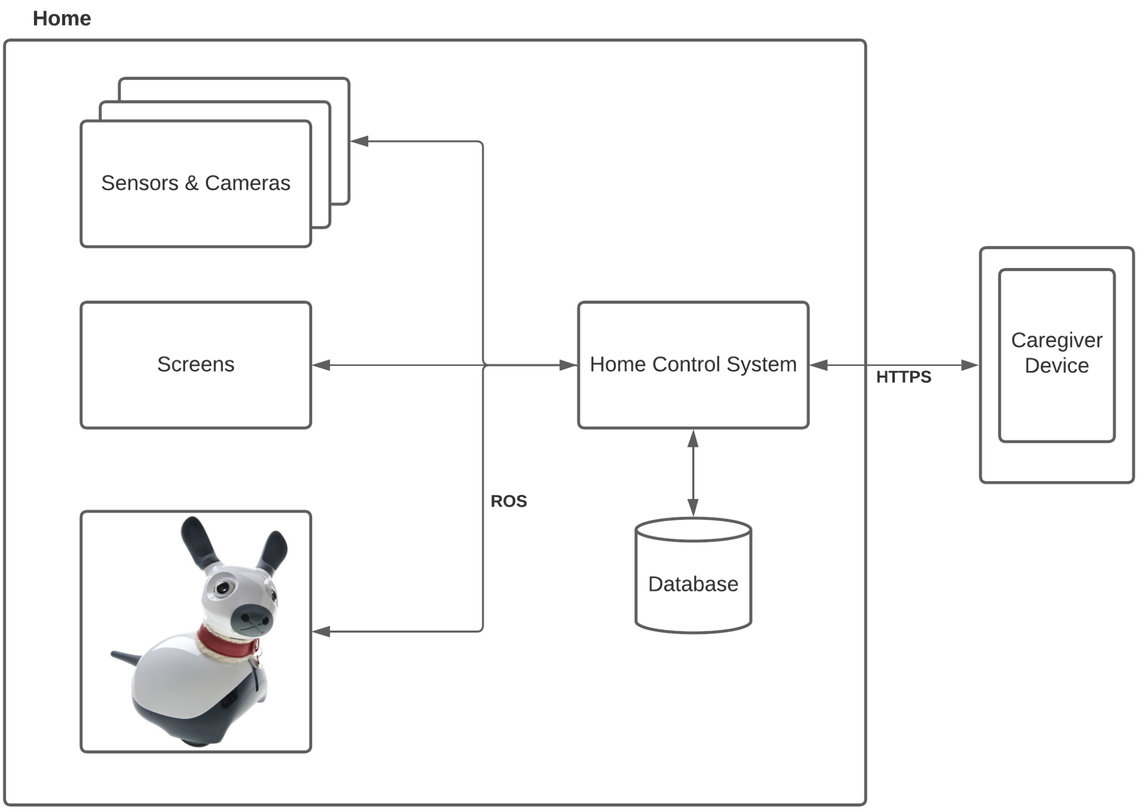


Figure 7.2: Local software architecture diagram.

7.2. Perception of Privacy

Ensuring that most private data are stored securely helps minimize the risk of a security breach. However, the technical details of this will be lost to the average user of the system. Privacy concerns are often mentioned by users as criticisms of IoT devices [97], even as early as 2004 [98]. In interviews with users of IoT devices, Psychoula et al. [97] found that more than eighty percent of participants were concerned about privacy in relation to in-home activity monitoring[1]. A similar percentage was bothered that their private data may be visible or accessible to others. That being said, almost seventy and almost fifty percent of participants would want information on their activity to be sent to their doctor or family members, retrospectively, if the data suggest the user may have chronic health issues. Participants of an older generation found it important to keep living in their own home, even if it comes at the expense of privacy. This shows that people may be more willing to give up some privacy if it would help their health.

Not all data should be accessible to the caregivers. Of course, they need access to reminder completion data, both of the current and of previous days, to be able to check up on their loved one and to be able to change the reminders if they currently do not work perfectly, but in the interest of the privacy of the person with dementia, there are limits to what they should be able to see. Giving the caregiver access to the camera feed, for example, would not be worth the cost of the person with dementia's privacy, compared to the potential added benefit of the caregiver's peace of mind.

[1]Note that this study did not focus on people with dementia.

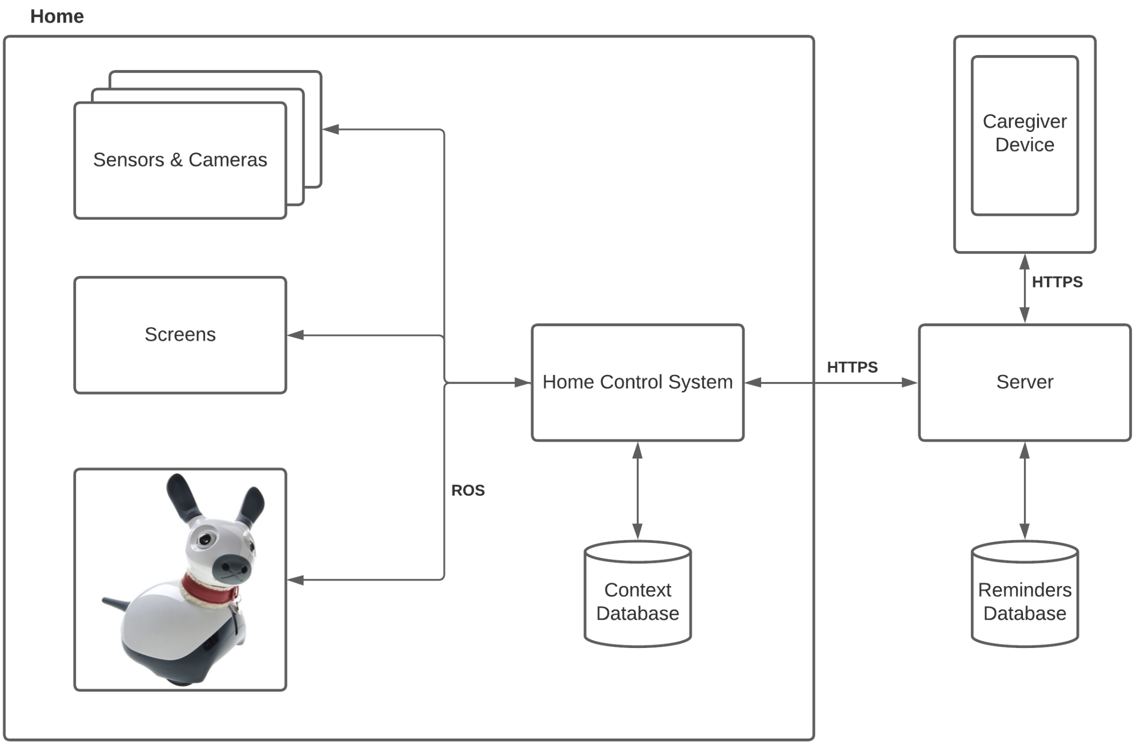


Figure 7.3: Hybrid or fog computing software architecture diagram.

7.3. Expert Evaluation of the Proposed System Architecture

To verify the proposed system architectures described earlier, two interviews with subject-matter experts active in the fields of security, privacy, and software architecture were held. These interviews were held in a semi-structured manner, and had a simple structure. First, I explained the general concept to the participant, to give them an idea of the context in which the system is used. I then presented the different possible system architectures. Finally, I asked several questions about the trade-offs of each of the proposals, other ways to ensure privacy, and what the implementation challenges of each system would be, among others. The list of questions can be found in Appendix E.

The first interview was with an associate professor in the area of software engineering and security testing. They did not see any major problems with any of the three system architectures, they could all work and could all be secured. They do have their own advantages and disadvantages. They thought that the chance of a full breach of all data would be more likely in the cloud-based architecture. Even without a breach, storing highly sensitive data on a server owned by a third-party company could be dangerous, the cloud provider may be able to access the data.

The cloud-based version would have some advantages, however. The expert mentioned the fact that the cloud-based system would allow collection of aggregated user data. These data could be used to improve the heuristic used for scheduling for all users. They also agreed that the cloud-based system would be easier to update, though the system used at home could prompt a central server regularly to see if there are updates available. Checking for updates every night, when the system is unlikely to be in use, would mean that updates would be postponed by at most a day. In general, the expert advised listing the pros and cons of each of the systems, and making a decision based on that. None of the options were necessarily the best or the worst, it depends on what exactly the requirements of the system are.

When I first asked if they know any ways to make the user feel like their privacy is being safeguarded more, the expert chuckled and said that this is not possible. The best you can do is tell the user what is being done with their data. If they know where their information is stored and what it is being used for, they may be more comfortable with the system. Unfortunately, it may not fully remove any uncomfortable feelings. They also thought that people would be more willing to give up some privacy if they get a useful product in return, and if they understand why giving up some privacy would be useful for the product. The study performed by Psychoula et al. [97] suggests this is especially true when it comes to matters regarding health.

The second interview was held with a privacy and cryptography researcher. They thought that both the local and the cloud-based solution would have its benefits. The cloud-based one would be easier to scale, less likely to go down, and it would be possible to aggregate user data. The local version, however, would be the most secure. It removes the risks of others being able to see data they should not have access to. This includes the development team, the cloud provider, and even caregivers of different people with dementia. They were not enthusiastic about the hybrid approach. They thought it inherited the drawbacks of both other alternatives, without adding many additional benefits. In general, they believed the local option would be the most appropriate. How much privacy you give up should be proportional to the usefulness of the system, and the privacy loss in the local version of the system in minimized.

We also discussed how the local option could be realized. For the in-house server and the caregiver application to communicate securely, they need to exchange encryption keys. Usually, this is done over the Internet, but in this situation, it may be possible to exchange these keys physically. When setting up the system, the caregiver could plug their phone into the server with a cable in order to complete set-up. This minimizes the risk that someone could attempt connecting with the server over the Internet by pretending to be a new caregiver device. Within the house, care should be taken when setting up the connection between the server and the different sensors, cameras, screens, and the robot. While the expert had no doubt doing this securely is possible, a bad implementation could cause security problems.

The second expert agreed with the first on the perception of privacy: fully removing the feeling is impossible, but explaining what is happening with the data would help. They thought that the local architecture would help with this. It may be easier to point at the server, and tell a user that all their data are stored in this box. This way, it may be more intuitive that no one else can access it. This is just a theory, however. The expert also thought that it may be possible to make the cameras less visible, for example by hiding them in a lamp fixture. They were not sure if this would be appropriate, however.

7.4. Final Recommendations

Following the advice of the first expert, I have made a table of pros and cons of the three different architectures. This table can be found in Table 7.1. The pros and cons are relative, the “low” security of the cloud solution does not mean it cannot be secured properly, it just means it is relatively harder to secure compared to the rest. The values in the table are based on the observations and suggestions of both experts.

Table 7.1: Relative pros and cons of the three proposed system architectures

	Local	**Cloud**	**Hybrid**
Security	High	Low	Medium
Data privacy	High	Low	Medium
Ease of updating	Medium	High	Medium
Implementation ease	High	High	Medium
Aggregated data insights	Low	High	Medium
Feelings of privacy	Medium	Low	Low
Setup ease	Low	Medium	Low
Downtime Resilience	Low	High	Partial

Based on the pros and cons, I believe that the local environment, shown in Figure 7.2, is the best option for the system. While the cloud- and fog computing-based architectures provide benefits that are harder to achieve in the local option, like easier updating, aggregated data over all users, and lower downtime, these are not worth the decrease in security and privacy. People seeing details about your personal life is acceptable if these people are your caregivers, but not excusable when it concerns third parties, who potentially include cloud-providers, governments, caregivers of other people, and hackers. The local architecture is the most private: only the caregiver can access the data, and the chance of a breach is low. The fact that all data are stored in the house could also be beneficial for the feelings of privacy. The manual or person installing the server could explain to the caregiver that all data remain in the house, and that none else can access them.

Through smart implementation, the local architecture can be made more secure. First, the connections between the server and the sensors should be handles securely. MQTT and ZigBee may be interesting options, but further research is required. One potential attack vector a malicious party could use, is pretending to be the device of the caregiver, in order to connect to the server in the home. This risk can be minimized by making the initial setup require on-site presence. The caregiver could connect their phone by cable with the server at first use, which could exchange the keys that will later be used to verify that the device is actually owned by the caregiver. This process would only have to be repeated when the caregiver gets a new phone, or when another caregiver also needs access to the system. I would recommend having the only way to do this verification be through a physical connection. Additional verification methods, like verifying a new caregiver device using an already verified caregiver device, would create another vulnerability. Someone could convince a caregiver to borrow their phone, and gain access that way. It would, however, require visiting whenever something goes wrong, which some caregivers who live far away, perhaps even in another country, may not be able to do. This method would have to be discussed with stakeholders to see if this would be a problem.

8

Final System Requirements

With the design, prototypes, workshops, and software architecture done, the system is nearly ready to be picked up by a development team for further iteration. One important step remains: the creation of the final system requirements. This chapter presents two approaches for system requirements. First, Section 8.1 presents user stories. These requirements are written from the point of view of different user groups, the users with dementia and the informal caregivers. Section 8.2 discusses the formal software requirements. These are written in a way to make it easy for a developer to start working on a requirement immediately.

8.1. User Stories

With the use cases discussed in Section 3.5 in mind, I wrote down several user stories. User stories are a popular method employed in requirements engineering, where the users' actions and reasons are central [99]. They differ from formal software requirements in their viewpoint. Formal requirements show what a system should do, but user stories show what users want to get out of a system.

There are two primary users of the system: the person with dementia and the informal caregiver. These users have different needs when it comes to the functionality of the system. The user stories for the caregivers can be found in Table 8.1, the user stories for the people with dementia in Table 8.2.

