Diploma Thesis

Context-Related Support of Elderly People During ADLs

submitted by

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Context-Related Support of Elderly People During ADLs

Zielstellung

Kontext. Entlang der aktuell stark bearbeiteten Forschungsfelder der Künstlichen Intelligenz und der natürlich-sprachlichen Interaktion entwickelt sich der Bereich der Robotik fernab von Industrierobotern in schnellem Tempo weiter. Insbesondere die Bereiche der Sozialen Assistenzroboter (SARs) und Mensch-Roboter-Interaktion bieten allerdings noch zahlreiche offene technische und auch anwendungsbezogene Fragen.

Ein zunehmender Bedarf an SARs erschließt sich im Umfeld von Menschen mit Beeinträchtigungen, Senioren sowie im Altenpflegebereich. SARs könnten hier eingesetzt werden, um die Selbständigkeit und Selbstbestimmtheit der Nutzenden zu fördern. Gleichzeitig können solche Assistenzsysteme dazu beitragen, den personell angespannten Pflegebereich zu entlasten.

Bisherige SARs verfügen noch nicht über einen breiten Funktionsumfang, um verschiedentliche Anwendungsfälle abzudecken und die Entwicklung von Software für SARs ist mangels plattformübergreifender Lösungen teuer. Eine besondere Herausforderung ist außerdem die Umsetzung einer gebrauchstauglichen Mensch-Roboter-Interaktion. Idealerweise wird diese benutzendenzentriert entwickelt und erlaubt eine automatische Adaption an die Anforderungen der Nutzenden, den Anwendungskontext und sich dynamisch ändernde Faktoren.

Ein Ansatz zur Lösung der beschriebenen Probleme kann die Entwicklung einer gemeinsamen Anwendungsarchitektur, basierend auf den Methoden aus der Softwarevariabilität, sein. Diese umschließt neben den implementierten Anwendungsfällen auch die Interaktion und ermöglicht daher die erforderliche Adaptivität.

(Fortsetzung Rückseite)

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Projektziel. Ziel dieser Diplomarbeit ist die Beantwortung der folgenden Forschungsfrage: Wie kann ein Assistenzroboter Kontextinformationen nutzen, um ältere Menschen proaktiv bei Alltagsaufgaben (ADLs) zu unterstützen? Zu diesem Zweck baut die Arbeit auf bereits abgeschlossenen Studierendenprojekten auf bzw. nimmt darauf Bezug:

Ermittlung von Alltagsaufgaben (ADLs) im Smarthome:

[1] Hauptvogel, Thomas. Activity Recognition in Smart-Home Environments. Master's Thesis. 2020.

Umsetzung von variablen Prozessabläufen für SARs:

[2] Gröger, Tim. Designing a Configuration Method for Adaptive Assistance Robot Interaction. Term Paper. 2021.

[3] Ziemann, Sophie. Construction of Variable App-Level Process Chains in Android. Term Paper. 2020.

Ablaufsteuerung für SARs:

[4] Ziemann, Sophie. A Concept for Prioritisation and Parallelisation of Activities for Assistance Robots. Research Field Analysis. 2021.

Technologieakzeptanz:

[5] Marangunić, N., & Granić, A. Technology acceptance model: a literature review from 1986 to 2013. Universal access in the information society, 14(1), 81-95. 2015.

Die Unterstützung von älteren Menschen im Haushalt mittels Assistenzroboter kann unterschiedlich aussehen: Einerseits können die Nutzer:innen dem Roboter direkt Aufgaben geben, bei denen Unterstützung gewünscht ist (bspw. Vorlesen von Nachrichten, Finden verlegter Gegenstände), andererseits kann auch der Roboter selbst proaktiv Unterstützung anbieten (bspw. an anstehende Aufgaben erinnern). Im einfachsten Fall wird zeitabhängig Unterstützung angeboten (bspw. Erinnerung an Medikamenteneinnahme). Allerdings sind auch kontextabhängige Unterstützungsangebote denkbar, die u. a. davon abhängen können, welcher Tätigkeit der:die Nutzer:in aktuell nachgeht. Während der Zubereitung einer Mahlzeit in der Küche könnte der Assistent die verbrauchten Lebensmittel auf eine Einkaufsliste setzen, Tipps für gesundes Kochen geben oder ähnliches. Hierfür muss allerdings der Kontext interpretiert werden und auf gebrauchstaugliche Weise eine unterstützende Funktion proaktiv aufgerufen werden.

Schwerpunkte:

- Einarbeitung in die folgenden Themengebiete inklusive Analyse des aktuellen Forschungsstandes; insbes. auch die o. g. Arbeiten [1, 2, 3, 4, 5]:
    - Akzeptanz von (proaktiven) SARs im Umfeld von Senioren (Technologieakzeptanz)
    - Wahrnehmung und Interpretation von für die Aufgabe relevanten Kontextinformationen
    - ADLs und Unterstützung bei ADLs durch einen SAR
    - Umsetzung variabler Abläufe zur Steuerung eines SAR
- Analyse der Anforderungen und Entwicklung eines systematischen Konzepts zur Erfassung und Verarbeitung des benötigten Kontextes sowie des Angebots von relevanten Unterstützungsaufgaben.
- Umsetzung des Konzepts unter Verwendung des Android-basierten Roboters Loomo
- Evaluation und Auswertung des erarbeiteten Verfahrens auf angemessene, wissenschaftliche Weise.
- Dokumentation der Ergebnisse in geeigneter, wissenschaftlicher Form

Confirmation

I confirm that I independently prepared this thesis with the title *Context-Related Support of Elderly People During ADLs* and that I used only the references and auxiliary means indicated in the thesis.

Dresden, 6th December 2021

S. Ziemann

Sophie Ziemann

Abstract

In our ageing society the gap between people in need of care and those who are able to provide it is predicted to widen in the decades to come. Employing assistive technologies, such as assistance robots, is one approach among many to cope with this problem. Assistance robots can ease the workload on care staff and help elderly individuals to remain independent in their own homes for longer.

When developing assistance robots for elderly people, many requirements have to be considered. The robot must for instance be easy to use, affordable and useful. In order to provide additional value to its users, it is beneficial or even crucial for a robot to be multifunctional and adaptive. There are different approaches to adaptivity. This thesis considers how a robot can proactively offer suggestions for activities that are adapted to the current context in order to support elderly people with their daily activities (ADL). For instance, the robot might suggest to turn off the lights in the context of the activity 'Going to Bed' or offer to document the intake of medication.

In this thesis a concept for a recommender system that derives a suggestion from the current context is proposed. The first step in that concept includes gathering context data from different sources into a context database. The most current data is retrieved on a regular basis and used as input for a rule-based classification module to generate an activity recommendation that suits the current situation. In the last step the robot communicates the suggested activity to the user.

The feasibility of the concept is shown by implementing a prototype in the form of an Android app, while the technology acceptance of the idea of a robot proactively suggesting an activity is evaluated through a pilot study. Most participants found the idea highly useful, however, they were not yet fully convinced by the ease of use of such a robot. Overall, the intention to use was moderate to high and can likely be improved even more with further research and extensive communication.

This thesis shows that it is possible to use context information to create an adaptive assistance robot that supports elderly people during their daily activities. It is a first step in the direction of a context-aware robot and identifies a lot of potential for further research.

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The Need for Context-Related Support of Elderly People During ADLs

While the elderly population grows globally [Uni19], a shortage in care staff can be observed [Wor13]. Assistive technologies, such as assistance robots, can be part of a strategy dealing with the challenges of elderly people in the future [Man+99; Esp+16]. This thesis focuses on how robots can support elderly people in their daily lives at home to help them retain their autonomy and improve their quality of life.

Typically, users directly address a robot to assign it a task to execute, and the robot responds immediately. However, to increase the robot's usefulness for the elderly, it can be beneficial if the robot proactively offers the users additional support during their activities of daily living (ADLs). The assistance robot could for example remind users to take their medication or autonomously start doing household chores. While these kinds of tasks can be programmed to be executed at a specific time, other support tasks can be more context specific.

If an assistance robot is able to perceive which activity the user is currently executing [Hau20], it can offer suggestions specific to the current situation. When the robot perceives that the user is preparing food, it may offer to fetch items, set the table, or put used up ingredients on a shopping list. The robot could also detect when the user's behavioural pattern changes. This could be used to for instance remind the user to brush their teeth if they forgot, as well as serve as a tool for medical professionals to observe a change in pattern in the daily schedule of an elderly person which could be a sign for decreasing health [BH02].

Implementing context-based proactive robot support suggestions poses different challenges than simply reacting to user commands. The suggestions should not be too obvious, as in that case the user might have already given the command themselves. The robot's initiative should not be annoying and provide value to be perceived as useful. Additionally, it should be regarded how the robot conveys its message, as the perceived friendliness might impact if users approve of the proactive actions or not.

The goal of this thesis is to examine what kinds of context information is available to an assistance robot and what kinds of support suggestions might provide value to elderly people. A concept for using context information to provide valuable support suggestions is going to be developed, which will then be evaluated regarding user acceptance.

Goals

Research Question *How can an assistance robot use contextual information to proactively support elderly people during ADLs?*

Subgoals

- Describe what kind of proactive robotic support would be beneficial for elderly people.
  - Research the role of assistance robots and assistance technologies in care/for elderly people.
  - Research applications of assistance robots in the care context.
  - Research how robotic assistance with daily activities could look like.
  - Research the acceptance of proactive social assistance robots in the context of elderly care.
- Identify contextual information available to an assistance robot.
  - Research what kinds of context information can be perceived by robots.
  - Research technologies using contextual information in the care context.
  - Research possibilities for robots to interact with external sensors to perceive the context.
- Give an overview of an assistance robot variability management approach.
  - Explain the need for the application of software variability techniques in the assistance robot domain.
  - Explain the basic terminology of software variability.
  - Present earlier student works contributing to an assistance robot capable of adapting its task execution to external factors such as user needs.
- Analyse the gathered background information regarding how they can contribute to solving the research question.
  - Specify the problem to be solved in this thesis.
  - Analyse the requirements for a possible solution concept for the problem.
  - Analyse the previously researched information regarding their suitability to contribute to the solution concept.
- Design a concept to solve the problem described in the research question.
  - Describe how a robot can collect context information.
  - Describe how the context information can be processed to generate relevant suggestions.
  - Select ADLs and provide possibilities for robot support.
  - Provide an interaction schema the robot can use to communicate with the user.
  - Create a workflow for creating support suggestions out of context information.
- Create a prototype for the concept.
  - Create a prototype geared to the Loomo robot that can be used to evaluate the concept in the next step.

- Design a study to evaluate the usability and acceptance of the concept and execute it evaluating the prototype. Interpret the study results.
  - Design the study.
  - Conduct study.
  - Evaluate results.
- Give a summary of the findings of the thesis and an outlook on further possible extensions of the concept.
  - Summarise the thesis.
  - Discuss the found solution and embed it into the context of the already existing body of research.
  - Answer to the research question
  - Give an outlook.

Structure of the Work

Firstly, this thesis gives an insight in the areas of daily activities in the lives of elderly people and contextual information assistance robots may access. The problem to be solved in this thesis is specified and requirements for a solution are formulated. Furthermore, the related work presented is analysed regarding its relevance for solving the problem.

This thesis then develops a concept for using contextual information to proactively support elderly people in their daily lives and a prototype implementing the concept is presented.

The acceptance of the concept will be evaluated through a user study. After gathering and interpreting the results of the evaluation, the thesis concludes by providing a summary as well as an discussion of the findings.