Table 8.1: Caregiver user stories for the integrated robotic reminder system

#	Use Case	Story
1.1	Setting reminders	As a caregiver, I want to set reminders for the person with dementia, with the ability to change certain elements of the reminder.
1.2	Setting reminders	As a caregiver, I want to make changes to existing reminders.
1.3	Setting reminders	As a caregiver, I want to set prerequisite reminders when creating or editing a reminder.
1.4	Setting reminders	As a caregiver, I want to set contextual rules, like ”no visitors”, for reminders I pick.
1.5	Reminder insights	As a caregiver, I want to see what reminders are often not completed, so that I can change them in the future.

Continued on next page

Table 8.1: Caregiver user stories for the integrated robotic reminder system (Continued)

1.6	Reminder insights	As a caregiver, I want to see what contextual rules make the sending of what reminders more difficult, so that I can decide whether it's smart to remove the rule or reschedule the reminders.
1.7	Feedback to Caregiver	As a caregiver, I want to receive notifications when the user with dementia has completed an important task, which helps me with my peace of mind.
1.8	Feedback to Caregiver	As a caregiver, I want to receive notifications when the user with dementia has not completed an important task, so that I can call or otherwise check up on them.
1.9	Feedback to Caregiver	As a caregiver, I want to be able to check which reminders were completed at any point during the day.
1.10	Feedback to Caregiver	As a caregiver, I want to get notified in case of an emergency.

Table 8.2: People with Dementia user stories for the integrated robotic reminder system

#	Use Case	Story
2.1	Receiving reminders	As a person with dementia, I want to receive reminders of important tasks.
2.2	Receiving reminders	As a person with dementia, I want to receive reminders close to where I need to do the task, such that it is easier for me to do it.
2.3	Receiving reminders	As a person with dementia, I want to be able to receive reminders wherever I am in the house.
2.4	Completing reminders	As a person with dementia, I want the completion of my reminders to be automatically completed whenever possible, such that I don't have to manually confirm them.
2.5	Completing reminders	As a person with dementia, I want to manually confirm whether the reminder was completed, if automatic detection is not possible.
2.6	Completing reminders	As a person with dementia, I want to tell the system that I have already completed the task if I completed it before I received a reminder.
2.7	Completing reminders	As a person with dementia, I want to be able to postpone a reminder if now is not a good time for me, as long as postponing the reminder is still possible.
2.8	Contextual Reminders	As a person with dementia, I want reminders to not be sent at inappropriate times and contexts, like showering while there are visitors.
2.9	Contextual Reminders	As a person with dementia, I want reminders to be schedules in a way that makes sure I complete as many important tasks as possible.
2.10	Contextual Reminders	As a person with dementia, I want reminders to not be sent at a time or context where I don't want to be disturbed.
2.11	Information and Help	As a person with dementia, I want the robot to introduce itself on first use.
2.12	Information and Help	As a person with dementia, I want the robot to re-introduce itself if I don't remember what it's for.

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Table 8.2: People with Dementia user stories for the integrated robotic reminder system (Continued)

2.13	Information and Help	As a person with dementia, I want the screen to show the time
2.14	Information and Help	As a person with dementia, I want the screen to show me the next reminder, so that I can decide to complete it earlier if I want to.
2.15	Safety	As a person with dementia, I want emergency situations to be detected.
2.16	Safety	As a person with dementia, I want to be told if an emergency was detected, so that I know help is on its way and I don't have to try to get out of it myself.
2.17	Play	As a person with dementia, I want to be able to play with the robot even when no reminder is given.

8.2. Formal Software Requirements

Software requirements are descriptions of what a software system should do. They are written in a way that makes it easy for a developer to start working immediately. I have split them up into four subsystems: the caregiver application, the robot for people with dementia, the screen on which reminders are shown, and the "system", which encapsulates functionality that is handled in the background. Users only indirectly interact with the functionality of this subsystem.

The features are prioritized using the MoSCoW method [100], which splits up requirements into *Must-Haves*, which together should form a minimum viable product (MVP), *Should-Haves*, *Could-Haves*, useful features with different level of priority, and *Won't-Haves*, features that may be interesting in a future development cycle. I consider the MVP, i.e., the Must-Haves, to be a system where a caregiver can set reminders and see if they are completed, and a person with dementia can be notified of these tasks by a robot that drives towards them, and guides them to a screen where they see the reminder and can confirm that they have completed it. I do not consider the integrated sensors used for contextual reminders and reminder completion to be part of the MPV. While they are certainly an important part of the design, without them the system should still help to solve the problem statements, and could already be an existing product.

The list of all requirements can be found in Appendix F. This list is not final. Through more co-design workshops and other forms of contact with the stakeholders, they would likely change. Some requirements may prove too technically difficult or too large in scope. These should be reworked or split up into multiple smaller ones.

9
Discussion and Future Work

The main research question of this thesis was "How can an integrated robotic reminder system effectively support people with dementia living at home in completing daily tasks while alleviating stress of their informal caregiver?" This multifaceted research question had three main sub questions, one about the design (SRQ1, discussed in Section 9.1), one about the interaction (SRQ2, discussed in Section 9.2), and one about the software architecture (SRQ3, discussed in Section 9.3). Besides discussing the research questions, I will discuss the robot and UI prototypes in Section 9.4, and the workshops in Section 9.5. This chapter will also present open questions and useful future work.

9.1. Design

Let us start by going back to the three problem statements discussed in Section 3.1: people with dementia forgetting important daily tasks, people with dementia having low quality of life, and informal caregivers experiencing stress because they are worrying about their loved one and spend a lot of time caring for them. The system designed in Chapter 3 aimed to help with these problems. Overall, I believe this was successful. The caregivers in the workshop (Section 6.6) thought the system would work well to help with these goals, and thought it would be especially valuable for the caregivers. One of the participants in the workshop with people with dementia (Section 6.7) enjoyed the company of the robot, and thought that getting reminders at appropriate times would be useful for them. However, another participant at the workshop was not interested in the system. It likely will not be a right fit for everyone.

The problem statement I am most uncertain about the system helping with, is quality of life. It is true that research suggests that robotic animals help increase quality of life, as seen in Section 2.3, and one participant in the workshop with people with dementia thoroughly enjoyed spending time with the robot. The caregivers in the first workshop did not say much about quality of life when asked about the system goals, but they aired no concerns either. The reason I am uncertain is twofold. First, I am afraid I specified the problem statement too vaguely. Quality of life is s broad concept, making designing for it and validating the designs difficult. I was less able to ask direct questions about it compared to, for example, caregiver stress, which is more clear. The concepts of caregiver stress and remembering important daily tasks are more clear and less open to interpretation. Another mistake I made during the first workshop, is that I asked the caregivers about all three problem statements in one question. They talked about quality of life only briefly, and mostly focused on the caregiver stress problem statement. Instead, I should have asked them as three separate questions.

My second concern regarding quality of life is that the system may decrease the amount of time caregivers spend with their loved one with dementia. This was also a concern mentioned by people with dementia and their caregivers in interviews held by Wang et al. [57]. Decreasing the amount of contact between the caregiver and the person with dementia could decrease their quality of life and lead to more loneliness. It is not certain, however, that using this system would actually decrease the amount of contact. Instead, it may decrease the amount of time the caregiver spends *caring* for their loved one, allowing them to spend more time simply *being with them* without having to provide care. This would be an ideal outcome, as it should help with both the stress of the caregiver and the quality of life of the person with dementia. It is my strong recommendation that, if this system is to be deployed in the real world, these concerns are researched and mitigated well beforehand.

One important method used in the design was value-sensitive design. The research sub-question related to that part was “How can the design of an integrated robotic reminder system balance the conflicting values of individuals with dementia and their informal caregivers?” (SRQ1) Going back to the values described in Section 3.4, the main values that were important for the design were *caring & empathy* (one value), *autonomy*, *safety*, *privacy*, and *participation*. At several points during the design, we saw trade-offs between some of these values. Overall, I stand by the decisions made. However, there are some where I think one value took a major hit in order to safeguard another value. One example of this is the fact that in the current design, there is no way for people with dementia to add reminders themselves. This is a major hit to *participation* and *autonomy*, but, in my opinion, a necessary one to guarantee a better level of *care* and *safety*, as people with dementia unfortunately might set reminders that are strangely planned, unhelpful, or even potentially harmful. If it is possible to find a way for people with dementia to easily set reminders for themselves, while mitigating the risks, it would be an invaluable addition to the system.

Another trade-off that got a lot of attention is the one between *privacy* on one side, and *safety* and *caring & empathy* on the other. I am content with the state of this trade-off in the final system. It skews quite heavily on the *safety* and *caring & empathy* side. If the target audience was the average population, the considerations would be different. All these cameras and sensors would be an invasion or privacy for the average person, without adding much value. But the system is not meant for the average population, it is meant for people with additional care and safety needs. The placement of cameras and sensors greatly improves the usefulness of the system, and can increase the quality and amount of help people with dementia receive. The information that is actually shared is also minimized to only the necessary information, the camera feeds are not accessible, for example. Furthermore, the data are only shared with the informal caregiver. This is quite different from sharing them with a third-party company or with the government. Nearly all informal caregivers are either the partner or the child of the person with dementia. For these reason, I believe that it is fair to decrease the *privacy* and skew closer to the *safety* and *caring & empathy* side. At a meet-up for people working on similar projects, a caregiver told me, “People are fine with Big Brother if there is no Small Brother.” The metaphor is not a perfect fit — there is a large difference between the government surveillance and control implied by the metaphor and sharing information with the informal caregiver, who usually is a loved one — but it is still interesting. Caring for people with dementia and guaranteeing their safety fully is impossible to completely ensure without a caregiver being present near-constantly. This is not feasible, so achieving the same goals through technology can be helpful, even if this technology decreases the privacy of the person.

That all being said, *privacy* is still an important value. Some things, while they may increase other values, are not worth the decrease in privacy. Take cameras, for example. Having cameras in the house can help with safety and the functionality of the system. This is a hit to the privacy of the person with dementia that is, in my view, a worthwhile compromise. But it is possible to increase the safety and care further, but you would have to concede more privacy. You could, for example, give direct access to the camera feed to the caregiver, available at all times, with the option to check previous moments in time. Arguably, this would help the system achieve its goal of reducing caregiver stress better and would make the person with dementia more safe. The caregiver can check up any time and get the peace of mind that the person with dementia is doing fine, which would help with lowering their stress. They could also help with detecting task completion. If the system is not otherwise notified that a task was completed, the caregiver could check the feed and manually confirm completion. However, I believe this is a bridge too far. The existence of cameras in the house is one thing, if the data stay secure and the use for them is explainable, this is an acceptable addition to the system. But allowing access to the feeds directly is no longer in proportion.

All these trade-offs are a long-term endeavor. If a design or development team were to pick up this project to realize it, they should not simply take my recommendations and roll with them, no questions asked. For each of them, it is worth talking to more stakeholders and changing the requirements to fit the needs and wants of them more closely.

There are some features that may be useful to change or add in the future. First, the robot can only be used inside the user's house. But indoors is not the only place where reminders are useful. Besides reminders in the garden, which could be served by a robotic pet other than the MiRo, giving reminders when the user is out and about would be useful too. They could, for example, be reminded to return home before a certain time. Having the robot accompany the person with dementia whenever they leave the house may be an option, but another, more portable, solution may be more appropriate. This would be a useful addition to the system.

Another feature that could use more work is that of repeating a reminder if it was not completed after the reminder was given. The current system, of repeating high-priority reminders until completed, repeating medium-priority reminders once to a few times, and not repeating low-priority reminders, is helpful, but more control may be useful. It could be added as a separate option in the reminder creation screen, or repeated reminders could receive a lower score in the heuristic used to schedule reminders, so that other reminders are prioritized. Adding an option to the reminder confirmation screen for the user to say that they are not interested in performing this task at all could also help. This would keep the person with dementia more in control of which reminders they would like to receive.

While the system was designed primarily for people with dementia living at home, during the workshops it became clear it could also be helpful in a care home setting. The caregivers believed a modified system could work well in some parts of the care home. The unit where people with dementia live may not be super appropriate, as they often have a later stage of dementia than the average person with dementia living at home. But for other units in the care home, such as those with older adults with physical problems, it may be more useful. While the medicine is given to people with dementia by the caregivers when they need to take it, people with only physical problems usually take their own medicine. They may still forget this, however, so a reminder system for this — and other important tasks — may be helpful for them.

9.2. Interaction

One core contribution of this thesis is the combination of robotic pets and reminder systems. Most robotic pets, as discussed in Section 2.3, have no care functionality, they are only pets. Reminder systems, as discussed in Section 2.2, usually use a smartphone as their medium. This has some downsides, as the user may not always be around their phone, and may misplace it. In the design, I presented a system that combines these two elements, creating an interactive robotic reminder system. The research question for this part was "How can a robotic pet effectively give reminders to people with dementia in a more interactive manner compared to traditional reminder systems?" (SRQ2)

Several options were explored in the design phase, and a major change was made after the first workshop. In the original prototype, the robot would drive towards the person with dementia, make animal-like sounds, then turn around to guide them towards the screen. Driving towards the participant was done slowly, following Saulnier et al.'s [54] recommendations for non-verbal interruptions. In addition to this, the robot looks at the person's face to make clear they are the one being addressed. In the workshop with caregivers, it became clear that this approach was not good enough. The caregivers were concerned that the robot would not be noticed by someone with dementia, and if it was, that it would not be clear to them that they should follow. They suggested the addition of speech. Originally, I had dismissed this idea, as I thought it would be unnatural for an animal-like robot to speak a natural language. The caregivers in the workshop understood this concern, but did not think it would be a problem for people with dementia. To people with dementia, their argument went, the robot is already a new and unexpected thing, speech would not make a large difference in this.