1 Activities of Daily Living and Contextual Information

This chapter firstly gives an overview of daily activities of the elderly and the current state of assistance robotics in elderly care. Moreover it is examined, how contextual information could be used to enhance the abilities of an assistance robot. Lastly, a brief introduction to the field of software variability is given, to provide a basis for understanding the framework into which the result of this thesis will be integrated.

1.1 Activities of Daily Living Among the Elderly

This section provides an overview of the scientific concept of the Activities of Daily Living and gives an insight into what activities take place in the daily lives of elderly people.

Basic and Instrumental Activities of Daily Living Sidney Katz and his team at the Benjamin Rose Hospital introduced the *Index of Independence in Activities of Daily Living* in 1959 [Kat+59]. They wanted 'to create a tool to measure gains and losses in physical function and serve as the basis for making prognoses for patients treated at the hospital for strokes, hip fractures, and other disabling conditions' [NB13].

List of basic ADLs

- Bathing
- Dressing
- Going to toilet
- Transferring
- Continence
- Feeding

Their *Index* was based 'on an evaluation of the functional independence or dependence of patients in bathing, dressing, going to toilet, transferring, continence, and feeding' [Kat+59]. After performing the functional evaluation they noticed a hierarchical pattern of functional dependence in these activities. The first activity in need of assistance was usually bathing. With progressing functional decline the activities dressing, going to the toilet, transferring and continence began to require assistance in that order. In most cases the last activity to become dependent was feeding. In the cases where this pattern did not apply, the order in which the activities required assistance differed in only one function.

The activities considered by Katz et al. are often called basic ADLs (BADL) [BWS90]. Initially designed in relation to fractures of the hip [Kat+59], the concept of the Activities of Daily Living is still widely used today in many different areas. Moreover, the concept evolved and was refined by various researchers [NB13].

One of the most noteworthy extensions are the *Instrumental Activities of Daily Living* (IADL) proposed by Lawton and Brody in 1969 [LB69]. These activities 'are more complex than ADLs and critical for older adults to continue living independently' [NB13].

List of IADLs

- Using the telephone
- Shopping
- Preparing food
- Housekeeping
- Doing laundry
- Using transportation
- Taking medications
- Handling finances

The BADL described by Katz et al. are linked to self-support, while the IADL usually require interaction with objects or other people. Unlike the BADL, which are viewed as habitual and therefore free of cultural influences [Loe+92], social and cultural influence can be observed with IADL [BH02]. Complex composite tasks, such as preparing food, are likely to be influenced by external factors [BH02].

More Daily Activities in the Lives of Elderly People While the scientific concept of ADLs is helpful as a scale to measure functional dependence in a medical context, it only shows a small glimpse of what the daily life of elderly people comprises. The ADLs only relate to a person's basic needs and are distinct from productive activities, such as paid employment, volunteerism, education, as well as from leisure, recreational, and social activities [Mal16].

In many cases, the exact categorisation of a concrete activity can be ambiguous. For instance, activities such as grooming or home maintenance may be performed as part of employment or for oneself. In the same way people might cook or go shopping for fun instead of out of necessity. How an activity would be categorised can hence depend on the context and meaning of that activity for a person [Mal16]. Nevertheless, the exact categorisation of activities is negligible in the context of this thesis. It is more important to get an overview of what activities take place in the daily lives of elderly people in order to determine where robot support can be beneficial.

The following comprehensive list was compiled in an earlier work [Zie21] and is mainly comprised of two different works observing the elderly's daily routines. It makes no claim of completeness, especially in the area of leisure activities, but serves to get an overview of what kinds of activities should be considered when thinking about robotic support with daily activities.

List of Daily Activities of Elderly People

- ***Obligatory Activities***
  - **Activities of Daily Living (ADLs) and Instrumental ADLs**
    - ⋆ Bathing / Showering
    - ⋆ Dressing
    - ⋆ Going to the toilet
    - ⋆ Personal hygiene (brushing teeth, self-care, washing face, continence ...)
    - ⋆ Eating, drinking, snacks
    - ⋆ Preparing food
    - ⋆ Shopping
    - ⋆ Housekeeping (e.g. cleaning, laundry, maintenance, dishes, ...)
    - ⋆ Financial affairs
    - ⋆ Paperwork
    - ⋆ Postal affairs
    - ⋆ Taking medication / medical treatment
    - ⋆ Transferring
  - **Transportation and Being out of home**
    - ⋆ Preparing for going out
    - ⋆ Use of public transportation
    - ⋆ Driving
  - **Resting activities**
    - ⋆ Sleeping
    - ⋆ Taking a nap
    - ⋆ Getting in bed
    - ⋆ Getting up from bed
    - ⋆ Relaxing / Taking a break
- ***Leisure Activities***
  - **Physical activities**
    - ⋆ Taking a walk
    - ⋆ Gardening
    - ⋆ Making short trips
    - ⋆ Sports / Exercise
  - **Mental activities and other hobbies**
    - ⋆ Cultural activities
    - ⋆ Continuing education
    - ⋆ Creative activities
    - ⋆ Reading
    - ⋆ Writing
    - ⋆ Playing games
    - ⋆ Singing
  - **Media consumption**
    - ⋆ Listening to radio
    - ⋆ Watching TV
    - ⋆ Computer use
  - **Socializing**
    - ⋆ Face-to-face conversation
    - ⋆ Phone conversation (audio or video)
    - ⋆ Visiting
  - **Volunteer social engagement**
    - ⋆ Helping family members
    - ⋆ Helping others
  - **Religious activities**
    - ⋆ Religious activities (e.g. prayer, meditation, ...)

The first list that served as a basis for the presented list was published in 1990 by Baltes et al. [BWS90] who wanted to collect data 'describing the everyday lives of the elderly in terms of external components such as type of activities, locations, and companionship' to 'provide a basis for a better understanding of aging processes'. To retrieve said data 49 mobile and independently living elderly people with a mean age of 72 were asked to record their daily activities over a six months period. As this paper was published in 1990, their list lacked some activities related to modern technology, such as computers or smartphones and included others that would can be considered a little outdated, such as needlework which they considered a BADL/IADL.

To remedy the shortcomings of the compilation of activities by Baltes et al., a second paper was considered when compiling this comprehensive list. In 2017 Chung et al. 'evaluated the value of workflow analysis supported by a novel visualization technique to better understand the daily routines of older adults and highlight their patterns of daily activities and normal variability in physical functions' [COD17]. They compiled their list of activities by examining self-reported activity diaries from six community-dwelling older adults for 14 consecutive days.

For the final list [Zie21] some of the outdated activities such as needlework were eliminated and some modern activities that have not yet been included, such as making video calls, were added. There is however no claim of this list being complete. Daily activities are very personal and can vary due to personal preference, accessibility of an activity and ability of a person. Especially the category of Leisure Activities is not exhaustive.

1.2 Assistance Robots in Elderly Care

It has long been known that the tense staff situation in the care sector will only worsen in the decades to come [Wor13], while at the same time the percentage of older people in our societies increases [Uni19]. It is hence wise to look into how technology and assistance robots in particular can play a role in easing the workload for care staff and increasing elderly people's quality of life.

In this section it will be examined why there is a need for assistance robot support for the elderly and where it can be beneficial. Subsequently, an overview over the state of research in the domain of assistance robots for elderly people is given. Finally, this section takes a look at how robotic solutions are currently perceived in the care context and how acceptance can be measured and improved.

The Need for Assistance Robots in Care In 2019 the United Nations declared population ageing a global phenomenon [Uni19]. They predicted the number of older persons, meaning people over the age of 65, to double by 2050. The percentage of older people in the world's population grew from 6 per cent in 1990 to 9 per cent in 2019 and is expected to reach 16 per cent in 2050.

At the same time, care services are overwhelmed by the constantly rising demand [MEC20]. In 2013 the WHO reported a global shortage of more than seven million health workers and predicted this number to rise to nearly 13 million by 2035 [Wor13]. These numbers clearly demonstrate the importance of developing concepts to reduce the workload for care staff.

Technology, such as assistance robots, can support people in many areas of care. They can support people in maintaining their independent life at home, which is preferred by most elderly persons, which reduces the number of people living in care facilities. Though for the most part people prefer care provided by human professionals, most wish for additional assistance [Kac+14].

Lastly, assistance robots can not only potentially enhance the elderly's well-being, they can also decrease the workload of caregivers [Kac+14].

1.2.1 A Definition for the Term Assistance Robot

Even though the term assistance robot is often used, there is no common definition for it [FM05; Neu16]. In this section, multiple approaches to defining what makes an assistance robot in the context of this thesis are going to be presented.

Firstly, definitions provided by the International Organization for Standardization that correspond with the image of an assistance robot in this thesis are going to be considered. Foremost, the term robot is defined as following:

Definition 1: Robot

'Actuated mechanism programmable in two or more axes with a degree of autonomy moving within its environment, to perform intended tasks.' [Int12]

Subsequently, the definition for the term *service robot* narrows down the area of application for an assistance robot.

Definition 2: Service Robot

'*Robot* that performs useful tasks for humans or equipment excluding industrial automation applications.' [Int12]

More specifically, the type of assistance robot referred to in this thesis can be classified as a personal care robot, according to this definition:

Definition 3: Personal Care Robot

'*Service robot* that performs actions contributing directly towards improvement in the quality of life of humans, excluding medical applications.'
'This might include physical contact [...] with the human to perform the task.' [ISO14]

The standard ISO 13482 describes typical types of personal care robots: mobile servant robot, physical assistant robot and person carrier robot [ISO14]. From these three, the mobile servant robot is the one most relevant for this thesis as it matches the idea of an assistance robot referred to in this thesis the most.

Definition 4: Mobile Servant Robot

Personal care robot that is capable of travelling to perform serving tasks in interaction with humans, such as handling objects or exchanging information. [ISO14]

Heerink et al. [Hee+10] and Orha et al. [OO12] present an approach that groups assistive robots into social and non-social assistive robots (see Figure 1.1). The non-social category includes robots providing assistance in rehabilitation [OO12], while the social category can again be divided into two areas: service robots and companion robots. Companion robots are employed for social

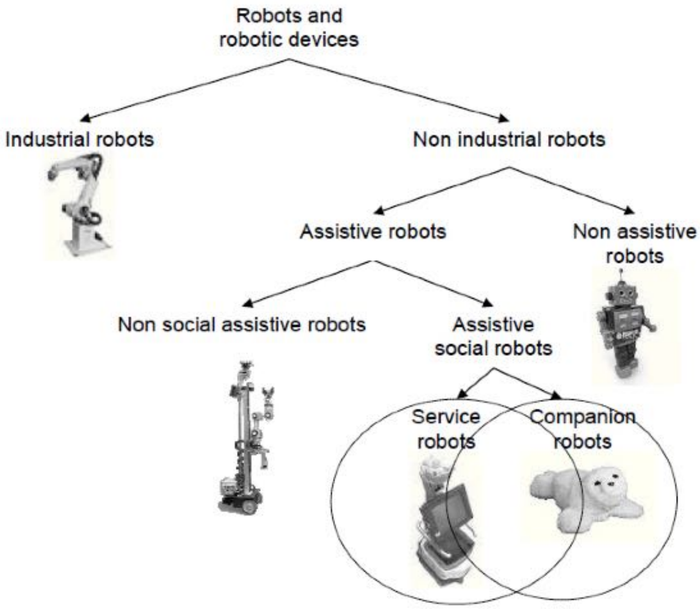


Figure 1.1 – A classification of robots and robotic devices [Hee+10; OO12]

companionship or robot assisted therapy. An example for this category is the robot seal Paro[1], which is used in therapy for dementia patients. Socially interactive service robots on the other hand offer physical and cognitive assistance to the users. Their main purpose is to carry out any kind of service task for the user. This type of robot is close to matching the idea of an assistance robot referred to in this thesis.

Many robots are focused on doing one thing right [SKB19], but the end goal of this thesis is an adaptive robot with a broad function range at an affordable price that is accessible to elderly people and improves their well-being and quality of life. Such an assistance robot should play the role of the servant as well as the companion and can support people by executing tasks for them (service) as well as by communicating with them and answering to their social needs (companion).

Figure 1.2 – The Evolution of Care-o-Bot. [Kit+15]

[1] `http://www.parorobots.com/`

1.2.2 State of the Art

In the year 2000 the robotics guru Joseph Engelberger predicted that a multitasking robot caregiver for older people would be developed, manufactured and marketed [Eng00]. Since then, many approaches inspired by this vision have been presented [VP20].

The German Care-O-Bot (see Figure 1.2) for instance was one of the first ones. The first version was published in 1999 [SM99], the second followed in 2004 [GHS04] and the third in 2009 [Rei+09]. The latest generation, Care-O-bot 4, was introduced in 2015 and 'was designed as a gentleman robot that allows the users to relate emotionally and socially with it' [Kit+15]. With a price close to € 300,000 [Ack15] the Care-O-Bot 4 did not become a commercially available service robot, but was provided as a technology development platform for research institutions [VP20].

Further attempts on developing a multitasking domestic robot for older people were made, for instance by Mitsubishi. They released the yellow 3-foot domestic robot Wakamaru in 2005 for the Japanese Market [Rob07], but due to the high price of $ 14,000-15,000 and weak demand it was not advanced beyond the first model [VP20].

Many more robots were developed in a quest to fulfil the vision of an omnipotent home robot, such as Hector, a mobile assistive robot and smart home interface, created by the CompanionAble Project[2] funded by the EU Seventh Framework Program, or the Hobbit project[3] [Fis+14], which was funded by the EU as well. Neither of these approaches have resulted in a commercial product [VP20].

Figure 1.3 – Wakamaru[4](left), Hector (middle) [Sch+13], Hobbit[3] (right)

Though it seems as if the pursuit of the ultimate multitasking robot caregiver from Engelberger's visions has not yet led to a commercially available product, there are robotic solutions designed for the care sector that are available to date. These solutions do not offer the expected range of a multitasking robot, but instead are usually focused on doing one thing right.

[2] `http://web.archive.org/web/20180326173509/http://companionable.net/`
[3] `http://hobbit.acin.tuwien.ac.at/`
[4] `https://robots.ieee.org/robots/wakamaru/`

Shishehgar et al. [SKB19] conducted a systematic review on the effectiveness of various robotic technologies in assisting older adults in 2019. They identified nine types of robot technology:

- Companion robots
- Telepresence robots
- Manipulator service robots
- Rehabilitation robots
- Health monitoring robots
- Reminder robots
- Domestic robots
- Entertainment robots
- Fall detection/prevention robots

The researchers found that the most used and most effective robots were companion robots, that can address memory cognitive impairment problems, followed by telepresence robots, which usually address social isolation and loneliness problems. However, research gaps were identified in the area of the activities of daily life, which would enable older adults to remain in their homes longer.

As for current trends in the field, in their systematic review, analysing papers published between 2013 and 2018, Allaban et al. [AWP20] identified three major themes in the area of robotics research in support of in-home care for older adults: *ambient assisted living* (AAL), *robot ecosystem*, and *social interaction*. Papers in the category of *robot ecosystems* usually proposed novel designs or algorithms for robots in the context of elder care, and papers regarding *social interaction* focused on reducing social isolation.

They divided the AAL category into three subcategories. Papers in the *smart home* category used wireless sensor networks to improve the quality of life of older adults. Papers with the theme of *human activity recognition* (HAR) reviewed different methods for analysing older adults' activity patterns. The last subcategory was *physical support tools*, which referred to papers regarding the development of robotics enhanced tools, such as a smart walker or an intelligent wheelchair.

While the robot from Engelberger's vision does not exist yet, researchers are working on finding solutions to employ robot platforms to aid elderly people. There are many different robots used in research, with many teams even developing their own. Going forward three exemplary robots used in research regarding the support of elderly people are going to be presented. This selection is by no means exhaustive.

TIAGo The PAL Robotics TIAGo robot[5] introduced in 2016[6] follows a modular approach and is configurable to fit the user's specific requirements (see Figure 1.4). The robot's height can be adjusted between 110 and 145 cm. The goal was to 'deliver a robust platform for research that easily adapts to diverse robotics projects and use cases'[7]. As the TIAGo robot is highly customisable, it is hard to name a concrete price for the robot. On their website, customers can configure the robot and request a quote[8]. To give a reference point, in 2017 a new TIAGo Steel with one arm cost €49,900[9]. In a 2019 interview the product manager of the TIAGo robot at PAL Robotics stated the starting price for the latest model, the two-armed TIAGo++, being around €90,000. Though the

[5] `https://pal-robotics.com/robots/tiago/`
[6] `https://robots.ieee.org/robots/tiago/`
[7] `https://www.therobotreport.com/tiago-robot-pal-robotics-ready-two-armed-tasks/`
[8] `https://pal-robotics.com/robots/tiago/#tiago-configurator`
[9] `https://www.eu-robotics.net/robotics_league/news/press/call-for-loan-for-tiago-steel-robots.html`

Figure 1.4 – A basic TIAGo configuration (left[5]) and a person interacting with TIAGo (right[11])

final price depends on the concrete configuration, devices, computer power, sensors and extras that each client can choose for their robot[7], these prices suggest that this robot might not be financially accessible to many end users.

Currently, TIAGo is being used for research in artificial intelligence/machine learning, human-robot interaction, manipulation, perception, navigation and motion planning[5]. Moreover, the fields of application include Ambient Assisted Living and Healthcare, Human-Robot Interaction, Smart Cities, IoT, Industry 4.0, CyberSecurity, Benchmarking and many more[10]. Due to its modularity it is well suited as a research platform that can adapt to the specific research needs. Projects in the area of elderly care/healthcare include for instance the EnrichMe project and the SHAPES project.

The *EnrichMe*project[12, 13] created an application for the TIAGo robot that provides support for elderly individuals suffering from dementia during their daily routines. It ran from 2015 to 2018. The robot would remind users of appointments and medication and suggest meals supporting a balanced diet. It could also locate lost objects and engage the users through mental and physical exercises. Through the data collected by the robot, caregivers and medical staff were enabled to track the progression of the cognitive impairments and detect emergencies. The feedback was positive as participants felt they gained autonomy in their routine and had a more optimistic outlook of the future. Most users engaged with the activities proposed by the robot which lead to them becoming more physically and mentally active.

Project *SHAPES*[14] (Smart & Healthy Ageing through People Engaging in Supportive Systems) 'aims to create the first European open Ecosystem enabling the large-scale deployment of a broad range of digital solutions for supporting and extending healthy and independent living for older individuals who are facing permanently or temporarily reduced functionality and capabilities'[15]. It is set to run from 2019 to 2023[16]. The PAL Robotics team contributes to the project by adapting

[10] `https://pal-robotics.com/collaborative-projects/`
[11] `https://blog.pal-robotics.com/innovation-radar-highlights-pal-robotics-breakthrough-developments-in-eu-funded-projects-part-i-healthcare/`
[12] `https://cordis.europa.eu/project/id/643691`
[13] `https://pal-robotics.com/collaborative-projects/enrichme/`
[14] `https://shapes2020.eu/`
[15] `https://pal-robotics.com/collaborative-projects/shapes/`
[16] `https://cordis.europa.eu/project/id/857159`

their TIAGo and ARI robots[17] to be used with the platform 'in order to help with mobility and/or rehabilitation exercises, engage in social activities, explore the use of the robot manipulator, and to be able to assist in specific tasks'[15].

Figure 1.5 – Pepper[19] leading an exercise class in a Japanese nursing home[18]

Pepper The 120cm tall Pepper[19] (see Figure 1.5) was the world's first full-scale social humanoid robot to be offered to consumers that was able to recognise faces and basic human emotions. It was optimised for human interaction enabled through conversation and its touch screen[20]. It was developed in 2014 by by the French robotics company Aldebaran Robotics which in 2016 became SoftBank Robotics[21].

While it was initially designed for a business-to-business (B2B) application in SoftBank stores, it has since been used in business-to-consumer (B2C), business-to-academics (B2A) and business-to-developers (B2D) contexts [PG18]. Currently SoftBank Robotics state on their website[22] that their Pepper and NAO robots, a 58cm tall humanoid robot[23], are used in a broad range of industries such as healthcare, retail, finance, government, tourism as well as education and research. In terms of elderly care SoftBank states that 'Pepper can elicit simple and individual instructions for activities such as exercise and enables processing and sharing of medical results to the medical professional enabling effective monitoring of elderly health'[24]. Moreover, the telepresence feature enables elderly people to communicate with their families and friends. They list typical use cases for the Pepper robot in healthcare to be fulfilling the roles of a medical receptionist, communicator, patient service representative, data generator, edutainment, health assistant, brand ambassador or sales associate[24]. Moreover, the Pepper robot is a popular research platform. In

[17] https://blog.pal-robotics.com/supporting-healthy-living-for-older-individuals-with-project-shapes/
[18] PASCAL MEUNIER/EYEVINE https://www.thetimes.co.uk/article/robot-carers-for-the-elderly-are-now-a-reality-in-japan-but-do-we-want-them-here-mw8zpw0zd
[19] https://www.softbankrobotics.com/emea/en/pepper
[20] https://robots.ieee.org/robots/pepper/
[21] https://www.softbankrobotics.com/emea/en/company
[22] https://www.softbankrobotics.com/emea/en
[23] https://robots.ieee.org/robots/nao/
[24] https://www.softbankrobotics.com/emea/en/industries/healthcare

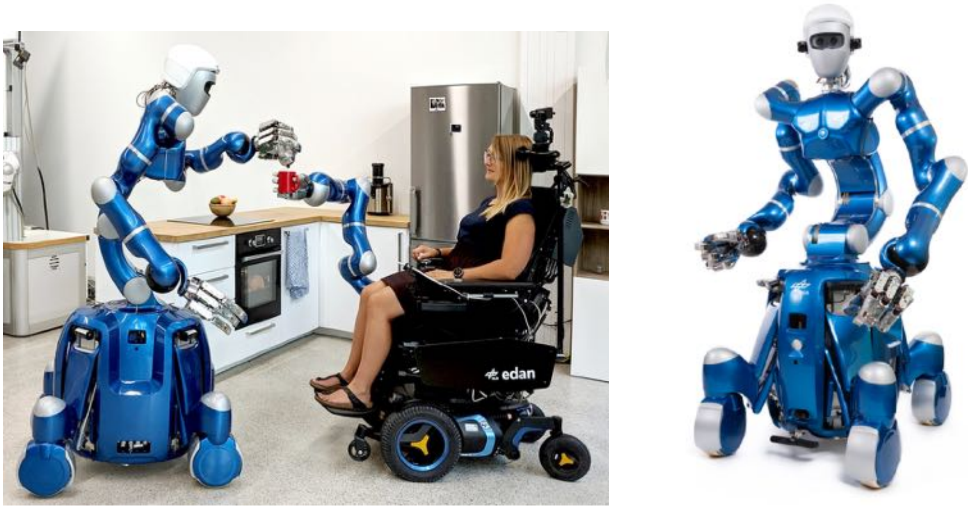


Figure 1.6 – The humanoid robot Rollin' Justin[28,29]

the area of elderly care Pepper has been used lately in research regarding for instance rehabilitation [Sat+20; Tan19], supporting people with dementia and their carers [RE20; MFM20; Sat+20], examining the acceptance of robots in elderly care [PM19; Tak+21; Kha+21], the reality of cohabitation with robots[Fat+20] or human-robot interaction in general [Car+20].