Speech was added to the prototype in three ways. In the form of an introduction, a cue for the participant to follow the robot, and a cue for them to look at the screen. Unfortunately, the audio of the robot was not loud enough, and the participant we asked to perform the demo in the workshop with people with dementia did not hear the robot. Considering this, we were able to verify that just the movement of the robot was not enough for this participant to understand they had to follow. Without hearing it, the participant did not follow the robot without help from the researchers, and they did not see or interact with the screen, even after help from the researchers. Because the participant could not hear the robot, we were unable to check whether speech would have helped. The participant did say that they would like it if the robot spoke, showing that indeed, for this participant, the animal-like robot did not create the expectation that speech would be unnatural.

Of course, one participant is not nearly enough to say whether the interaction is understood or not understood by most people with dementia. The participant we asked for the demo lived in a full-time care home. It is possible that they are in a further stage of dementia than the average person in our target audience, those that still live at home. This could have influenced their perception of the screen and robot. Additional workshops, ideally with people with dementia who live at home, would make it possible to draw better conclusions. If we wanted to study one specific element of the interaction, a controlled experiment would be helpful. You could think of the addition of speech, the speed of interruption, the prompt to look at the screen. The code of the robotic prototype should make it easy to iterate quickly.

9.3. System Architecture and Software Requirements

The final research theme of this thesis was the system architecture, presented in Chapter 7, and the software requirements, presented in Chapter 8. The research sub-question for this part was “What are the recommended system architectures and requirements for implementing the integrated robotic reminder system in a real-world setting, ensuring easy development and high security, privacy, and usability for both the users with dementia and their caregivers?” (SRQ3).

In order to help us answer this question, two interviews with privacy and security experts were held. They helped us decide which software architecture would be best for the system. This ended up being the local version, where all data is stored on a server located in the house of the person with dementia. This minimizes security and privacy risks, which was worth it compared to the benefits the other architectures had to offer. The local version has some drawbacks, however. It is more difficult to gather aggregated user data, which could be used to improve the system for all users. There is also a higher chance of downtime, if the Internet connection in the house goes down, the system becomes completely inaccessible, while in the cloud- and hybrid-based solutions there would still be some data available. Finally, the local version may be more difficult to set up. Overall, while these drawbacks are relevant considerations, they can be minimized through good implementation. The risk of a data breach in the cloud- and hybrid-based solution is simply too large, and the effects would be too bad, to choose those architectures.

In Chapter 8, both user stories and formal requirements were presented. These requirements are a first backlog, a development team picking up this project should continually reevaluate requirements. Some, especially those in the Could-Have category, may currently be too large in scope to be picked up and completed in one sprint of two weeks. Some others also require extra contact with stakeholders or experimentation before being specified to the desired level. This is done on purpose. Changing requirements, even late in the development process, is an essential part of agile software development [101]. Further contact with the stakeholders and knowledge of the team’s development processes will allow developers to specify these not-fully-defined requirements in a way that is most useful for the stakeholders and most productive for the team.

9.4. Prototypes and Robot

The robot prototype was built with the purpose of being useful during the workshop. I believe this was mostly successful. Unfortunately, there were some problems with the robot during the second workshop. The robot was unable to detect the participant that walked with the robot. There could be several reasons for this. First, the participant used a walker to walk around. This made the robot unable to see their whole body, which, while it is accounted for in the software, could still cause the YOLOv8 model to be unable to detect them. Another possible reason is that other people, who were sitting down, were detected as standing up. If two people stand, the robot does not know who to drive to. The setting of the second workshop was busier than the first, it could be that that caused someone else to be wrongly detected as standing. It could also have something to do with the lighting conditions. The room where the workshop took place in had large windows, and there is a chance the robot's cameras auto-exposed on the outside, meaning the participant would be less visible. This is less likely to be the problem, however, as the robot was calibrated beforehand and as the camera feed did not look wrongly exposed when looking at the camera feed during the workshop — something that would have been easy to notice.

One small thing I would change in the prototype, is the default behavior when it comes to the cliff detection. The current code defaults to having the cliff reflex on. This means that the robot uses two sensors at the front to not fall off a surface. Unfortunately, the cliff reflex also detects some types of floors as cliff, refusing to drive on them. Still, to decrease the chances of the robot falling off a table when testing, I decided the default behavior should be to keep the sensors on. The default should have been the other way around, keeping it off unless turning it on. The cliff detection is not reliable enough to work well. Sometimes, after not working with the prototype for a while, I would forget to turn it on and spend time trying to find the problem.

In order to further specify the needs of the target audience, more design workshops or other forms of user research are recommended. For this, the prototype may need to be extended or changed. The current code structure makes it easy to make these changes. If, for example, the QR code system is ditched, you only have to change the QR service and the client code. Depending on how the new system works, the changes in the client code may not be more complicated than changing the thresholds for closeness and ripping out the code related to the bright pink detection. If the changes are more significant, the client code is structured by functionality (e.g., driving, ears, sound), making it clear where the changes should be made. More major changes, like adding complete pathfinding and 3D spatial awareness, may require a more significant overhaul, but this is only natural for such a large change.

During the workshops and expert interview, people often mentioned aspects of the physical robot that could be improved. They thought the robot was too small, and that people may trip over it. They thought that the wheels would be inappropriate for many houses, due to staircases and rugs (the latter being something that "older people really love"). Finally, and most importantly, the robot's audio is simply not loud enough for everyone to hear. This also caused problems during the workshop. While these suggestions, of course, cannot be implemented into the MiRo prototype, it is worth considering switching to a different robot for prototyping and development at some point, especially if a prototype is to be tested in a realistic setting over a longer period of time.

Similarly to the robot prototype, the purpose of the UI prototype was to be able to show it to the people participating in the workshop in order to get feedback on it. For this purpose, it was successful. There are a few things I believe could have been done better, however. I think some functionality should have been added. During the workshop, the caregivers tried tapping on a reminder to get more information. It would have been useful if this was an option. It would have also been nice to add all options for the category section in the screen where you add reminders, so that I could have gotten feedback on whether the categories made sense.

One of the design goals of the UI prototype was for it to be usable for older adults without dementia, as around half of caregivers care for their partner [8]. Overall, I think this worked out well. The two views for the reminders are similar to other applications and physical objects they may have used before. The overviews in the recurring reminder and smart rule screens contain a lot of information, but I believe it is presented in a clear way. The more info screens, for both the recurring reminders and smart rules, similarly contain a lot of information. While the recurring reminder screen is a simple calendar view, I think it may be difficult to understand the information in the smart rules screen, as the same information is shown twice with two different categorizations. Before deploying the caregiver app in the real world, some more studies should be performed. These could include heuristic evaluations, cognitive walkthroughs, and user evaluations. These studies make the system more in line with the needs of caregivers, looking at what information and functionality they would want to see and how it should be presented.

9.5. Design Workshops

The goal of both design workshops was to improve the design and to gauge the general acceptability of the system. Four research questions were used, which can be found in Section 6.1. I believe the workshops produced satisfactory answers to the research questions. For WRQ1, about the integration of the robot into the system, we found that right now, we cannot say for certain whether the robot and reminder system are perceived as integrated. The participant with dementia did not notice the screen. The audio, which was added as a way to make it more clear what to do, was not heard by the participant. Regarding WRQ2, about some of the specific features of the system, all features were perceived positively, and that the workshops helped refine some specifics. Acceptability wise, which relates to WRQ3, one participant seemed very willing to integrate the robot into their life, while another participant was not interested. The system is likely not something that everyone will want to use, the caregivers agreed with this notion. Further research would be necessary to find out for how many people and for what kind of people the system is acceptable. The final research question (WRQ4) was about the three problem statements. This was already discussed in Section 9.1.

One of the participants in the workshop was unfortunately not actively participating, as they were not feeling well. Another participant was uninterested in the system, which is still useful information, but does mean that we were not able to ask some questions, like suggestions for things to get reminders on. This could have been solved in a few ways. First, a second workshop could have been hosted. If done with the same participants, it might have been the case that the participant who did not enjoy the robot did like it now. A second workshop with other participants would, of course, also have been valuable. Alternatively, we could have invited more people to the workshop. Besides possible practical issues with this, I believe the two active participants we had now were enough, having more may have made it too chaotic.

After the workshop with people with dementia, I performed a thematic analysis. Overall, this was a useful choice, but I do not think that the types of notes needed a thematic analysis. The method would be more useful for larger scale research, where it is possible to compare between several sessions and different people. Still, the thematic analysis did prove useful. Categorizing the insights made it easier to look at them again in the future, compared to searching for specific details in the notes manually.

There are a few things that, in hindsight, I would have liked to ask more questions about. First, there is the problem statement of improving the quality of life of people with dementia. As mentioned before, I asked about the three problem statements in one question, and the discussion led us to not talk about the quality of life problem statement. Another thing that should have been discussed in more detail is how the users with dementia could add their own reminders. This is not an option now, but perhaps with the input of the caregivers or people with dementia we could have conceived of a way to implement this well.

9.5.1. Recommendations for Hosting Workshops with People with Dementia

Say, you would like to host a co-design workshop with people with dementia. This section will tell you some of the things I have learned, hosting a workshop myself.

My first recommendation is keeping the caregivers active when holding a focus group with people with dementia. Besides the safety benefits of having them around if something goes wrong or if a participant with dementia feels uncomfortable, they asked interesting follow-up questions and helped in communication. At the end of the session, they also provided insights not mentioned during the first session.

Secondly, I would recommend keeping the goals of the session broad. I found that people with dementia do not always your questions as directly as you might want them to. If the goal of the session is to get specific feedback on one element of the design, you might be disappointed if they are not interested in that aspect. For example, if I had focussed on only the participant's attention to the screen, I would not have been able to get much feedback, as the participant did not notice the screen. Whereas if the goal is more broad, like getting feedback on all aspects of the system and seeing what the participants like, dislike, and miss in the system, I believe it is more likely that you get useful insights out of the session.

Finally, on the practical side, I would recommend starting the human research ethics approval procedure as early as possible. It is likely there is something you will have missed, or that is unclear to the approvers, which means you will have to fill in a revision form. This can take more time again, meaning the process can unfortunately take quite a long time. Also make sure to discuss the informed consent procedure with the caregivers again close to the workshop. In my workshop, this ended up being somewhat disorganized, while discussing it again would have made the process more smooth.

10 Conclusion

This thesis combined two useful assistive technologies for people with dementia: robotic pets and reminder systems. Most robotic pets found in literature try to imitate real pets: the user can pet them and play with them. This is valuable on its own, but additional care functionality could be added. Reminder systems, on the other hand, are useful in helping people with dementia remember to do important daily tasks, like having meals and taking medicine. They usually use phones as their medium. This is not ideal, as it can be misplaced and as it is harder to check what reminder you just got. Some reminder systems make use of contextual clues to decide when to send reminders.

This thesis described the design of an integrated robotic reminder system for people with dementia living at home. The system aimed to solve three problem statements: people with dementia forgetting important daily tasks, people with dementia experiencing low quality of life, and high stress experienced by caregivers. The system did this with the animal-inspired MiRo robot. This robot comes to the user with dementia, guides them to a screen placed in the house, where they are told what their reminder is. If possible through the use of sensors, this reminder is automatically marked as completed in the system. Else, the user has to confirm manually. In order to fit the needs of individual users better, the system makes use of contextual clues. These clues can be added by the caregiver, it may not be fitting to give a reminder to shower when there are visitors in the house. The precise scheduling of reminders is done using a heuristic, which uses information about the reminder, like the urgency or how close to the deadline we are, and past information, like during which times the user usually ignores the reminder, to try to make sure that as many reminders as possible are completed.

To help with the stress of the informal caregivers, a phone app was designed. The caregiver can add reminders through this app, but it also allows them to check up on their loved one when they are not with them. It sends mobile notifications when the user with dementia completes (or fails to complete) important reminders. It also shows an overview of which reminders are often ignored or remain unsent, which allows them to reschedule reminders to a more appropriate time.

The main research project of the thesis was “How can an integrated robotic reminder system effectively support people with dementia living at home in completing daily tasks while alleviating stress of their informal caregiver?” This multi-faceted question was split up in three main topics. The first research topic was that of value-sensitive design. When designing the system, the values of both important stakeholders, the users with dementia and their caregivers, were taken into account. Sometimes, these values clashed. For example, placing sensors and cameras in the house make the system provide better care and make the user more safe, but it comes at the cost of privacy of the user. The conflicts between these values was explored in this thesis. Secondly, the interaction between the robot and the person in the context of a reminder system was researched. When the robot is driving towards the user, it should be clear it is trying to convey a reminder. Through verbal and non-verbal communication, the user is prompted to follow the robot, and look at the screen to receive the reminder. The final topic relates to the software architecture and software engineering requirements. Recommendations were made regarding the ideal software architecture of the system, aiming to make the system as useful as possible, and making sure private data is stored securely. In order to make the decision on the software architecture, two interviews with experts were held.

In order to evaluate and improve the system and core interaction with stakeholders, a high-fidelity robot prototype was made. It finds a person using the on-board cameras, drives towards them, asks them to follow, guides them to a screen, and tells them to look at the screen. It does this through the use of the robot operating system for operations, and computer vision to find the person and the screen. Finding the screen is aided by a QR code placed under it. When detecting the person, it also extracts information on the position of limbs. This is used in several ways, for example to look at the user's face. The code of this prototype was made to be easily extensible. A prototype for the user interface of the caregiver was also made. It shows how a caregiver can create reminders, view today's reminders, and how they can get insights in recurring reminders and contextual rules, so that they can tailor the system better to the needs of this particular user.

To improve the design and assess the general acceptability, two design workshops were held. The first was with professional caregivers. We showed them the robot and user interface prototypes, and asked them general questions about people with dementia, and asked them for feedback on certain features of the system. With their input, changes were made to the design. For example, speech was added, as it would make the interaction more clear, and as they believed it would not seem strange to a person with dementia to see the animal-like robot speak. The second workshop was held with people with dementia living in a care home. We showed them the robot prototype, and similarly asked them similar questions as before. This workshop confirmed that the speech was an appropriate addition. Unfortunately, the speech was not loud enough, and the participant asked to perform the demo did not understand the interaction through non-verbal behaviors alone. The workshop also showed that the system was accepted by some, may not be suitable to all people.

Dementia is a condition affecting millions. Technology can play a big role in making sure people with dementia are able to live at home for longer, which is beneficial for them, and would alleviate capacity issues experienced by care homes. This is a valuable goal, but the human touch is equally — if not more — important. Through the use of value-sensitive design and a human-centered approach, I hope I was able to keep this human touch. A single piece of technology cannot solve all problems experienced by people with dementia, but hopefully it can help them with their daily routine and some negative symptoms. Similarly, one piece of technology cannot remove all stress experienced by informal caregivers, but I hope this system would allow them to live their own life to the fullest, and get as much out of their time with their loved one with dementia as possible. If someone with dementia is better able to take care of their own essential needs through technological assistance, perhaps the caregiver can spend less time being a caregiver, and can spend more time simply being with their loved one as just that — a loved one.

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A

Personas

Robert de Graaf

Figure A.1: Robert de Graaf. Source: [102]

Robert de Graaf is a 73-year-old retired facility manager who lives at home in Woerden with his partner of 35 years, Suzanne. They have two adult children, one lives in Breda, the other lives and works abroad in Singapore. Robert was diagnosed with early-stage dementia six months ago, though his symptoms already started a year before his diagnosis.

Robert has gray hair and wears glasses. He is of average height and weight. Due to his dementia, he sometimes buttons his shirts incorrectly or forgets to shave. Susan helps him with dressing and personal grooming.

Robert is known as a kind and patient man. Despite his condition, he maintains a positive attitude and tries his best to engage in conversations and activities. He has a good sense of humor and likes sharing stories of his past.

Robert has a passion for poetry and literature. He used to read books in Dutch, English, and German. Sadly, his reading abilities have been affected by dementia. He still tries to read, but often gets frustrated when he can't figure things out.

Robert wakes up around 08:00 and starts his day with a breakfast prepared by Suzanne. They often go on walks around the neighborhood, which keeps Robert active and gives him some fresh air. Robert occasionally tries to go on a walk himself, but when he does, he sometimes gets lost. Suzanne tries to make sure he doesn't leave the house unsupervised. Suzanne also helps him with medication management, ensuring that he takes the correct dosage every day. Besides going on walks, Robert likes listening to music on his CD player and doing simple puzzles to stimulate his mind. Suzanne takes care of most household tasks, including the cooking.

Suzanne is Robert's primary informal caregiver. She ensures he stays health and active, and she keeps him company. She does not leave the house alone often, only for necessities. She feels too concerned about Robert when leaving him alone. Robert and Suzanne's first child, Daan, lives in Breda. It takes him an hour to drive to Woerden, and he comes to visit around once per two weeks. When Daan is there, Suzanne is able to relax a bit more. Their second child, Lotte, lives in Singapore. She is only able to visit around twice per year, but she does video call with her parents often.

Jopie Meijer

Figure A.2: Jopie Meijer. Source: [103]

Jopie Meijer is an 86-year-old woman who lives in the outskirts of Amsterdam. She lives alone, as her husband Ben passed away a few years ago. Her husband and herself used to operate a local grocery store together. Her only child, Ben (Jr.), lives a few streets over. He took over management of the grocery store from his parents. Ben comes over to take care of his mom often, but while he is at the store, he is not able to come over for small things. Jopie has early-stage dementia, which is currently undiagnosed.

Jopie is a short woman and is slightly overweight. Her hair is white and quite short. She usually wears oversized shirts, as they are easy to put on.

Jopie tends to be very direct, and often says how she's feeling without much regard for others. She also has quite a foul mouth. This can sometimes be quite jarring for people that don't know her well, who often perceive her as rude.

Jopie used to be an avid collector. She has large collections of Smurf figurines, but she also collected coins and stamps. She still likes to go over her collections, as many items have interesting stories attached to them. In her free time she also likes to watch soap operas on her TV.

Every day, Ben drops by Jopie's house early in the morning to wake her up and make her breakfast. He then leaves for work. This leaves Jopie alone in the house until Ben's lunch break around twelve. Ben usually brings back some lunch from the grocery store, and they have lunch together. In the afternoon, Ben comes back when the store has closed, around six in the evening. Ben provides food for Jopie, but because his day is often quite busy, he usually brings back take-out or something that can be heated up very quickly without much effort. Ben occasionally stays with Jopie until she goes to bed. Ben then goes home to sleep at his own house.

Besides Ben, there are not many people able to take care of Jopie. She is quite stubborn, and not willing to go to the doctor. She realizes there is something wrong, but she does not want to get diagnosed. This is quite stressful for Ben, most of his time not spent working is spent taking care of Jopie. He does this with love, but he would like to be able to relax more often. While he is at work, he also tends to be quite stressed, as he is not sure whether Jopie is able to take care of herself.

B Storyboards

This appendix shows all storyboards. The Dutch versions can be found in appendix C.2.