Rollin' Justin The 1,91m tall humanoid service robot Rollin' Justin[25] (see Figure 1.6) was developed by the German Aerospace Center (DLR) in 2008. While in the past this robot had mainly been used in the area of space research, the project SMiLE[26] (Service Robotics for People in Life Situations with Disabilities) [Vog+18] aims to employ this robot to 'provide people with disabilities and people in need of care with effective daily support'[26]. The initial project ran from 2017 to 2018 and has been continued as project SMiLE2gether[27] which is scheduled to run until 2024. The researchers state that their project goal is to bring the technology to a level that allows testing in realistic environments such as hospitals and age- or disabled-appropriate housing[27]. This project shows a lot of potential for producing a multifunctional robot that helps elderly people and people with disabilities in their daily lives, however it is still in its early stages and factors such as affordability can not yet be considered.

Concrete Suggestions for Robotic Support

In order to determine how robotic support and context information can be brought together, it is important to get an impression of the situations in daily life in which assistance robots can support older people.

Esposito et al. compiled an overview of technologies that can improve the elderlies' quality of life [Esp+16]. They focus on seven main service areas and provide possible services a robot

[25] `https://www.dlr.de/rm/desktopdefault.aspx/tabid-11427`
[26] `https://www.dlr.de/rm/en/desktopdefault.aspx/tabid-12424`
[27] `https://www.dlr.de/rm/en/desktopdefault.aspx/tabid-14351`
[28] `https://www.dlr.de/rm/en/desktopdefault.aspx/tabid-14351#gallery/35850`
[29] `https://www.dlr.de/rm/desktopdefault.aspx/tabid-11427/#gallery/27298`

might perform for users as well as technical solutions for each area. The service areas are: social interaction, information, safety, health, leisure, physical support and mobility. The list of possible services for each area can be found in the Appendix (see A.1.1). For most categories they provide three to five suggestions, except for physical support where 14 possible services are proposed and mobility which only includes two activities. As this list is based on identified service areas, the suggestions for robotic support compiled here focus more on fulfilling the overall goals of employing an assistance robot than under what context conditions a specific recommendation should be made.

Another list of suggestions for robotic support originates from a survey conducted by this author in an earlier work to find out about expectations elderly people and people working with the elderly have regarding assistance robots have [Zie21] (see A.1.2). From a comprehensive list of daily activities in the lives of elderly people (see Section 1.1) 27 were chosen for the survey. The participants were asked to give a rating on a five-point scale from very well to not at all regarding how well they can imagine being supported by an assistance robot during a particular activity. Following that question the participants could provide ideas on how this robotic support could look like for the activities they had given a well or very well rating.

The resulting list of suggestions for robot support is quite extensive. To facilitate filling out the survey, two or three activities have been grouped together, which resulted in 12 broad categories where people could provide input. Most categories contain four to nine suggestions, except exercise and games which contains 10 suggestions and emails/text messages and phone/video calls which both only contain three items. As this list is based on identified ADLs it is easy to gain an insight in which suggestions might be perceived useful under which context circumstances.

1.2.3 Acceptance of Assistance Robots in the Context of Elderly Care

Having established that there is a need for assistance robot technologies (see Section 1.2) and that even though the ultimate robot has not yet been created, there are some robotic solutions for the elderly available, it is necessary to have a look at the acceptance of assistance robots. There are two aspects to this: Firstly, how do people perceive the existing solutions and secondly, how do people feel about the general idea of an assistance robot.

The existing solutions are not perceived as sufficient by most researchers, Rebitschek et al. for instance state that they are not yet good enough [RW20]. Pino et al. [Pin+15] state a 'mismatch between solutions and needs' offered by current robot models in their qualitative interview study. In the same way Martinez-Martin et al. [MEC20] conclude in their review paper, that current robots do not cater to all of the needs elderly people and people with disabilities have. However, they find the prospect highly promising.

When looking at whether there is at least a high level of acceptance regarding the idea of assistant robot technology in elderly care, one is again disappointed. Rebitschek et al. found that there is currently a lack of acceptance in this area [RW20]. They discovered that especially people above the age of 70, women and people with an education in the nursing or medical field are more critical of robots in care.

In order to increase acceptance one must not only prove the benefits of assistive robots in care to all stakeholders, including the elderly themselves as well as care-givers, relatives, policymakers or nursing home managers [Kac+14; Pin+15], but also clearly communicate their intended role as a possible component of elderly care [RW20].

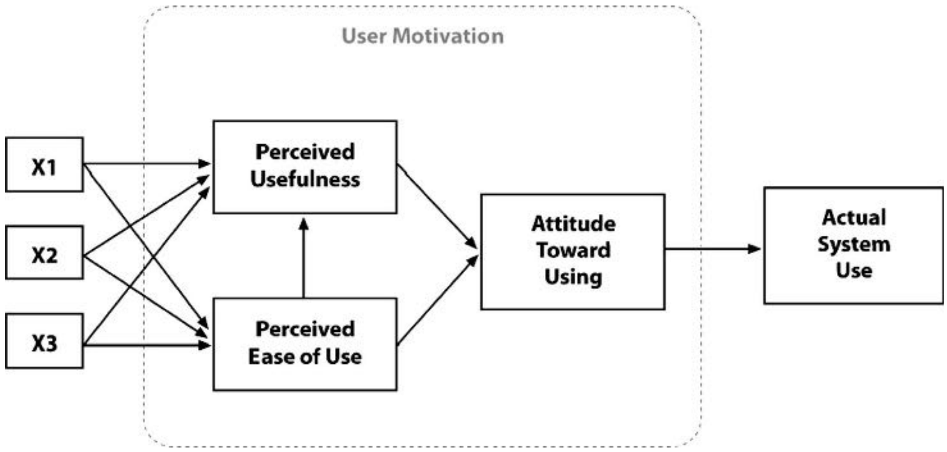


Figure 1.7 – The original TAM [Dav86]

1.2.4 Measuring Acceptance - The Technology Acceptance Model TAM

The acceptance of robots and other technology is influenced by many factors [SZ06], such as peoples' initial positive emotions and attitudes [Bro+10] or whether the users' needs are fulfilled [Mit+14]. It has been shown, that the perceptions of robots play an important role in predicting the acceptance of robots and other technologies [Hee+10; Sta+10].

The most prevalent model for predicting technology acceptance is the Technology Acceptance Model (TAM) proposed by Davis in 1989 [Dav89]. The original version of this model suggests that user motivation towards a technical system can be explained by three factors: perceived ease of use, perceived usefulness, and attitude toward using (see Figure 1.7) [Dav86]. Perceived ease of use is defined as 'the degree to which a person believes that using a particular system would be free of effort', while perceived usefulness was defined as 'the degree to which a person believes that using a particular system would enhance his or her job performance' [Dav89].

Over the years the model evolved and various extensions were developed [MG15]. Davis and his associates found that the attitude factor 'did not fully mediate the perceived usefulness and the perceived ease of use' [MG15]. Removing this factor resulted in the simplified version called parsimonious TAM [Dav89]. Nowadays, the TAM 2 model introduced in 2000 by Davis and a colleague is often used (see Figure 1.8) [VD00], but even more extensions by various authors exist [MG15].

Though it emerged from the field of psychology, TAM and its modifications are nowadays widely used in fields such as information and computer technology as well as learning and teaching. Furthermore, it has been shown, that the TAM factors perceived ease of use and perceived usefulness are good predictors of robot acceptance [EFR09; Bro+12].

This thesis aims at making a contribution towards the acceptance of assistance robots by providing proactive context-based support to the users and thus increasing the perceived usefulness.

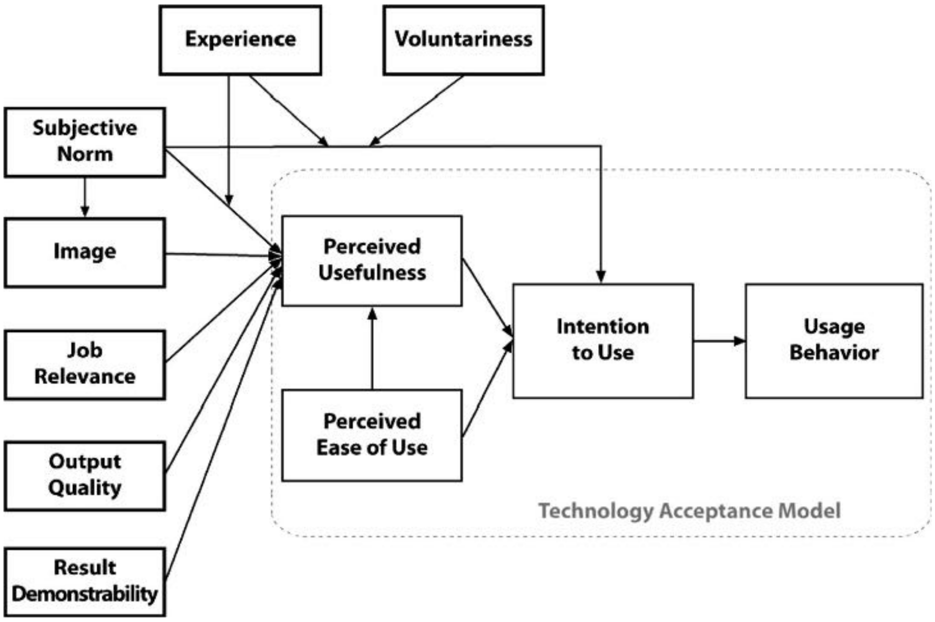


Figure 1.8 – The updated TAM2 [LIC03]

1.2.5 User Experience, Usability and the Interaction Principles

Mlekus et al. proposed an extension to the TAM, the User Experience Technology Acceptance Model, to include user experience characteristics as technology-inherent determinants for the TAM to create 'starting points to design better technologies' [Mle+20]. They showed that 'a technology that fulfills the UX criteria output quality, perspicuity, dependability, and novelty is more likely to be accepted and consequently used' [Mle+20].

Having established that the user experience (UX) influences the technology acceptance, the term should be defined. The standard ISO 9241-11:2018 explains that the UX encompasses the 'user's perceptions and responses that result from the use and/or anticipated use of a system, product or service' [Int18]. One factor that influences the experience a user has with a system is the usability of that system. In order to improve the UX, the usability should be increased [Int18].

Usability is defined as the 'extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' [Int18]. In this context effectiveness means 'the accuracy and completeness with which users achieve specified goals' [Int20], efficiency encompasses 'the resources used in relation to the results achieved' [Int20] and satisfaction describes 'the extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations'[Int20].

One way to support the usability is adhering to the interaction principles [Int20]. They can be used as general goals when designing and evaluating interactive systems and aim at identifying key impacts on usability. The standard ISO 9241-110:2020 elaborates that the system-user interaction can affect the three components of usability. Some interaction principles may only mainly affect one of the components, while other influence all three [Int20]. In the next chapter the interaction principles will be used to develop the requirements for a context-aware assistance robot that proactively offers support to elderly people.