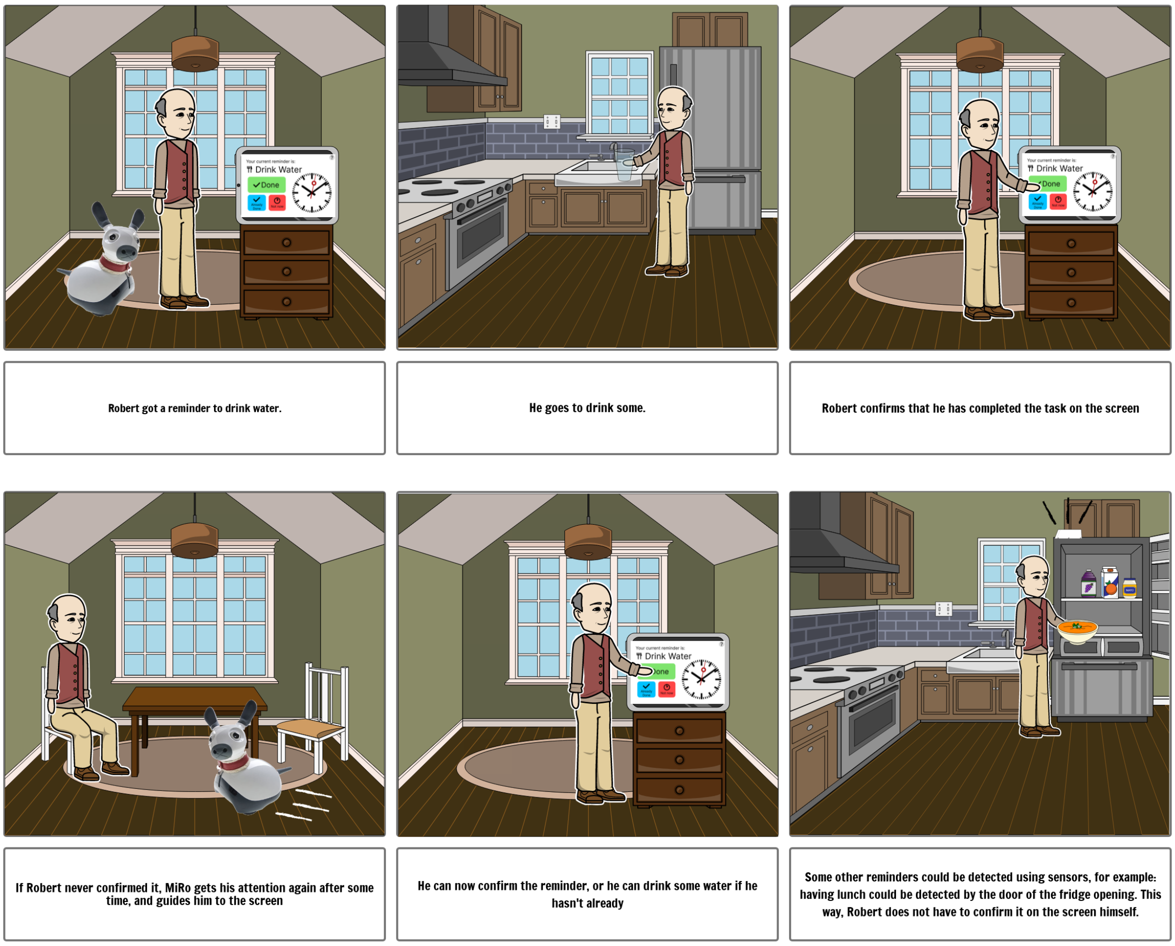


Figure B.1: Storyboard for completing reminders

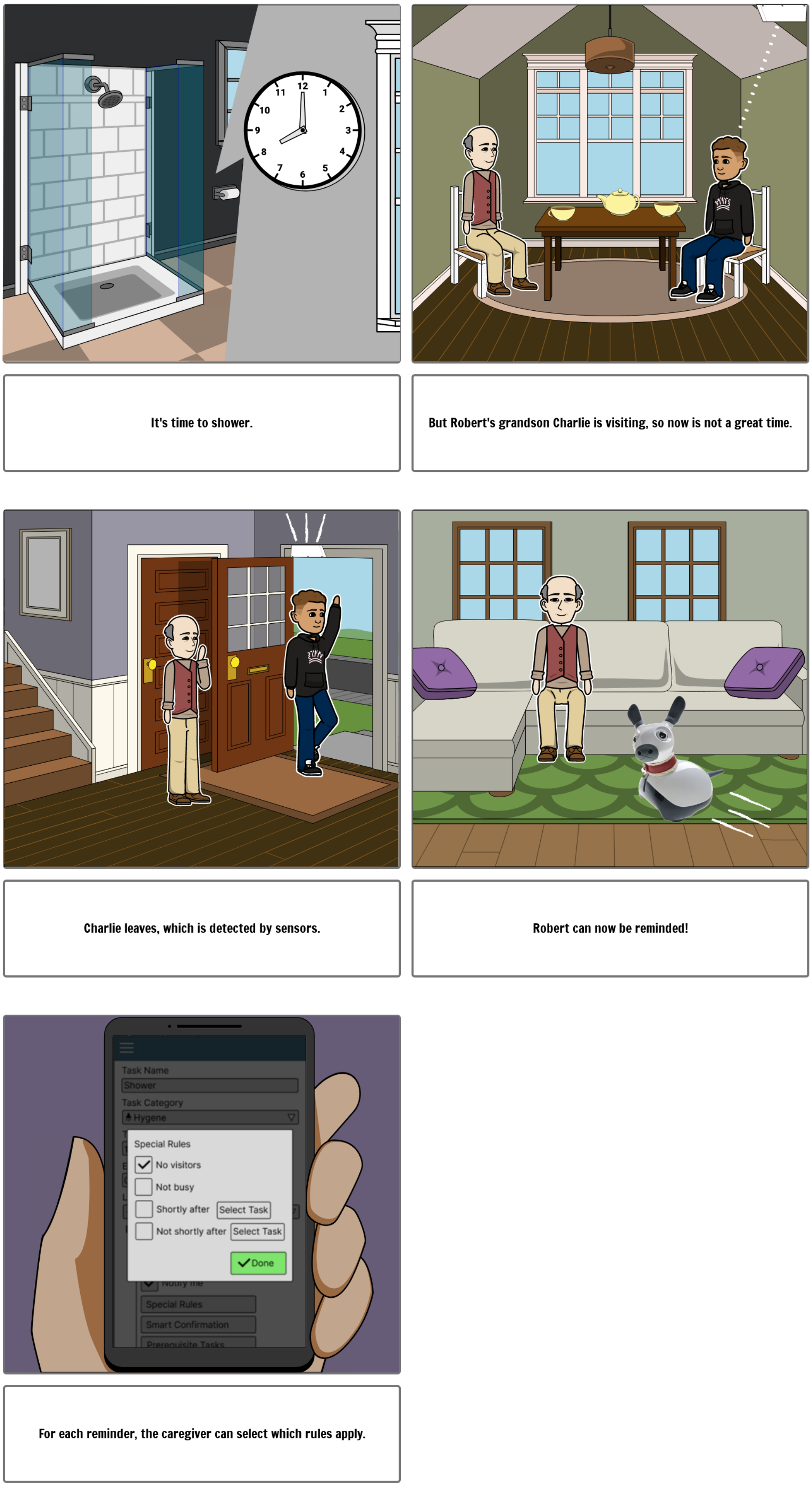


Figure B.2: Storyboard for contextual reminders

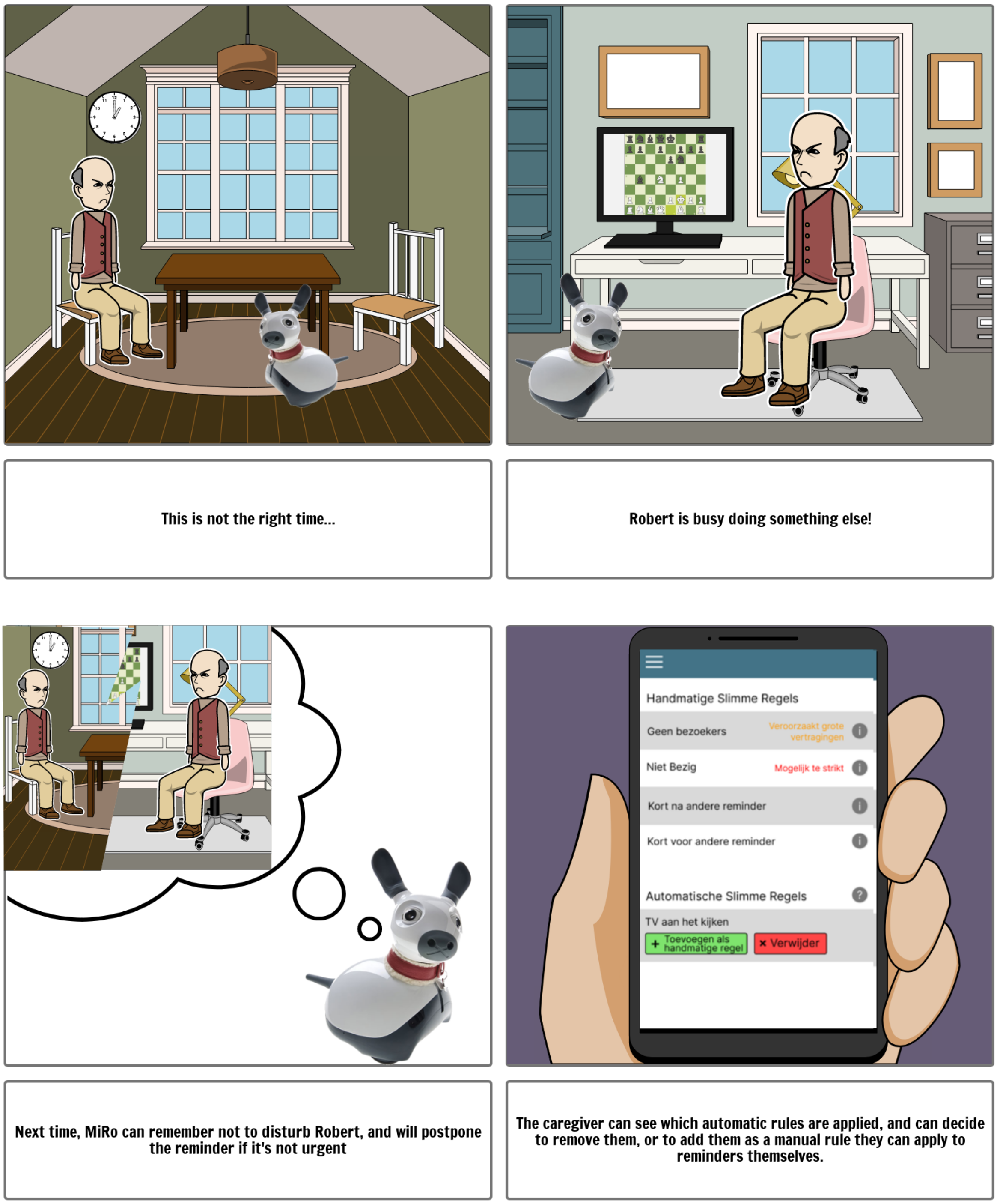


Figure B.3: Storyboard for personalized reminders

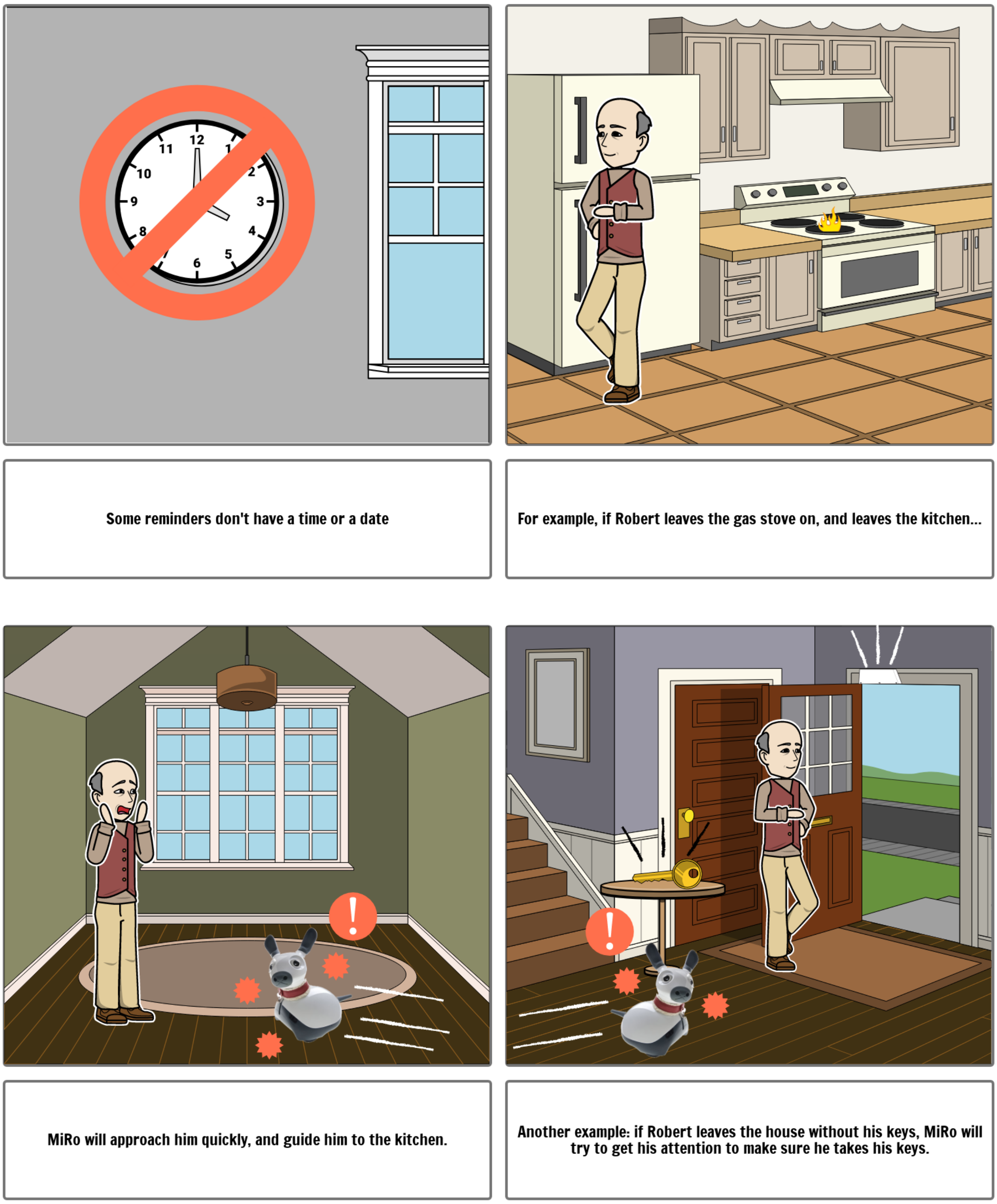


Figure B.4: Storyboard for rule-based reminders

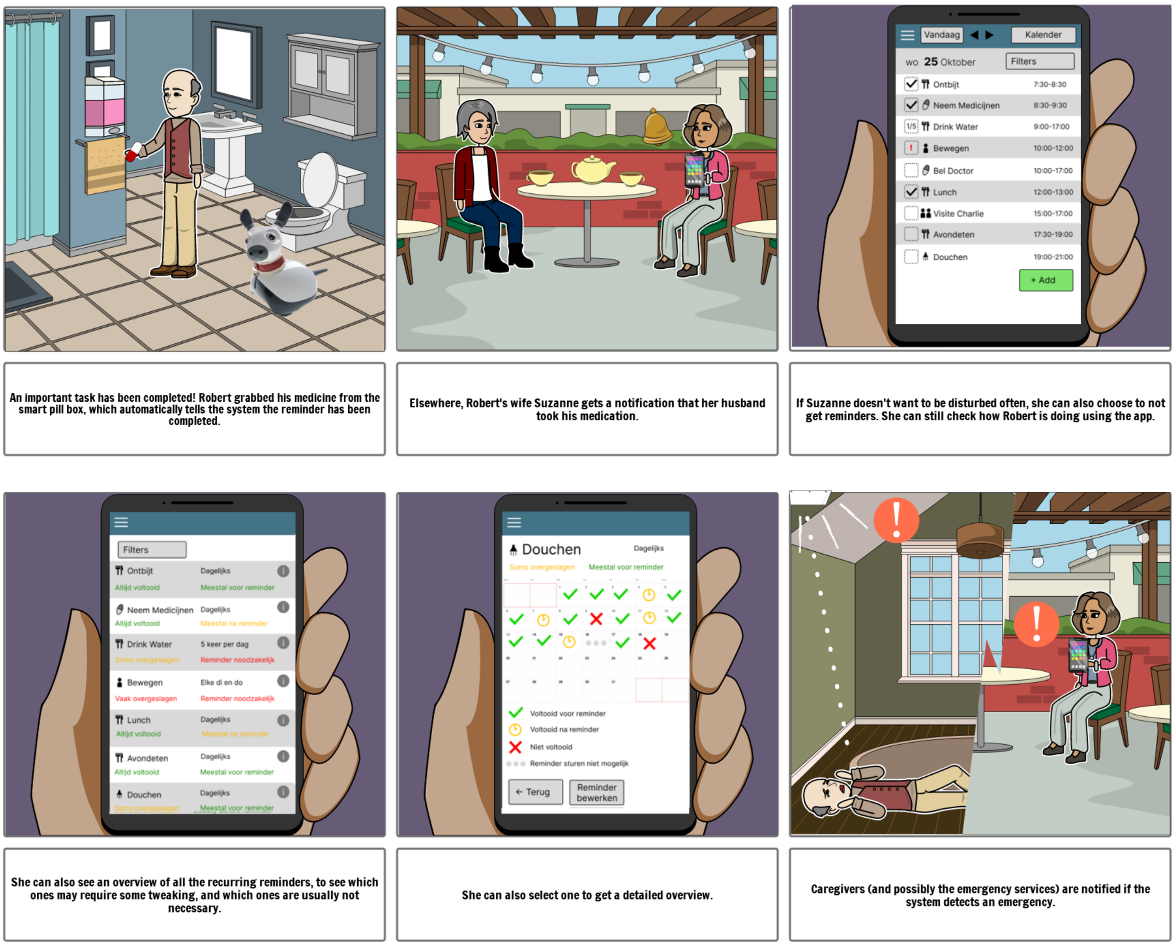


Figure B.5: Storyboard for feedback to caregivers

Figure B.6: Storyboard for help page

C

Dutch Materials

This appendix shows the Dutch version of materials shown throughout the thesis. In most cases, the English version was created first, but in some cases the Dutch version was the original. Either way, all translations presented are my own.

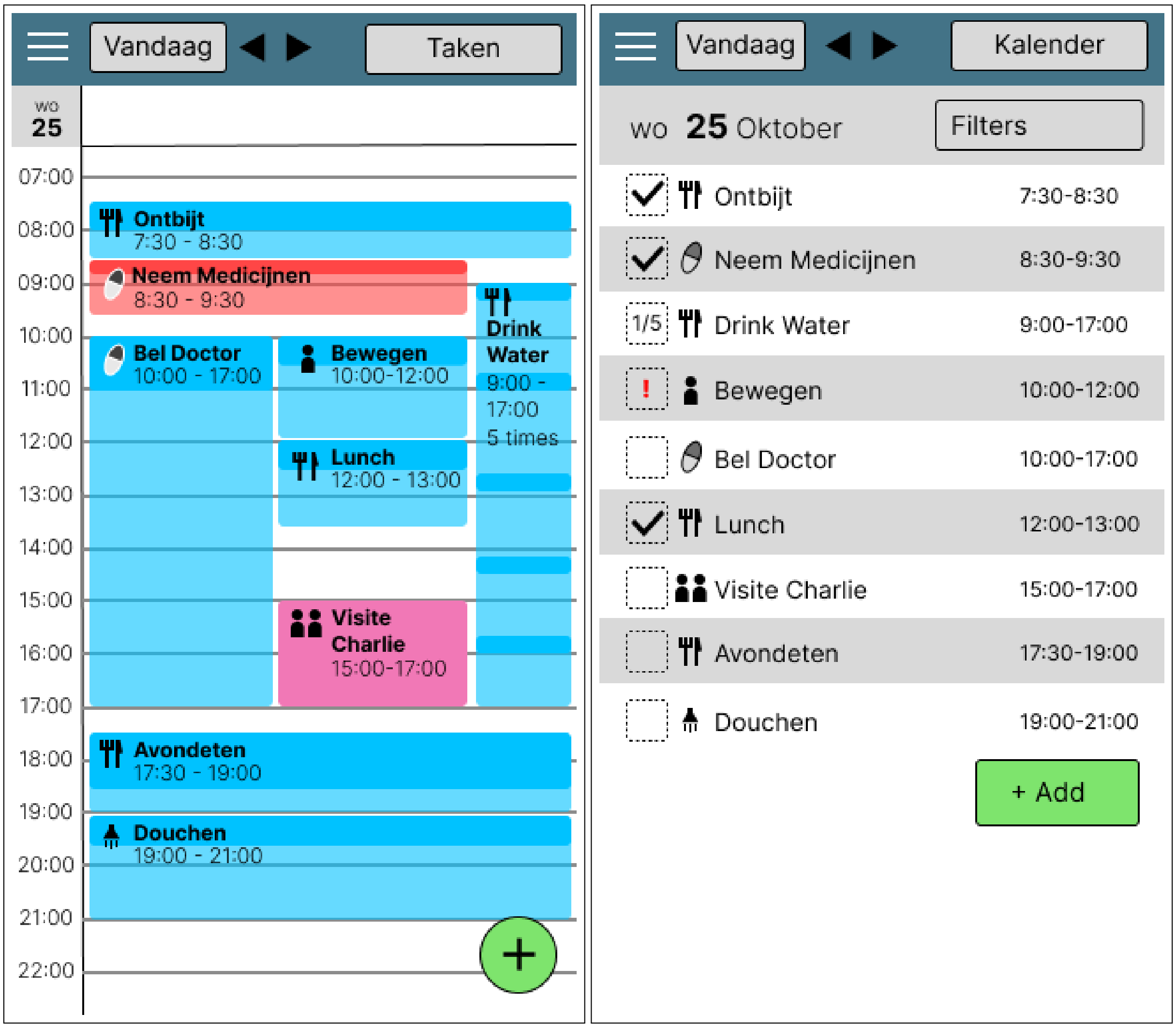
C.1. Prototypes

(a) Idle screen shown when no reminder is active.

(b) Reminder screen shown when a reminder is being given.

(c) Reminder screen used during the workshop with people with dementia, with only the "Done" button visible.

Figure C.1: The two screens of the tablet prototype.



(a) The calendar view of today's reminders.

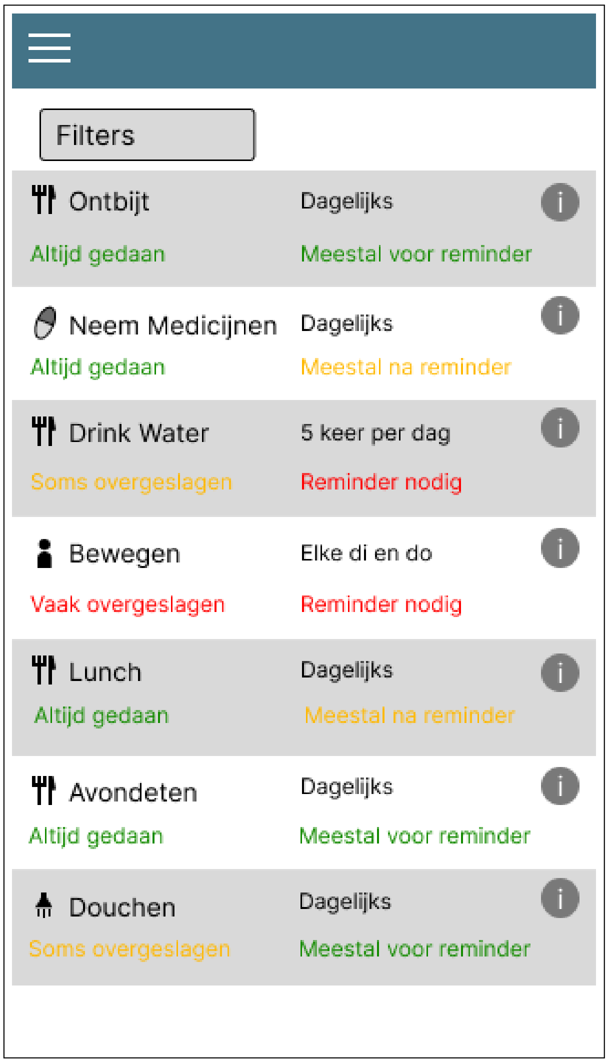
(b) The task view of today's reminders.

Figure C.2: The two ways to view today's reminders.

(a) The reminder creation screen. The "Advanced Options" can be expanded or hidden, and start out hidden.

(b) The overlay to select which smart rules should be active.

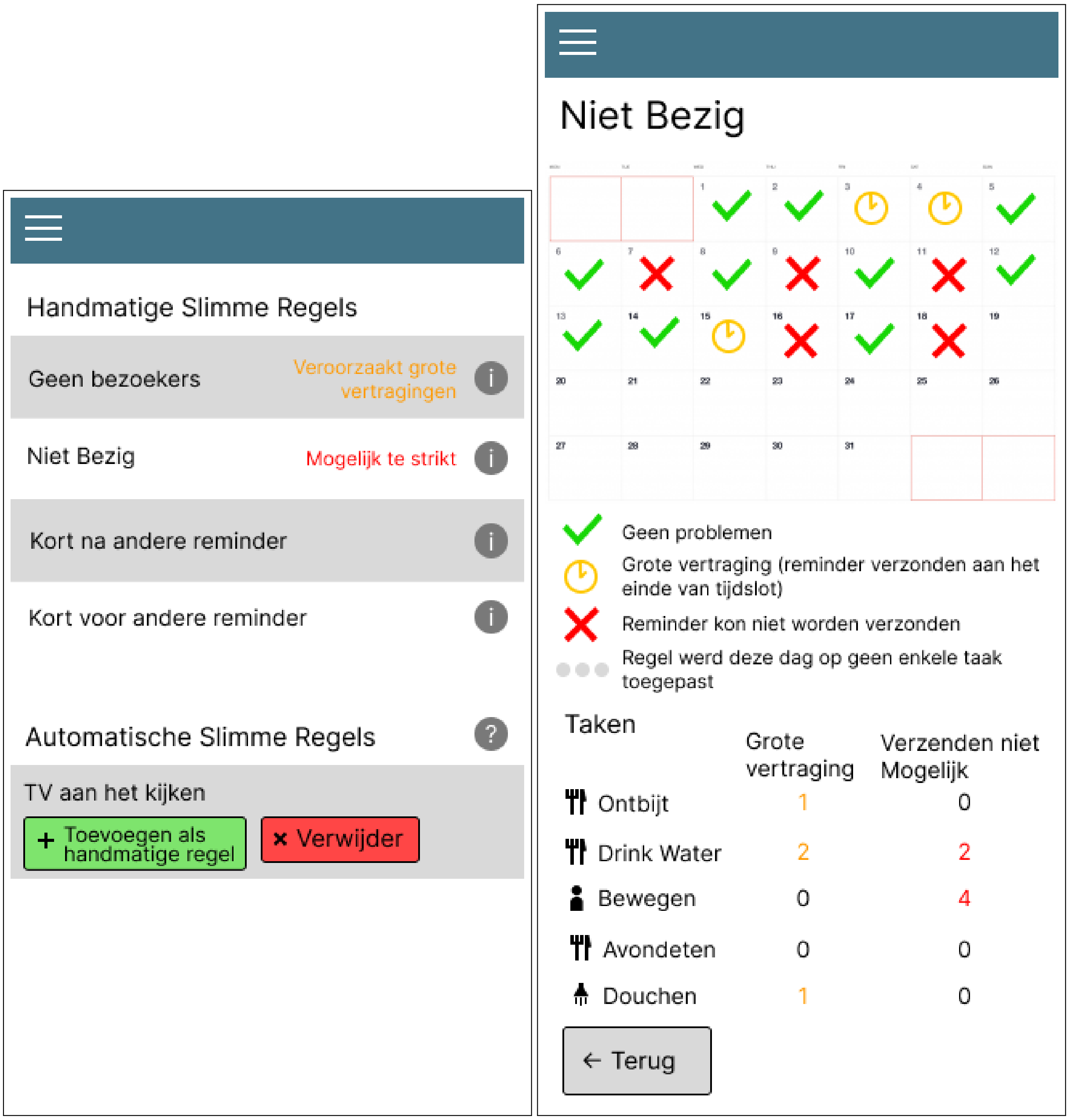
Figure C.3: The reminder creation screen.



(a) Overview of all recurring reminders.

(b) Detailed information on one recurring reminder.

Figure C.4: The recurring reminder screens.



(a) Overview of all manual and automatic smart rules.

(b) Detailed information on one smart rule.

(c) Smart rules pop-up.

Figure C.5: The smart rule screens.

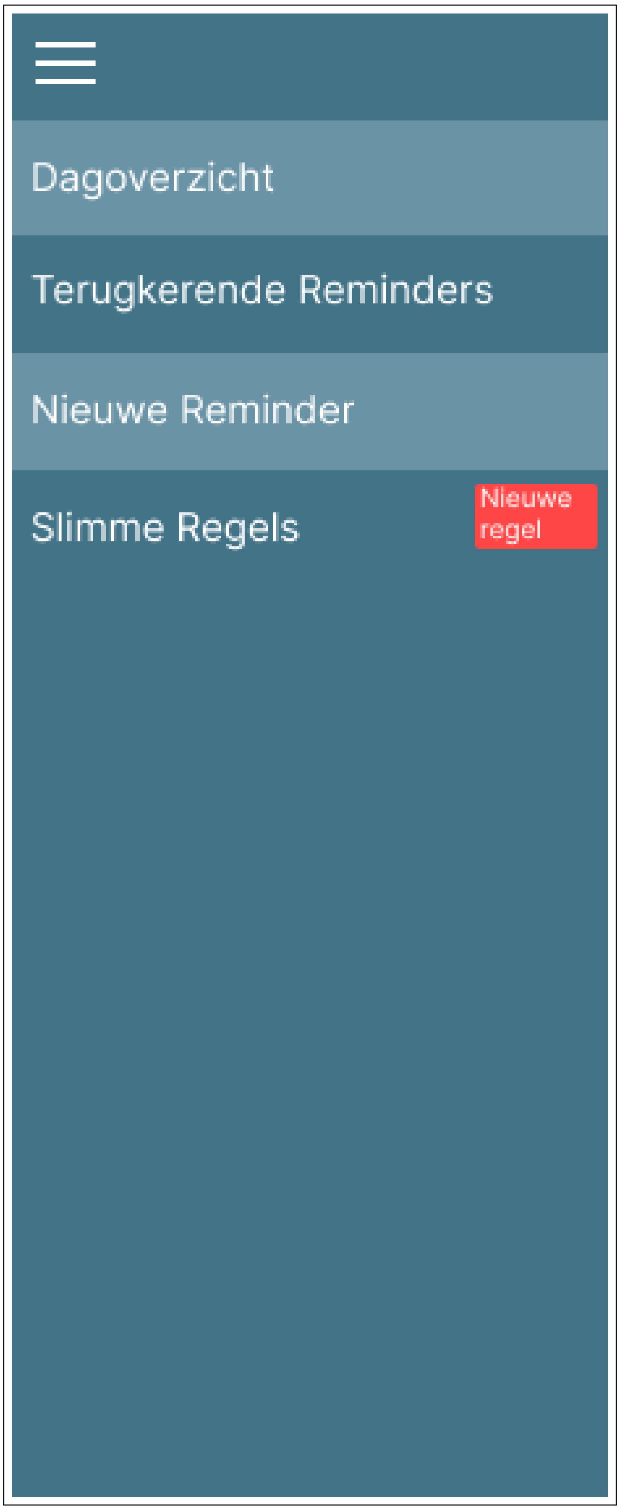


Figure C.6: The navigation menu.