Interaction Principles

- **Suitability for the user's tasks**
  - Identifying suitability of the interactive system for a given task
  - Optimising effort in task accomplishment
  - Defaults supporting the task
- **Self-descriptiveness**
  - Presence and obviousness of the information
  - Clear indication of processing status
- **Conformity with user expectations**
  - Appropriate system behaviour and responses
  - Consistency (internal and external)
  - Changes in the context of use
- **Learnability**
  - Discovery (of information and controls that users are looking for)
  - Exploration (of information and controls that users have discovered)
  - Retention (of information about the system)
- **Controllability**
  - Interruption by the user
  - Flexibility
  - Individualization
- **Use error robustness**
  - Use error avoidance
  - Use error tolerance
  - Use error recovery
- **User engagement**
  - Motivating the user
  - Trustworthiness of the system
  - Increasing user involvement with the system

1.3 Contextual Information

In its simplest form, a robot is a machine which runs a program. For many machines it suffices that they execute their task without any knowledge of their surroundings. A coffee maker will prepare coffee when a button is pressed, just as a simple vacuum cleaner sucks up dust when turned on. They either do not require any information about the context they are in, the coffee maker works the same no matter where it is deployed, what the outside temperature is or who uses it, or because there is a human, who is able to observe the context, operating it. In the case of the vacuum cleaner for instance, a human decides to use it when they observe that the floor is dirty.

This does not suffice for the robotics domain, where 'the identification and exploitation of contextual knowledge plays a key role' [Blo+16]. Nigam et al. state: 'A robot requires: the ability to understand its inputs, correctly identifying the current situation it and its interactants are in, and the ability to perform contextually appropriate actions.' [NR15]

In this section the term context is defined and the types of context information available to assistance robots are described. Moreover, an overview of existing works regarding the use of context information for assistance robots is given.

1.3.1 Defining and Formalising Context Information

Before describing what types of contextual information is available to robots, the term context should be defined for this thesis. There is no universal definition for the term context [Blo+16] and many existing definitions are very specific or use examples or synonyms to define context [Dey01]. This makes it difficult to apply those definitions to other domains than the one they were designed for. This thesis will use the following definition:

Definition 5: Context

> 'Context is any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.' [Dey01]

This definition does not use synonyms or examples to define context, which makes it easier to apply it universally. As it is consciously held rather unspecific, it is 'easier for an application developer to enumerate the context for a given application scenario. If a piece of information can be used to characterise the situation of a participant in an interaction, then that information is context' [Dey01]. As the goal of this thesis is to find a way for robots to use context information available to them, the entity referred to in this definition is the assistance robot itself and context is every bit of information describing its situation.

Menezes et al. propose a more domain-specific definition of context while researching the role of context information in human-robot interaction. They say: 'Context is the set of information that is relevant, affects or constrains how some action is taken, without being the at center of interest of the search or action' [MQD14]. This already takes into account what the robot can do with the context information and only considers information that influences a robot's actions as context. It can however be argued, that not every available context information must necessarily influence the robot's actions, even though it theoretically could.

The robot's exact position in a room is a kind of context information, as it describes the robot's situation. It is relevant context when navigating, however, if the user asks the robot a question it does not matter where the robot is, it can answer from anywhere. In the same way the noise level in a room might influence how loud the robot has to speak to be heard, but it is not relevant information when driving somewhere and will hence not influence that action. The developer can also choose to ignore context information, as this might be easier and quicker to implement. If the robot always speaks at the same level of volume the context of noise level still exists, the robot just disregards it. Hence the definition for the term context by Menezes et al. is not applied in this thesis.

A robot whose actions are influenced by context information can be called *context-aware*, according to the following definition by Dey:

Definition 6: Context-Awareness

> 'A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task' [Dey01]

Referring to this definition, the goal of this thesis is working towards designing a context-aware assistance robot.

In order to integrate context into the decision process of a robot, the context information should be formalised in some way. Menezes et al. [MQD14] explain that a common approach for representing context information is to use explicit descriptions about the environment conditions and what behaviours should be executed in their presence. They elaborate that complex knowledge domains however need more general and flexible representation besides explicit representations (e.g. first-order logic). The authors state that ontological approaches are partially addressing this problem, but context models still lack a formalism that promotes an objective representation of information and allows the application of generalized algorithms.

They conclude that ‘there is still an open challenge to establish a well founded formalism that can represent context information, which can adjust to its dynamic nature’ [MQD14]. Moreover, it is unlikely that a universal formalism can be found, as ‘the formalization of “context” depends on the actual implementation’ [Blo+16].

1.3.2 Types of Contextual Information

According to Definition 5, any information to characterise the situation of an entity is context. As there are countless entities (persons, places or objects) in the world, there are also countless types of context. Only when one chooses a domain and an entity, one can try to enumerate the context information available and relevant for that entity. For this thesis, the relevant entities are assistance robots. In this section, categories that can be used to summarise context information are going to be presented.

A classification for context knowledge was proposed by Turner in 1998 [Tur98]. In their paper they present an approach to context-sensitive behaviour called CMB (context-mediated behavior) that they implemented for an intelligent controller for autonomous underwater vehicles. In their definition of context they identify three categories, environmental information, mission-related information and agent self-knowledge. Contextual information is defined as the sum of these three contributions.

Bloisi et al. [Blo+16] elaborate on this taxonomy and explain what these categories mean for robots. *Environmental knowledge* formalises environment-dependent data that does not directly depend on the robot’s actions. It can be perceived through the robot’s sensors and is derived from the current status of the scenario the robot is in (e.g. presence of people or obstacles). These information about the external world are not crucial for fulfilling the robot’s immediate goals, but they contribute to an ‘exhaustive and clear modeling of the typical scenarios’ [Blo+16]. They can be used to detect relevant situations and adapt the robot’s behaviour to these situations. Environmental knowledge is for instance critical for any navigation application. Important parameters could be trafficability, the presence of obstacles, terrain conditions or illumination conditions.

Then there is what Turner calls mission-related information and Bloisi et al. call *task-related knowledge*. This kind of information is inflicted by the mission specifications. The operating conditions and task constraints, such as time constraints, priorities, and locations, influence the execution of the task. They do not modify the outcome or the requirements, but the goal is to increase robustness, efficiency and overall performance. Bloisi et al. use the example of a coordinated team of robots that have been tasked to search for a lost object. In that case, the robots can execute the task in various modalities by taking into consideration the current day time, the location where the robots are searching for the item, information processed by the other team-mates, the known locations where a particular object normally is or further information gathered during the search (e.g. a robot can receive information regarding where the object has been detected the last time). This information can 'drastically [influence] the task execution (e.g., ordering) such as sensor and mission management, and thus, the performance of the system (e.g., timeliness, accuracy)' [Blo+16].

Lastly, there is *self knowledge*. Bloisi et al. call this '[an often] underestimated aspect in robotic systems' [Blo+16]. This kind of context is derived from the robot's status and its internal representation of the surrounding environment. While executing a task the robot status and reliability of its decisions can be evaluated. In the previously mentioned example of the multiple robot search it is imaginable that one of the robots self-diagnoses a malfunction or a low battery level and conveys its status to the rest of the team. The team can then treat the information coming from that robot as unreliable until this issue is resolved.

Another classification of context information for assistance robots was proposed by Rhee et al. [RLK12]. They designed an ontology-based knowledge model for a personal service robot to provide personalised services based on the current context and user preferences. In their paper they identify four types of contextual knowledge that are 'closely interlinked with each other, providing richer semantic knowledge':

- '*Environmental context* describes the knowledge on the surrounding environment. It consists of spatial information on the surrounding environment, and context knowledge derived by situational events.' [RLK12]

  This category matches with the one in Turners taxonomy [Tur98]. Environmental information can be gathered with the robot's own sensors. Many assistance robots for instance come with sensors such as cameras or distance sensors to be able to move in a space without colliding with obstacles. A robot's perception could also be extended by connecting it with other sensors installed in the living space.

- '*User preference knowledge* describes each user's attributes and preferences on other types of knowledge.' [RLK12]

  Knowledge about the users is not mentioned in Turners taxonomy. The reason for that might be that their focus was not on robots that directly interact with humans as assistance robots do. An assistance robot can have access to a database containing information about the user that were initially provided or have been collected over time and are stored in user profiles.

- '*Application-specific context* represents available devices and their settings, and the tasks (services) they can perform.' [RLK12]

  This category most closely relates to Turners self-knowledge, but goes further in including all possible devices in the robot's network. A robot can be part of an robot ecosystem [AWP20] or an Internet-of-Robotic-Things, as Simoens et al. call it [Sim+16]. Connecting an assistance robot to a network of sensors or a smart home environment extends its ability to observe the context many times over. Each devices' self-knowledge, such as availability or battery status, their settings and abilities, belongs to this type of context.

- '*Data-centric context* covers various objects and their attributes, both physical objects such as books or cups, and non-physical contents such as music or video.' [RLK12]

  This is the most unspecific category as it encompasses a multitude of imaginable material and immaterial objects and contents that exist in the robot's surroundings. On top of that, with internet access a robot could gain access to third-party services and address any public interface, to retrieve data centric context such as weather information.

The two classifications presented each have a different focus. While both mention environment information, Turner focuses more on the execution of task and includes task-related context, while Rhee et al. focus more on the assistance robot domain, which is why user preference knowledge is included. They also mention data-centric context, which can also not be clearly sorted into Turners categories. Combining these two approaches leads to the following categories of contextual information:

- Environmental context
- Application-specific knowledge
- User preference knowledge
- Task-related knowledge
- Data-centric context

Having established the broad categories of context, the next step includes specifying what information each category encompasses, especially with regard to this thesis. As this analysis is a personal contribution it will take place in the next chapter (see Section 2.1.1 and Section 2.1.2).

1.3.3 Related Work

In this section, some areas of research regarding the inclusion of context information in the domain of assistance robotics is going to be presented.

Context-aware navigation Context information can be used to determine the position of the robot and plays an important role in robot navigation. De Lucca Siqueira and de Pieri [LD15] propose a framework for intelligent navigation of mobile robots that uses environmental context knowledge to influence the decision making process. They link context information with the robot trajectory, which they state other context-aware systems failed to do. Their proposed framework is founded on three main concepts: 'context (information about the agent and the environment), semantic trajectory (a concept model to organize and linking [*sic*] the context information with the agent movement) and behavior tree (a decision making model that defines the proper behavior of the agent based on the context)' [LD15]. Experiments showed that their approach enables them to implement intelligent navigation for a patrol robot based on its energy level. They compute new context information from the stored data which results in a more complete and complex behaviour tree. This improves the efficiency of the application.

Internet-of-Robotic-Things Sensors and wearables can be used to gain knowledge about the context and activities a person is in [Lee+14]. Many of them are employed in smart home environments, but so far, the acquired information 'is mainly applied in intelligent mobile and cloud-based software applications', while 'the reverse path from the cyber to the physical world remains far less exploited' [Sim+16]. Examples for existing applications include automation algorithms controlling thermostats or light armatures, as well as service robots such as vacuum cleaners and lawn mowers [Sim+16]. Simoens et al. propose to include assistive social robots as additional actuators, as they are'much more dexterous and versatile' than single purpose actuators commonly used in existing smart home environments [Sim+16]. This creates an Internet-of-Robotic-Things (IoRT), combining 'the computational power of the cloud and the context information provided by sensors and wearables to intelligently define robotic tasks and support the execution thereof'. They go on to present their '[IoRT] system architecture design for a case study on personal interactions by a companion robot to alleviate behavioral disturbances of people with dementia' [Sim+16].

Activity Recognition in Smart-Home Environments Assistance robots can benefit from being part of a smart home environment. The sensors in this environment can be used to detect additional context information which can then be made available to the robot. One possible type of context that can be captured this way are situational events (see environmental context), for instance which activity a person currently executes. This information can then be used to enable robotic support during this activity, as it is the goal of this thesis.

In their thesis Hauptvogel [Hau20] worked towards recognising which ADL a user was executing only using simple smart home sensors. They used a Raspberry Pi 3 to run the hub and connected it to motion detectors, door contacts, motion detectors, temperature sensors and humidity sensors. Their goal was to not exceed a price of 750€ for the whole setup. For privacy reasons no cameras or microphones were used. Furthermore, they created a graphical user interface to enable the users to see the collected data as well as to make manual data entry possible. To classify the activities they used a hybrid approach, combining the benefits of the machine learning and the rule-based approach. In the evaluation the users were quite satisfied with how the activities were recognised and with how the user interface was structured.

Hauptvogels thesis provides the basic structure for how context data regarding ADLs can be collected. This thesis will then work towards using these information among other kinds of context information to provide support for elderly people.

1.4 Variability Management for Assistance Robots

Unlike industry robots employed in manufacturing, service robots must deal with a variety of unknown situations and be able to adapt to the specific needs of the current user [Gar+19]. A robot capable of adapting its behaviour to user preferences or disabilities, the environment, its own state, or cultural norms provides better service to its users and makes the investment more worthwhile.

Adapting how a task is executed to certain requirements results in a variant of the standard task execution process. Handling the creation of these variants requires handling variability and hence a mechanism for dealing with variability is needed. One possible solution to this is adapting concepts from the field of software variability for the robotics domain. In this section the basic terminology from the domain of software variability is going to be introduced and a variability management approach for assistance robots is going to be described.

1.4.1 Terminology

Software Family The term software family is often used to refer to variable software systems. Parnas describes them 'as a set of programs whose common properties are so extensive that it is advantageous to study the common properties of the programs before analysing individual members' [Par76]. The premise is the assumption 'that there exists more commonality than variability in a family of software systems' [Par76].

One commonly known type of software family are software product lines (SPL). The products of a product line have shared commonalities and variable configurable features.

Variability Model The knowledge about the variability of a software family (variability knowledge) can be made explicit by describing it in a variability model [Sch+12]. Schaefer et al. state that 'variability models define the commonalities and variability of a system's artifacts with organization-specific and domain-specific properties and dependencies.' [Sch+12]

There are many kinds of variability models, but the most widely used are feature models (see Figure 1.9) and decision models. In their systematic review on Variability Management in Software Product Lines Chen et al. [CAA09] found that out of the 33 examined approaches, 14 used feature modelling and 6 used decision modelling. They also identified 12 other kinds of variability models, but none of them were reused by another approach.

Variation Point Jacobson et al. describe variation points as 'one or more locations at which the variation will occur' [JGJ97]. For instance, in the case of the sample feature model in Figure 1.9 the nodes GPS and Screen represent a variation point each, because multiple options are available at these points. The Calls feature however is mandatory and therefore not a variation point.

Variant In the literature there is no universal definition for the term variant. Some use it to describe a one concrete option at a variation point [PBL05; GBS01; BB01; Anq+10]. Using the example in Figure 1.9, a Basic Screen would be a variant by this definition.

Other authors [AK09; Ros+11; Hab+13; SSA14] however use the term variant to describe a concrete, valid, fully configured member of a software family. This is the definition that is going to be used in this thesis.

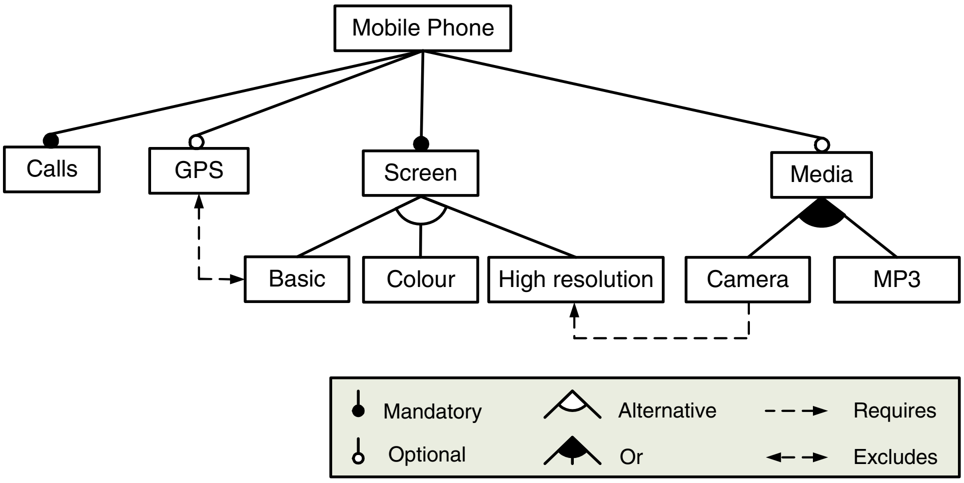


Figure 1.9 – A sample feature model [Ben+13]

Definition 7: Variant

'A variant of a software family denotes the realisation of one member of the set of software systems encompassed by the family that is valid with regard to the configuration rules governing variability.' [SSA14]

In Software Product Line engineering this use of the term variant is synonymous to the term product. Using the example displayed in Figure 1.9, a variant is a fully configured mobile phone, where a configuration for each variation point is selected.

Realisation Assets Realisation assets refer to the building blocks needed to implement a variant. This can include source code as well as design models, certification materials or documentation. [SSA14]

Variability Realisation Mechanism To assemble an executable software system from the conceptual configuration knowledge and the realisation assets, a variability realisation mechanism [Sch+12] has to be employed. The result of that mechanism is a fully implemented variant of the software family. In Figure 1.10 the variant derivation process is visualised.

1.4.2 A Variability Management Approach for Assistance Robots

'Mastering the software complexity becomes pivotal towards exploiting the capabilities of advanced robotic components and algorithms' [Sch+15]. Schlegel et al. explain that on top of that, the robotics domain comes with extra challenges. They state that the greatest difference to other domains is that 'the robot itself depends on run-time exploitation of (software) variation points in order to manage its (typically scarce) resources to face open-ended environments and to meet non-functional requirements' [Sch+15].

Moving from a code-driven approach to a model-driven one, which is formalised and can therefore be automatically processed at runtime, can enable a robot to make decisions at runtime

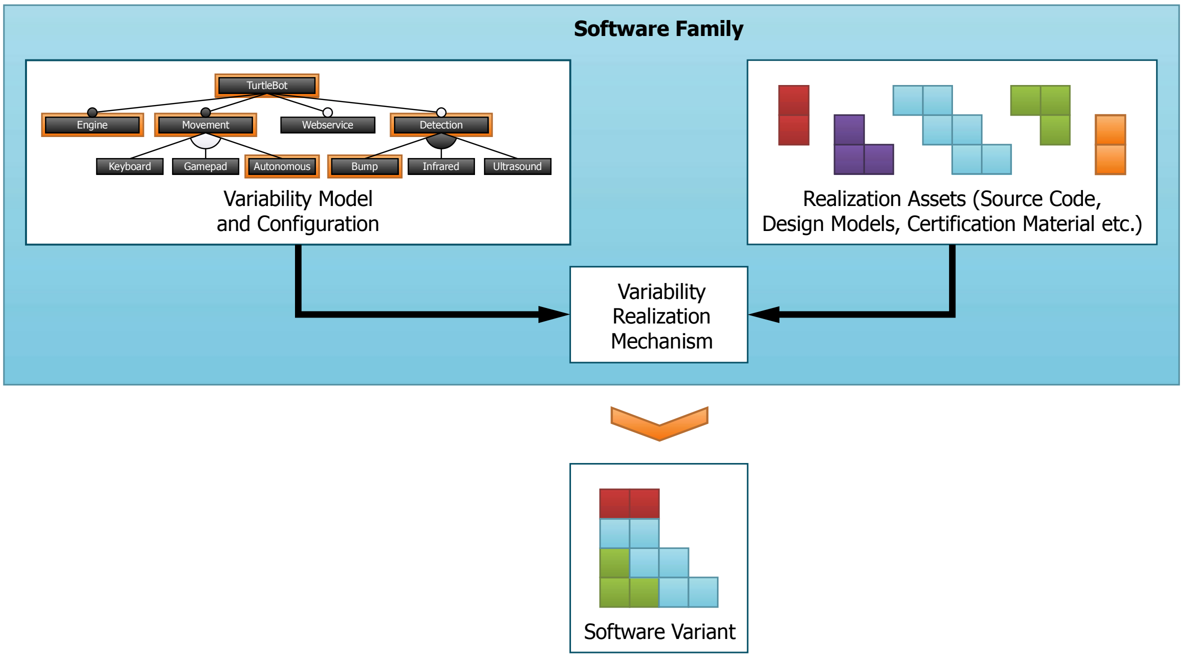


Figure 1.10 – The variant derivation process [SSA14]

[Sch+15; BCH15]. While model-driven dynamic variability techniques can offer solutions for coping with the runtime requirements [BCH15], up to this point dynamic variability remains an unsolved and ongoing common challenge, although some approaches by different researchers exist [Gar+19].

Student research was conducted at the chair for human-computer interaction at the TU Dresden in order to work towards creating an adaptable assistance robot. This describes a robot that can take the user's preferences and requirements into account, as well as information about the context and the environment when executing a task. In this section the existing papers and theses working towards an assistance robot that adapts the execution of tasks to the user's needs will be presented.

Construction of Variable App-Level Process Chains in Android In this paper a concept for executing variable process chains was developed [Zie20]. To fulfil the need for adaptability for assistance robots the execution of tasks should be adapted to user needs. To do that, tasks can be split into atomic subtasks which can then act as building blocks to form variants of this task that consider specific user needs. The resulting sequence of atomic tasks forming a complex task is called a process chain in this paper.

A platform-independent and technology-neutral concept for creating and executing process chains was proposed (see Figure 1.11). It includes a central manager component that receives a user command and forwards it to a task configurator component, possibly enriched with additional information about the user or the context. The configurator creates the process chain from the requirements and stores it in a task object which is then given to the manager. The manager starts the first subtask in the process chain and hands over the task object. This enables the execution of the process chain without the involvement of the manager component throughout.

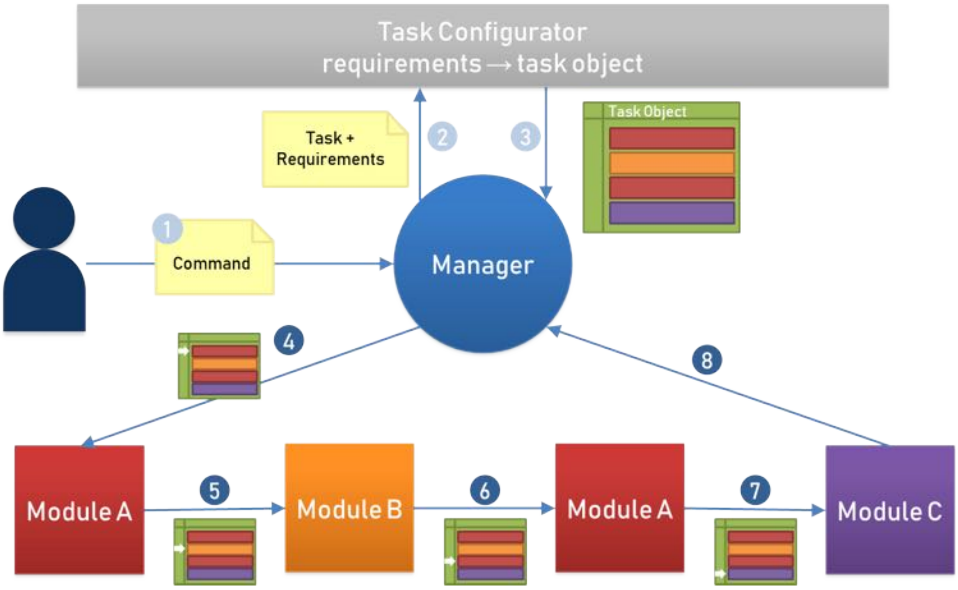


Figure 1.11 – A concept for executing process chains [Zie20]

A prototype was created to show the feasibility of this concept for the Android platform, as the assistance robot Loomo is Android based. The subtasks were represented by apps, as was the manager component. The task object was encoded in the JSON format and forwarded between apps via an Android Intent. The task configurator was not implemented in the prototype.