C.2. Storyboards

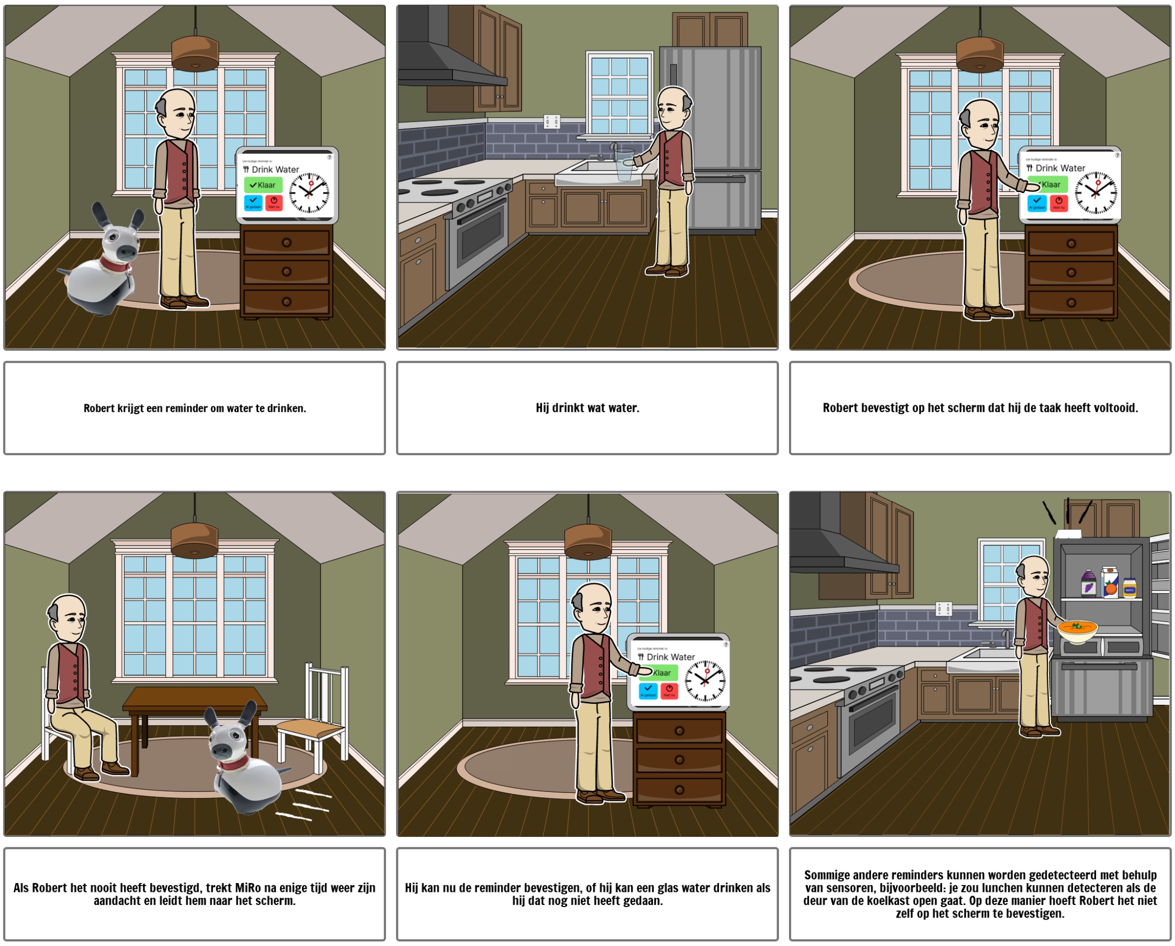


Figure C.7: Storyboard for completing reminders in Dutch

Figure C.8: Storyboard for contextual reminders in Dutch

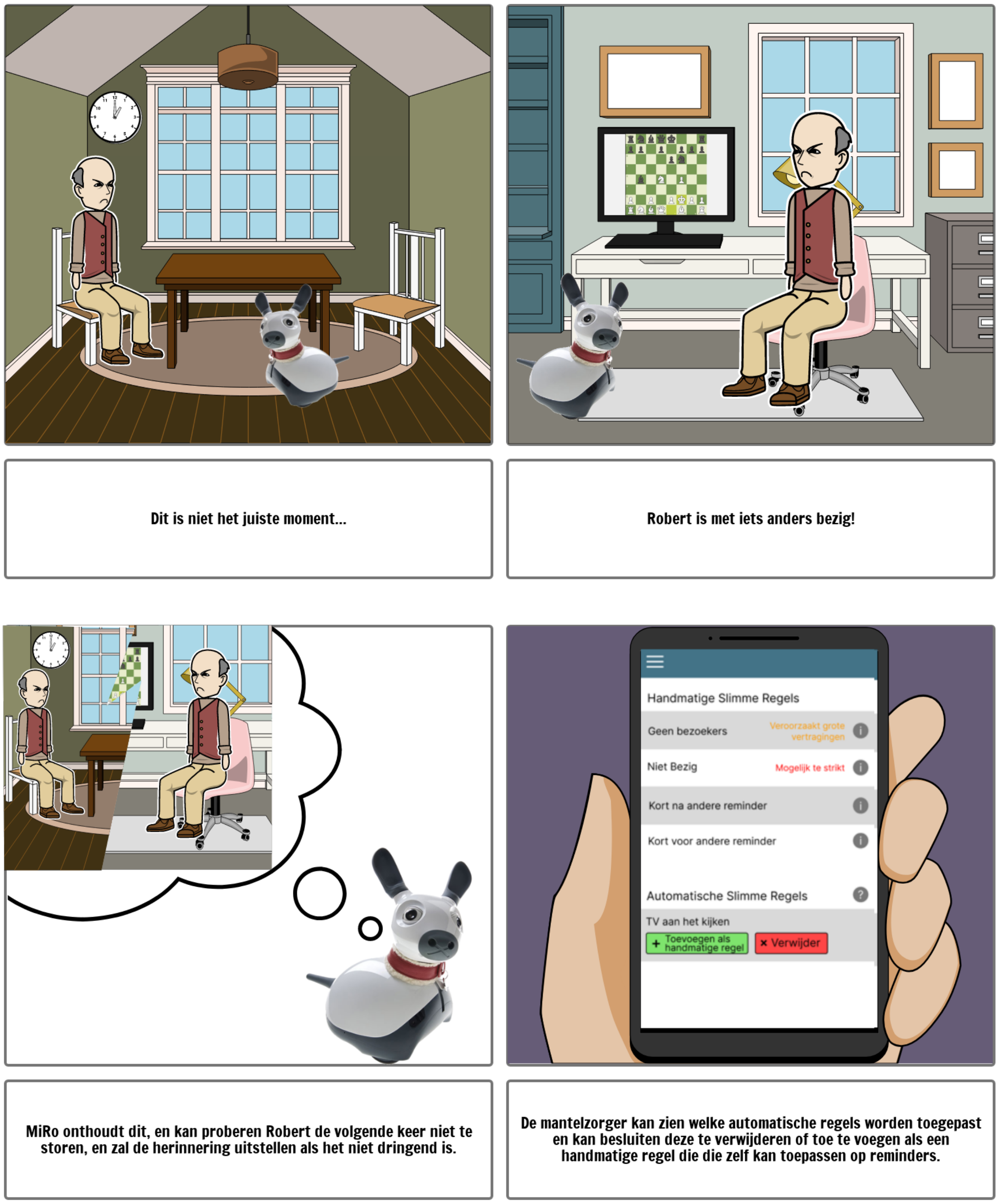


Figure C.9: Storyboard for personalized reminders in Dutch

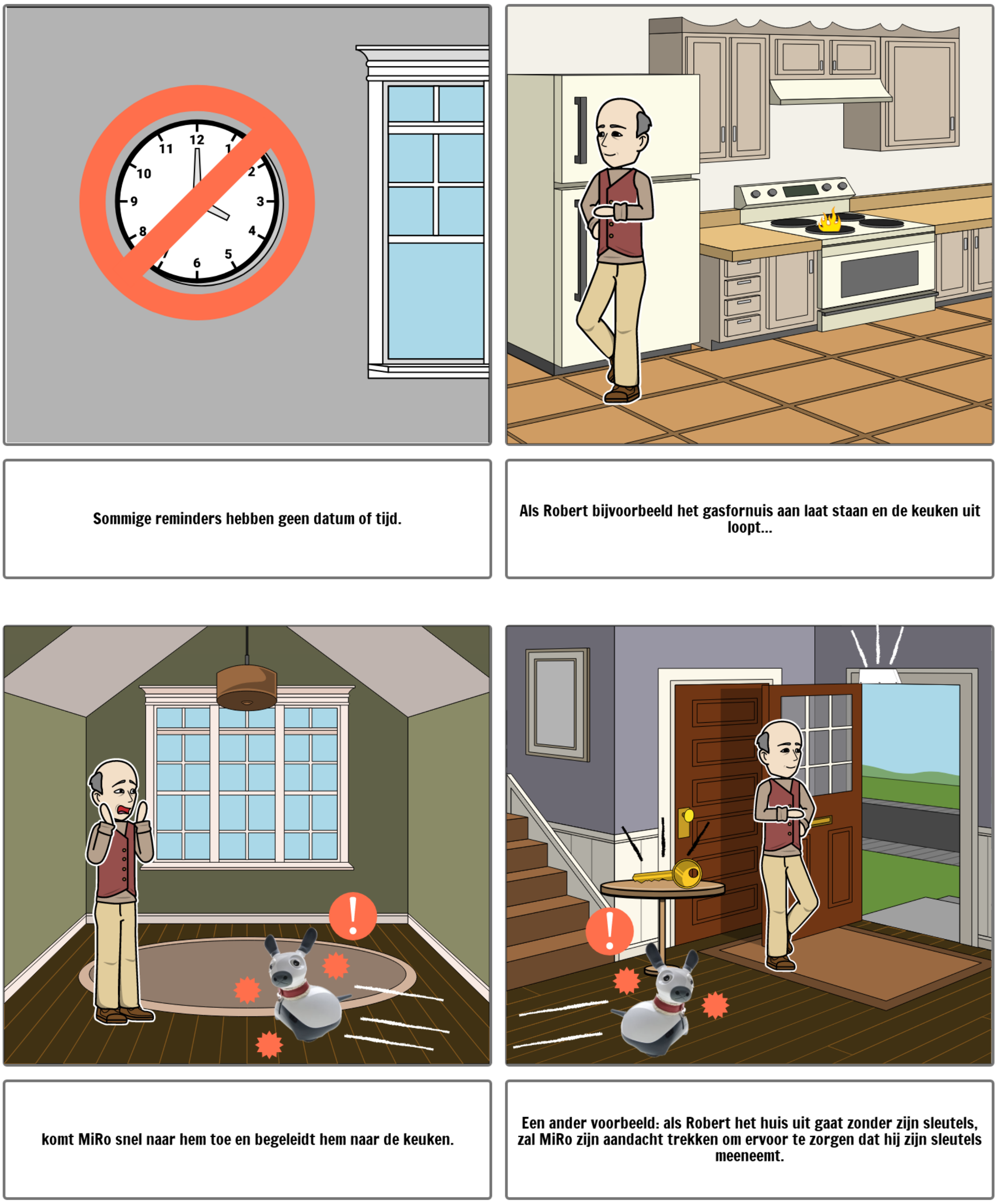


Figure C.10: Storyboard for rule-based reminders in Dutch

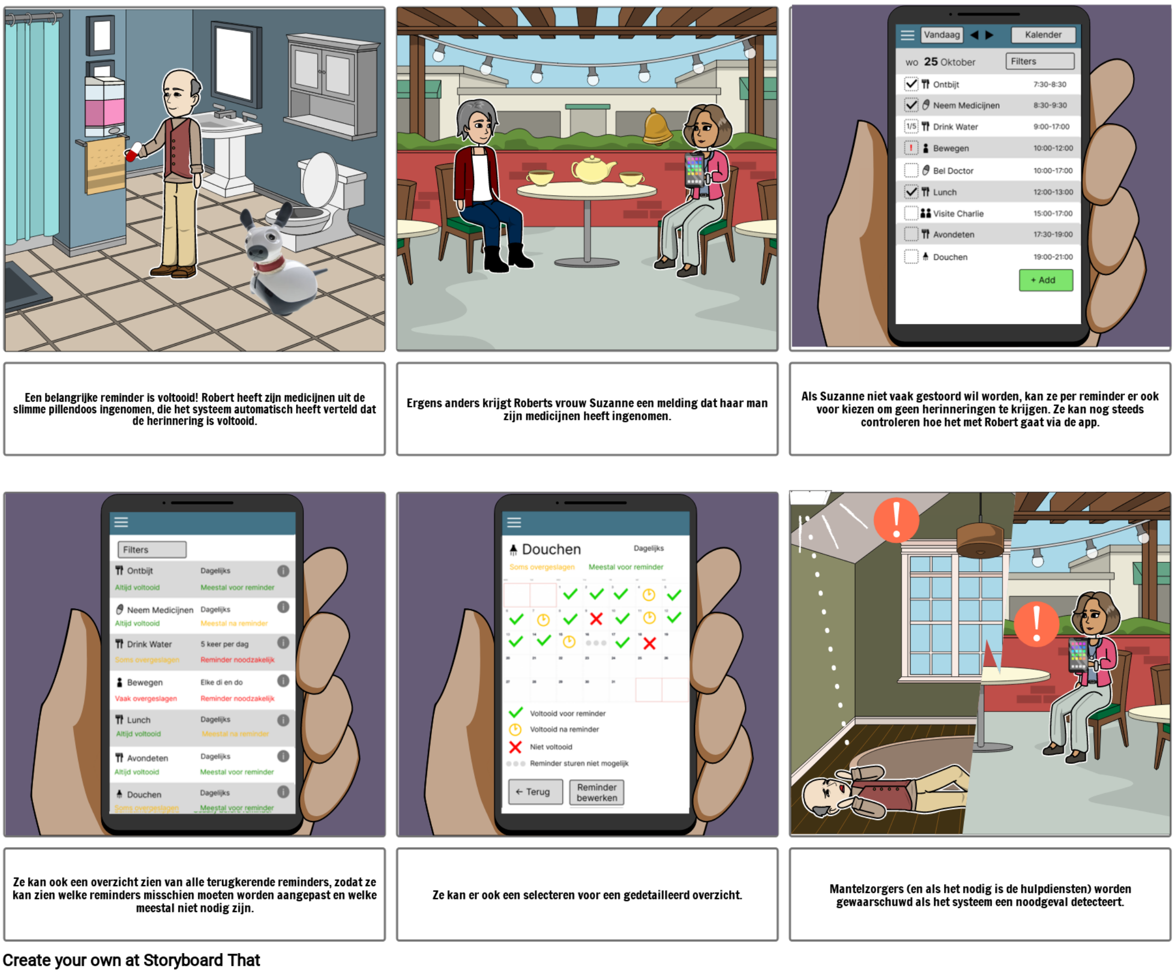


Figure C.11: Storyboard for feedback to caregivers in Dutch

Figure C.12: Storyboard for help page in Dutch

D

Workshop Questions

This appendix contains a list of questions written down before the workshops. The workshop questions were asked in a semi-structured manner, meaning follow-up questions were asked too. This list does not contain these follow-up questions. Some questions on this list were cut in the interest of time. The questions were originally written in Dutch, and have been translated to English for this thesis through machine translation. The translations were manually verified afterward.

D.1. Caregivers

D.1.1. General Questions

These questions were asked before the demo.

- What does an average day of a person with dementia look like?
- How often does an informal caregiver or professional caregiver visit someone with dementia living at home? What do they do when they are there? How long are they there?
- What are some important things someone with dementia needs to do in a day that they may forget?
- Do people with dementia use reminder systems (at home or here)?
  - Yes: What kind of systems? Who creates the reminders? What kind of reminders?
  - No: Why not do you think?
- What kinds of reminders would be helpful?
- What other technology is used by people with dementia?
- What kinds of robots might be useful for people with dementia living at home? Do you know of any robots used for this purpose?

D.1.2. Workshop Questions

These questions were asked after the demo.

Robot

- Was it clear what the robot was trying to tell you? Are there other ways by which it could be clearer?
- What do you think of the screen? Does it help? Would it be better without it?
- Did you feel that the robot was part of a system? Why or why not?

- How can the robot convey information to someone with dementia? Because it looks like an animal, it seemed strange to us if it could talk, do you agree with this? What other ways could help with communication? Sound, movement (robot or parts of robot)? Speech?