Designing a Configuration Method for Adaptive Assistance Robot Interaction In his paper Gröger [Grö21] considered the manager component described in the previous paragraph. Their goal was to develop a self adapting interaction concept on the basis of process chains.

After analysing which impairments persons in need of care could have, they examined which interactions are possible with which impairments. From the combination of impairments and interactions requirements were derived that were then worked in to a concept for a system with variable interactions (see Figure 1.12).

The manager service is responsible for the process flow and decides based on the users impairments which interaction is chosen when a new command comes in. They use a feature model extended with rules to store the configuration knowledge. To build a concrete process chain they use a compositional realisation mechanism.

Development of User Profiles for Adaptive Assistance Robots In the previous paragraph the concept considered possible impairments a user can have when constructing process chains. In order to create an assistance robot that can consider the user's preferences and requirements it is necessary to store that information.

In their thesis Fuchs [Fuc21] wanted to find a way to use user profiles to realise an adaptive social assistance robot for elderly people. They created a user model, which resulted in a user profile when enriched with user information. The user profiles were implemented in a JSON format.

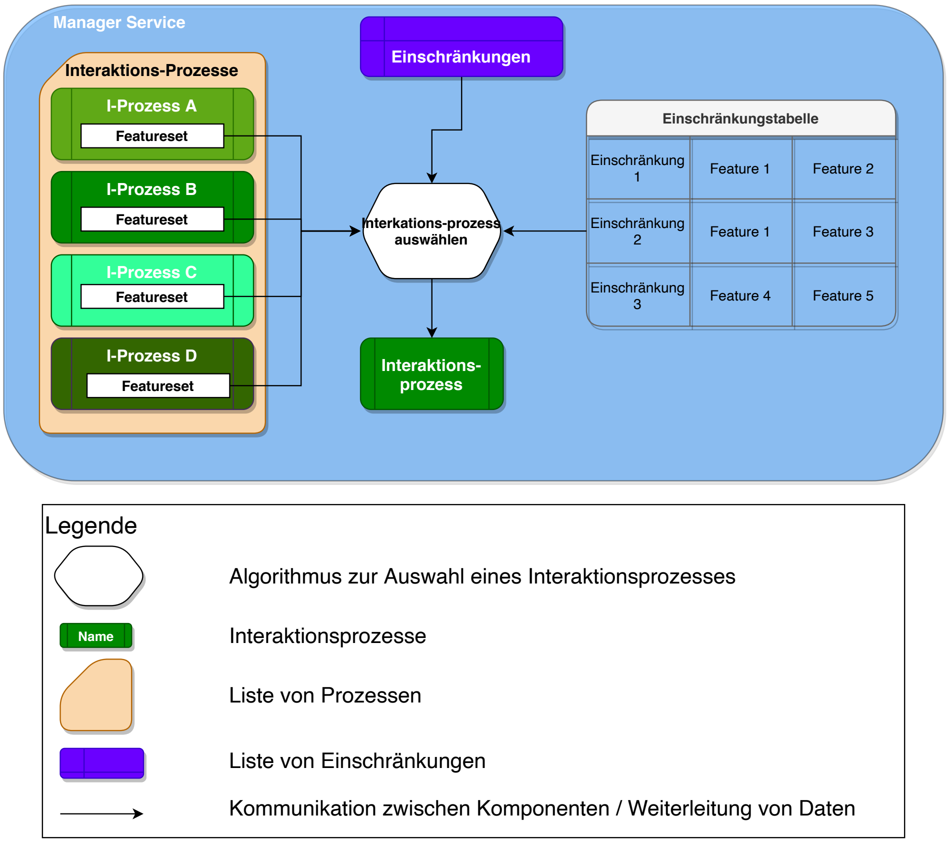


Figure 1.12 – Selection of the interaction process by the manager service [Grö21]

A Concept for Prioritisation and Parallelisation of Activities for Assistance Robots Besides considering the user's needs when executing tasks, another aspect relevant for adaptive assistance robots is the prioritisation of tasks. This paper [Zie21] identified different kinds of tasks an assistance robot might execute and proposed a concept for prioritisation if parallelisation is not possible. The two big categories are reactive and proactive tasks. When a user gives a command, the robot reacts by executing a task to fulfil the command. Furthermore, the robot might proactively execute tasks without a directly triggering command. Five categories of proactive tasks with descending priority were identified: emergency tasks, reminders of high, middle and low priority and circumstantial tasks. Emergencies, such as a fire or a patient who has fallen, always take precedence. High priority reminders are triggered by external events, such as an incoming phone call. Reminders of medium priority are scheduled by the user and are time sensitive. This includes for instance timers or alarms. Low priority reminders are not time sensitive and can be executed sequentially. This category includes tasks where only one piece of information should be delivered, such as reminders to take medicine, notifications about new messages or the robot's status. Finally, circumstantial tasks include tasks that take longer and have a lower priority than all the proactive tasks described before. Activities in this category include planned workflows, such as scheduled household tasks, as well as tasks resulting from the robot's self-initiative that do not revolve around simply notifying the user.

Contribution of this Thesis The goal of this thesis is to build on these papers to work towards creating an adaptive assistance robot that takes the user's needs and preferences as well as context information into account when executing tasks. The works previously described contribute towards the implementation of variable process chains, describing how process chains can be executed, created and how knowledge about users that can be used as constraints to customise the process chains can be stored. Furthermore, a prioritisation concept has been presented describing how to handle possible task conflicts that arise when the robot is enabled to proactively execute tasks beyond simply receiving commands [Zie21].

In this thesis, context information is introduced as another possible constraint that can be used to adapt how and when tasks are executed. Moreover, the idea of proactive tasks is taken up and support suggestions are introduced as a form of proactive task. Overall, this thesis follows the same vision of an adaptive assistance robot as the previously presented works.

1.5 Summary

This chapter gave an insight into the concept of the Activities of Daily Living. The basic and instrumental activities only cover activities related to living an independent life, but leave out productive, leisure, recreational, and social activities. For this reason a previously compiled list of activities taking place in the daily lives of elderly people was included.

Moreover, the need for assistance robots in care was explained and the term assistance robot was further defined to convey the type of assistance robot this thesis refers to. An overview of the state of the art in the area of assistance robots in elderly care was given and the acceptance of assistance robot in the context of elderly care was examined. The Technology Acceptance Model TAM was introduced as a means to measure the acceptance of assistance robots. Moreover, it was explained that the usability of a system contributes to the user experience, which itself contributes to the technology acceptance. The Interaction Principles were introduced as a means to support the usability and consequentially the technology acceptance.

Furthermore, this chapter gave an insight into the area of context information. The term context was defined and an overview in how context can be formalised was given. Types of context information were described and existing works using context information in the robotic domain were presented.

Lastly, an overview over the terminology used in the software variability domain was given and several student works were presented that work towards a framework for an adaptive assistance robot that considers user preferences and needs.

2 Analysing the Requirements for Context-Related Support of Elderly People During ADLs

In the last chapter background information on the domains relevant to answering the research question was given. In this chapter, firstly, a list of context information relevant for the concept in this thesis is going to be derived by analysing the categories of context. Secondly, the requirements for a possible solution concept for the research question are going to be developed.

2.1 Context Analysis

In this section, the previously researched categories of context are going to be analysed regarding which concrete context information might fall under each category and can potentially be available to an assistance robot. Moreover, this extensive list of possible context information is going to be examined and information that is relevant for this thesis is going to be identified.

2.1.1 Overview of Available Context

In order to compile a list of potentially available context for assistance robots, it is helpful to look at the list of types of contextual information provided in Section 1.3.2:

- Environmental context
- Application-specific knowledge
- User preference knowledge
- Task-related knowledge
- Data-centric context

Environmental context Environmental context is mentioned by both classifications introduced in Section 1.3.2 [Tur98; RLK12]. When describing Turners taxonomy Bloisi et al. state that robots ‘see world through sensors’ [Blo+16] and derive the current environmental context from these sensor observations. Examples they mention for environmental context are the presence of obstacles or people, terrain conditions, illumination conditions, trafficability and constraint information. Trafficability, terrain and illumination conditions are all important factors for a robot that moves outdoors, which was the focus of Turners work. The robots in this thesis are assistance robot that will mostly be employed indoors, making these kinds of context-information potentially less useful for this scenario. The knowledge about whether the robot is currently situated indoors or outdoors is additionally proposed as available context information. Similarly, weather information could be helpful to robots. Outdoors the robot might want to avoid getting too wet, while an assistance robot could relay the weather information to the user or let it influence proposed activities. Lastly, the term constraint information brought up by Bloisi et al. can refer to many possible restrictions. They mention stopping at a red light as a constraint for an autonomous vehicle. Constraints for an assistance robot could include the robot knowing that it is not equipped for a specific terrain or if an environment requires a certain maximum velocity to be drivable.

Unlike Turner, Rhee et al. [RLK12] focus on a personal service robot. They mention currently detected users around the robotic agent, recognised nearby objects and the robotic agent's location as environmental information, as well as spatial information, which can be used to build an internal representation of the environment to help navigate in the surroundings, and context knowledge derived by situational events. In the context of this thesis it stands to reason to suggest that these situational events could for instance relate to the user's current activity. Moreover, not only the robot's location might be relevant, but also the user's location or the location where the situational events take place. While Bloisi et al. also mention the presence of people, they only consider detecting obstacles, not general objects. An assistance robot might not consider every object an obstacle, as it might be necessary for them to interact with certain objects, e.g. to fetch it and bring it to the user.

Application-specific knowledge The second category of context is application-specific knowledge. Turner related this type of context to the concrete robotic device's self-knowledge. For this taxonomy Bloisi et al. mention the robot status, e.g. battery level, malfunctions and the resulting reliability, as well as the internal representation of the surrounding environment. Though robots perceive the environmental context through their sensors, they will usually build an additional internal model of their surroundings for instance in order to apply algorithms to it, which can be useful for navigation or perception purposes. The term reliability refers to whether a robot makes reliable decisions the user can trust [Blo+16]. It could also be put in the context of a robot receiving information from other devices. When the robot knows another device has a malfunction, they can consider any information coming from that device unreliable [Blo+16].

Rhee et al. on the other hand focus on how a robot might interact with other devices or sensors in the network for application-specific context knowledge. In this category they consider available devices and their settings, and the tasks or services they can perform [RLK12]. If a robot can access other devices, it can increase its function range by employing them to do tasks or by utilising their perceptive capabilities. Moreover, it can be suggested that the robot might check the status of the devices it wants to connect to in order to get to know their availability, reliability or current activity. This can help the robot's decision making process or influence how tasks are executed (see task-related knowledge).

User preference knowledge User preference knowledge is only considered by Rhee et al. [RLK12] and means the user's attributes, needs and preferences. This kind of information can be stored in user profiles to allow a robot to adapt its interaction to the current user. Fuchs [Fuc21] for instance includes the user's name and their preferred language as well as knowledge about the user's disabilities/impairments in their user profile. Additionally, their profiles include the task history with frequency of execution and the currently executed task. Depending on the application, it is imaginable to store any information about a user in profiles. The users might be able to adapt the robots interaction modalities manually and have personalised default interaction settings based on their preferences. This could be an addition to the robot knowing about the user's needs (e.g. impairments) and automatically adapting its communication. Moreover, it can be helpful for the robot to have access to health information, such as required medication, signs for a sudden decline of health it has to look out for, or dietary restrictions.