Storyboards

- Completing reminders
  - What do you think about this?
  - Is giving the reminder again helpful, or could you skip it for some reminders?
  - What do you think of the "already done" and "not now" buttons?
- Contextual reminders
  - Is this a good idea?
  - How could family caregivers make these rules? (See also the app)
  - What kind of rules might be helpful?
  - Would it be more convenient to come up with some standard rules and give them as options, or is it better to give caregivers the freedom to come up with their own rules?
- Personalized reminders
  - The system would use smart rules or AI to schedule reminders at a time that is most convenient for the user.
  - Is this a good idea?
  - Besides time and activity, what could be other things the system could use in scheduling?
  - The caregiver is notified when there is a new rule and can choose to use it as a manual rule or delete it. What do you think about this?
- Rules
  - Some reminders could be completely without a time aspect.

  - Is this a good idea?
  - Is this convenient to use the robot for this? Or would it be better to bring these things differently?
- Feedback to family caregivers
  - Is this a good idea?
  - Would this reduce or increase stress?
- Help page
  - Is this a good idea?
  - Are there ways to make it a little clearer that the screen belongs to the robot?
  - Are there other ways to do this?

General Questions

- What kind of reminders would you like to see in this system?
- In the storyboards, I showed sensors several times. The robot also has a camera that is used to find the user, for example. This data is stored securely, but you might not have the sense of privacy if there are sensors in your home. Could people with dementia or the caregivers perceive this as a problem? What steps could we take to reduce the problem?
- The system has three purposes. For each purpose, do you think this system could help, and why?
- What other functionalities might the system have? For example, play with the robot or safety features?

D.2. People with Dementia

D.2.1. General Questions

These questions were asked before the demo.

- Have you ever used a robot? What did you think of it?
- Would you like to have a robot animal that you could pet, for example?
- What other technology would you find useful?

D.2.2. Workshop Questions

These questions were asked after the demo. Originally, this included the same storyboard questions as the ones asked in the first workshop, but these questions were not asked.

Robot

- Was it clear what the robot wanted to tell you? Did you understand that you had to follow the robot? Are there other ways by which it could be clearer?
- What do you think of the screen? Does it help? Would it be better without it?
- Did you feel that the robot belonged to the screen? Why or why not?
- How did you feel about the robot talking?

System

- Completing reminders, how did you feel about tapping the screen to complete the reminder?
- If for a moment you don't remember what the robot is for, what is a convenient way for it to explain it to you? For example, we thought of a short video on the screen, but the robot could also tell you.

General Questions

- What kind of reminders would you like to see in this system?
- Do you think this could help you get important things done?
- If you were to use this system, do you think it would make you feel better?
- What other functionalities could the system have? For example, playing with the robot or calling someone if you fall?

E

Expert Interview Questions

This appendix contains a list of questions written down before the expert interviews. The questions were asked in a semi-structured manner, meaning follow-up questions were asked too. This list does not contain these follow-up questions. Some questions on this list were cut in the interest of time.

- What are the benefits and drawbacks of each of the systems?
- What are the trade-offs between security and implementation challenges in this context?
- What is the biggest security concern for each of the three architecture options?
- Are there other options? Other types of system architecture?
- For the gateway system, would it be better to still process the raw camera data locally?
- What would the implementation challenges be for these systems?
- Which of the three systems would you recommend?
- What communication would you recommend between the sensors and the home control system/gateway? MQTT, ZigBee?
- What other ways can the system be designed to minimize the collection, storage, and processing of unnecessary data?
- If the system needs to be updated, would that be a problem for any of these architectures?
- Do you know of ways to make the user *feel* like their privacy is being safeguarded?
- Are there any other security or privacy concerns I should account for?
- Privacy is not just important with regard to people accessing the system or hackers, but there's also a question of privacy from the person with dementia with regard to their caregiver. Is that a problem with any of these systems?

F

Formal Software Requirements

Table F.1: Formal Software Requirements

Use case	Story	Requirement
Caregiver Application		
Must-Haves		
Setting reminders	1.1	The caregiver app shall allow the caregiver to add a reminder with a name, an acceptable time window (start and end), and a date
Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify the location where the reminder should be given when creating a reminder.
Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify whether they want to be notified on completion when creating a reminder.
Setting reminders	1.1	The caregiver app shall allow the caregiver to set up recurring reminders that appear on different days (e.g., daily, every Tuesday)
Setting reminders	1.2	The caregiver app shall allow the editing of all aspects of a reminder
Setting reminders	1.2	The caregiver app shall allow the deletion of a reminder
Reminder feedback	1.7	If set up in reminder creation, the caregiver app should send the caregiver a push notification when a reminder is completed
Reminder feedback	1.9	The caregiver app should show an overview of which reminders are active today
Reminder feedback	1.9	The caregiver app should show which reminders were completed today
Reminder feedback	1.9	The caregiver app should have a task list overview of each reminder in a day
Reminder feedback/insights	1.9/1.5	The caregiver app should make it possible to see reminders of days in the past and future
Should-Haves		
Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify a category (e.g., food or hygiene) when creating a reminder.

Continued on next page

Table F.1: Formal Software Requirements (Continued)

Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify an estimate for the duration when creating a reminder.
Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify the priority when creating a reminder.
Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify whether they want to be notified if the reminder was missed when creating a reminder.
Setting reminders	1.4	The caregiver app shall allow the caregiver to also specify contextual rules (e.g., no visitors, not busy) when creating a reminder.
Setting reminders	1.3	The caregiver app shall allow the caregiver to also specify prerequisite reminders when creating a reminder.
Setting reminders	1.1	The caregiver app shall allow the caregiver to also specify systems for reminders to automatically be marked as completed (e.g., shower turned on, fridge opened) when creating a reminder.
Reminder feedback	1.8	If set up in reminder creation, the caregiver app should send the caregiver a push notification when a reminders is not completed
Reminder feedback	1.9	The caregiver app should show which reminders are not (and can no longer be) completed today
Reminder feedback	1.9	The caregiver app should have a calendar overview of each reminder in a day
Reminder insights	1.5	The caregiver app should have an overview of recurring reminders, showing the name of the reminder, and how often it recurs
Reminder insights	1.5	The overview of recurring reminders should show whether the reminder has always been completed, sometimes been skipped, or often be skipped
Reminder insights	1.5	The overview of recurring reminders should show whether the task is usually completed before the reminder was given, usually been completed after the reminder was given, or whether the reminder is always necessary
Reminder insights	1.5	Each recurring reminder should have an additional information screen, showing the name of the reminder, and how often it recurs
Reminder insights	1.5	The additional information screen of recurring reminders should show whether reminders are usually completed
Reminder insights	1.5	The additional information screen of recurring reminders should show whether tasks are usually completed before or after a reminder
Reminder insights	1.5	The additional information screen of recurring reminders should show a calendar overview of the past/current month, which shows on which days reminders were completed before the reminder, after the reminder, not completed, and on which days reminders were unable to be sent
Reminder insights	1.6	The caregiver app should have an overview of contextual rules that caregivers can apply to reminders

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Table F.1: Formal Software Requirements (Continued)

Reminder insights	1.6	The contextual rule overview should show whether these rules are too strict (if they cause reminders to remain unsent too often), and whether they cause major delays
Reminder insights	1.6	In the contextual rules overview, it should be possible to filter how many of the past reminders are taken into account, so that a recent change in behavior influences the information
Reminder insights	1.6	Each contextual rule should have an additional information screen, showing the name of the rule
Reminder insights	1.6	The additional information screen of the contextual rules should have a calendar overview of the past/current month, which shows for each day whether reminders with this rule attached were completed with no problems, whether the contextual rule caused major delays, whether reminders with the rules remained unsent, or whether the rule was not applied to any reminder on that day.
Reminder insights	1.6	The additional information screen of the contextual rules should show a list of reminders the rule is applied to, and should show for each of them how often the rule caused major delays, and how often the rule caused the reminder to remain unsent and uncompleted.
Reminder feedback	1.10	The caregiver should receive a notification when the system detects an emergency
Could-Haves		
Setting reminders	1.3	The caregiver app shall allow the caregiver to specify whether contextual rules are required (default) or preferences.
Setting reminders	1.1	The caregiver app shall allow the caregiver to set reminders that appear multiple times on one day
Reminder insights	1.5	It should be possible to filter how many of the past recurring reminders are taken into account, so that a recent change in behavior influences the information
Reminder insights	1.5	For reminders that occur multiple times per day, the additional screen of recurring reminders should show how often reminders were completed before the reminder, completed after, not completed, or unsent
Reminder insights	1.6	The contextual rule overview should show a list of automatically detected smart rules
Reminder insights	1.6	It should be possible to convert the automatically detected smart rules to manual rules, which can then be added to reminders of the user's choice
Reminder insights	1.6	It should be possible to remove the automatically detected smart rules
Robot		
Must-Haves		
Receiving reminders	2.1/2.3	The robot shall drive towards the person with dementia when giving a reminder

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Table F.1: Formal Software Requirements (Continued)

Receiving reminders	2.1/2.3	The robot shall stop close to the person with dementia when giving a reminder
Receiving reminders	2.1/2.2	The robot shall verbally tell the person with dementia to follow it
Receiving reminders	2.1/2.2	The robot shall guide the person with dementia to the location where the reminder is to be given
Receiving reminders	2.1/2.2	When guiding, the robot shall occasionally check whether the person with dementia is following it
Receiving reminders	2.1/2.2	When guiding, the robot shall drive towards the person with dementia again if it notices that they did not follow it. The procedure for this shall be the same as the original approach
Receiving reminders	2.1/2.2	After guiding the person with dementia to a screen where a reminder is shown, the robot shall verbally tell the person with dementia to look at the screen
Should-Haves		
Receiving reminders	2.1/2.3	The robot shall make sounds when driving towards the person with dementia
Receiving reminders	2.1/2.2/2.3	When guiding or driving towards the person with dementia, the robot shall avoid obstacles
Safety	2.16	When an emergency is detected by the system, the robot shall drive towards the person with dementia and verbally tell them that it has detected an emergency, and tell them whether people have been notified.
Play	2.17	When the person with dementia is engaged with the robot without a reminder being relevant, the robot shall move around slightly, wag its tail, and make animal sounds, mimicking a pet
Could-Haves		
Receiving reminders	2.1/2.3	The robot shall detect whether the person with dementia notices it after driving towards it
Play	2.17	When the person with dementia is engaged with the robot without a reminder being relevant, the robot shall react to its own name, looking at and driving towards whoever says it
Play	2.17	When the person with dementia is engaged with the robot without a reminder being relevant, the robot shall chase a toy, mimicking a pet
Play	2.17	When the person with dementia is engaged with the robot without a reminder being relevant, the robot shall move around slightly, wag its tail, and make animal sounds, mimicking a pet
Screen		
Must-Haves		
Receiving reminders	2.1	The screen shall show the current reminder
Receiving reminders	2.1/2.2	The current reminder shall be shown on the screen at the location selected in reminder creation

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Table F.1: Formal Software Requirements (Continued)

Completing Reminders	2.4/2.5	The screen shall have a “Done” button
Should-Haves		
Completing Reminders	2.4/2.6	The screen shall have an “Already done” button
Completing Reminders	2.4/2.7	The screen shall have a “Not now” button
Information and Help	2.13	The screen shall show the current time along with the reminder
Information and Help	2.13	The screen shall show the current time when no reminder is being shown
Information and Help	2.12	The screen shall have a ? button, which shows a video explaining the reminder system and robot
Safety	2.16	After an emergency was detected, the screen shall have a button that can be pressed to tell the system the emergency has passed or it was a false alarm
Could-Haves		
Information and Help	2.14	The screen shall show the next reminder when no reminder is being shown
System		
Must-Haves		
Receiving Reminders	2.1	The system shall be able to send reminders
Should-Haves		
Contextual Reminders	2.8	Through the use of sensors, the system should be able to detect whether contextual reminders are active
Contextual Reminders	2.8	If a caregiver selected a (mandatory) contextual rule in reminder creation, a reminder should not be given when this context is active
Contextual Reminders	2.8	If a caregiver selected a prerequisite reminder in reminder creation, a reminder should not be given unless this prerequisite reminder was completed already
Contextual Reminders	2.9	The system should have a heuristic for precise reminder scheduling. This is called the priority score. It dictates which reminder is sent when two are available, the reminder with a higher heuristic value is sent first. The heuristic is a weighted sum of several aspects.
Contextual Reminders	2.9	The time away from the reminder deadline (end of the allowed timeframe) shall be included into the calculation of the priority score.
Contextual Reminders	2.9	The time a reminder takes, as estimated by the caregiver, shall be used subtracted from the reminder deadline for the purposes of the priority score.
Contextual Reminders	2.9	High priority reminders are not included in the priority score system, they should always be given as soon as possible.
Contextual Reminders	2.9	The priority of a reminder (medium or low) shall be included into the calculation of the priority score.

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Table F.1: Formal Software Requirements (Continued)

Safety	2.15	The system should detect emergencies. This requirement should be interpreted broadly, any camera or sensor that is able to detect any emergency can be used.
Could-Haves		
Information and Help	2.14	The screen shall show the next reminder when no reminder is being shown
Contextual Reminders	2.9	The time a reminder takes will be estimated using previous data. If this estimate is accurate enough, it will be used in place of the caregiver estimate for the calculation of the priority score.
Contextual Reminders	2.9	Contextual rules set as preferences by the caregiver shall be included into the calculation of the priority score.
Contextual Reminders	2.9	The system will keep information on the activity of contextual rules over time. This is used to calculate a probability for each future 15-minute non-sliding window of whether a given contextual rule will be active or not.
Contextual Reminders	2.9	The probability of contextual rules being blocking or non-blocking in the future shall be included into the calculation of the priority score, if the calculation is accurate enough.
Contextual Reminders	2.10	The system will keep information on whether reminders are completed or not at given times and considering contextual rules. This is used to calculate a probability that a reminder is ignored at a given time.
Contextual Reminders	2.10	The probability of a reminder being ignored, now and in the future, will be included into the calculation of the priority score, if the calculation is accurate enough.