Task-related knowledge Task-related knowledge, or as Turner calls it mission-related knowledge, aims at modifying the task execution according to the task requirements and specification [Blo+16]. Bloisi et al. mention operating conditions and the task constraints (e.g. time constraints, priorities, and locations). Using their example of a multi-robot search mission they propose time, history information related to the task, information from/about other devices involved in the task (e.g. status, current activity, ...) and information gained during task execution. As Turner focuses on autonomous underwater vehicles (AUV), they provide being 'on a sampling mission' and being 'on a rescue mission' as examples for missions that can influence how tasks are executed. While on a sampling mission the AUV might have to move 'so as to avoid disturbing the sites from which data is to be collected' [Tur98], while during a rescue mission the 'AUV should focus its attention on the main mission task, even at the expense of other goals that might otherwise be quite important, such as "determine location"' [Tur98]. In the context of assistance robots similar scenarios such as an emergency task can be imagined, where the robot should focus completely on helping the user in a potentially dangerous situation.

Naturally, this kind of knowledge is very hard to define without looking at a concrete task, as every task will have different requirements which might also differ with each execution as other context information influences the task. Overall it can be said, that the information in this category can influence the management of the task execution, e.g. in which order subtasks are executed, and consequently the performance of the system (e.g., timeliness, accuracy) as well as the modalities used to execute the task. Unforeseen events or the context in which a task is executed can also change the execution of a task.

Data-centric context Lastly there is data-centric context information included only by Rhee et al. [RLK12]. They define it as covering 'various objects and their attributes, both physical objects such as books or cups, and non-physical contents such as music or video'. This category is the most open-ended of the categories provided and not much detail was given elaborating what would fall under this category. It can be interpreted as referring to any kind of data object that can have a meaning to an assistance robot.

Compiling the suggestions for context made by Rhee et al. [RLK12] and Bloisi et al. [Blo+16] and adding some own suggestions results in the following list of possible context information for an assistance robot (see Table 2.1). It should be kept in mind that this list can not be considered complete, as the field of context information is so broad it is impossible to list everything that can be considered a context information. Moreover, the goal is not to provide an strict categorisation of context, but to get an overview of available context information. It has already been established that the categories are closely interlinked [RLK12]. Some items could therefore be grouped into more than one category, which does not impact the purpose of this list.

Environmental context	- presence of people/users [Blo+16; RLK12] - presence of obstacles [Blo+16] - recognised nearby objects [RLK12] - terrain conditions [Blo+16] - illumination conditions [Blo+16] - trafficability [Blo+16] - constraint information [Blo+16] - spatial information on the surrounding environment [RLK12] - indoor/outdoor (own suggestion) - weather information (own suggestion) - context knowledge derived by situational events [RLK12], e.g. current user activity (own suggestion) - location of the robot [RLK12], the users or the situational events (own suggestions)
Application-specific knowledge about the robot or other connected devices	- status (e.g. battery level, malfunctions) [Blo+16] - reliability [Blo+16] - internal representation of surroundings [Blo+16] - available devices [RLK12] - device settings [RLK12] - tasks (services) a device can perform [RLK12] - device's current activity (own suggestion) - device's availability (own suggestion)
User preference knowledge	- name [Fuc21] - preferred language [Fuc21] - disabilities [Fuc21] - preferred modalities (own suggestion) - health information (own suggestion)
Task-related knowledge	- operating conditions [Blo+16] - task constraints (e.g. time constraints, priorities, and locations) [Blo+16] - time [Blo+16] - history information related to the task [Blo+16] - information from/about other devices involved in the task (e.g. status, current activity) [Blo+16] - information gained during task execution [Blo+16]
Data-centric context	- physical objects (e.g. book, cup, ...) [RLK12] - non-physical contents (e.g. music, video, ...) [RLK12]

Table 2.1 – An overview of available context information

2.1.2 Overview of Relevant Context

The goal of this thesis is to propose a concept for how an assistance robot can use contextual information to proactively support elderly people with ADLs. This section will look at the available types of context compiled earlier, evaluate if each type of context is relevant for achieving this goal and what concrete context information in each category should be considered in the concept.

The most obvious application for *environmental context* is navigation, because in order to move around in an environment a robot must gather knowledge about its surroundings. While navigation is an omnipresent aspect in robotic applications, it is a research area in itself that is not going to be considered in this thesis. Nevertheless, some aspects of environmental context can be relevant in the context of this thesis. Factors that mostly relate to the navigation aspect can be excluded. This covers the presence of obstacles, terrain and illumination conditions, trafficability and spatial information. Constraint information regarding the environment will also be ignored in this thesis. A robot may have other constraints that need to be considered during its action, however, these very device-specific requirements are too abstract to be considered here. Then there is the proposed context of being indoors/outdoors. As the assistance robot considered in this thesis operates indoors, this context will also be excluded for now, however, when an assistance robot can operate indoors as well as outdoors, this information can be valuable to provide context related support. For the same reason weather information will not be considered relevant context for this thesis.

Lastly, information about the present users and nearby objects, situational events, such as current ADLs, and the location of the robot, the user or the situational event remain. Those will all be considered relevant for this thesis. When no user is around, there is no need for the robot to offer support. A certain object might allude to a certain ADL, for instance full grocery bags means the user will probably put away the groceries next and the robot can offer appropriate support. When the robot senses that a specific event, such as an ADL, is being executed, it can offer its support related to this activity. This directly addresses the goal of this thesis of providing support for ADLs. Finally, the location of the robot, users or detected activities can influence the type of support suggested. The user sitting down in the living room versus in the bathroom can have vastly different implications.

The next context category is *application-specific knowledge*. Concrete information that can be relevant for providing proactive support during ADLs might include accessible devices, their abilities and availability. External devices can either help perceive the environment to gather environmental context information or provide the user with additional services outside of the robot's function range. For the purpose of this thesis, the concrete device settings and current activity are going to be neglected. Considering settings is difficult, as they are very device-specific, and the current activity of a device is less significant than the availability if a robot wants to access the external device. Other information identified for this category were the internal representation of the surroundings, the reliability and the robot's status. The internal environment model is mostly needed for applying algorithms related to navigation or object detection, which are omnipresent during every robotic action but not the focus of this thesis. The status and the resulting reliability are similarly ubiquitous concepts and relate to the general ability of the robot to currently provide support. The status can be related to the battery status of the robot or other devices in the network. If on a low battery the robot might only be able to provide the most basic services. The status of the network and internet connection might also be of interest, as some services may only be available with a stable internet connection. Though status information could influence which support suggestions can actually be made, they do not directly trigger support specifically for ADLs, which is why this kind of information is going to be neglected for this thesis.

User preference knowledge is necessary to adapt the robot's behaviour to the user it is interacting with. Although it is a very important field of research, considering user information while providing support during ADLs goes beyond the scope of this thesis. However, considering that using user preference knowledge affects every aspect of robot interaction, as assistance robots rarely do things without interacting with users, it is inevitable that the paths of these two directions of research will cross further down the road.

Task-related knowledge directly relates to the task that is being executed and is therefore quite specific. As the research question mentions proactive support, this type of context information is difficult to consider for this thesis. It can only be accessed while executing a mission, but when providing proactive support, the robot is by definition not yet carrying out a task. Therefore, knowledge that is closely tied to a concrete task, such as operating conditions, task constraints, information from/about other devices involved in the task and information gained during task execution, is not going to be considered relevant here. It is imaginable that if the robot executes a task following a proactive offer for support, task-related knowledge can be applied during that task. However, this is out of the scope for this thesis. This leaves history information related to a task and the time of day. The current time might influence what kinds of support suggestions a robot makes. Moreover, historic information about tasks and routines may be considered to tailor support suggestions to the users needs.

Lastly, there is *data-centric context*. Rhee et al. [RLK12] left it relatively open what could fall under this category, only mentioning physical objects such as books or cups, and non-physical objects such as music or videos. Many of the information that can be viewed as data-centric context could also fall under other categories, as the categories are closely interlinked. It is not the goal of this section to provide an exact categorisation for each piece of context knowledge, but to get a better understanding what relevant context is.

It has been suggested in the previous section that data-centric context relates to any kind of data object that can be relevant to an assistance robot. In the context of a task (task-related context), data-centric context might include objects relevant to the task, either because they are required, e.g. when an item should be retrieved, or because they could be helpful to the robot or the user. As data-objects originate from objects sensed in the environment, this matches the nearby objects from the environmental context category which has already been considered as relevant context. Moreover, non-physical contents could be sensed by an assistance robot, for instance music playing through another device or the beeping of a washing machine indicating it is finished. This has not yet been considered in another category, but enabling the robot to consider sounds when offering support to users could enhance the opportunities for support.

This analysis of context information from the perspective of what is relevant for this thesis leads to the list found in Figure 2.1.

Even though a robot might not consider every piece of context for every action, the goal of this thesis is to create a context-aware robot, which means using context to provide relevant information or services to users (see Definition 6). Dey declares: 'There are three categories of features that a context-aware application can support: presentation of information and services to a user, automatic execution of a service for a user and tagging of context to information to support later retrieval' [Dey01].

Environmental Context	Task-Related Knowledge	Application-Specific Knowledge	Data-Centric Context
• present users • nearby objects • situational events (e.g. ADLs) • location of robot, user or situational events	• time of day • historic information about tasks and routines	• accessible devices • their abilities • their availability	• non-physical contents, e.g. sounds

Figure 2.1 – Context information considered relevant for this thesis.

2.2 Requirements Analysis

The goal of this thesis is to propose a concept for providing proactive assistance robot support during ADLs. In this section the requirements for this concept are going to be analysed and a list of concrete requirements is compiled.

In order to provide value to users and to be accepted, the concept should achieve technology acceptance. As explained in Section 1.2.5, the user experience influences the technology acceptance and to achieve a good UX, the usability should be improved. One way to do that is to adhere to the interaction principles.

According to the TAM the main factors that influence the user's attitude towards using a system are perceived ease of use and perceived usefulness. In order to achieve user acceptance for the concept developed in this thesis it is necessary to achieve these acceptance criteria, which is why they are going to be included in the requirements catalogue. The perceived usefulness implies that any proactive suggestions made by an assistance robot should provide value to the users. If the suggestions are unnecessary or annoying users will opt out, leaving the feature useless. The perceived ease of use implies that the support feature should be intuitive to use and there should be no unnecessary elements that needlessly complicate the interaction leaving users frustrated.

A good starting point to achieve usability are the interaction principles defined in the international standard ISO 9241-110:2020 [Int20] (see Section 1.2.5). They can be used as general goals when designing and evaluating interactive systems and aim at identifying key impacts on usability [Int20]. As the interaction principles are supposed to be applicable for a myriad of different systems they are phrased rather generically. Going forward, requirements for the concept in this thesis are going to be derived from the interaction principles. The focus is on how the interaction principles can be interpreted in view of an assistance robot using context information to proactively support elderly people during ADLs.

Suitability for the user's tasks implies that the robot 'supports the users in the completion of their tasks' [Int20]. In the case of this thesis the task could be an ADL, during which the robot can proactively offer its support. The categories for this principle include that users should have all information to complete tasks, as well as the demand that the robot clearly communicates its function range so that users can determine if the system will be helpful to them. In the context of this thesis this means that the robot should clearly explain how the functionality of proactive context-related support works and how users can interact with this feature. This can be done in an introductory tutorial for the feature. The category for this principle are default choices. The proactive support feature should contain default suggestions in order to facilitate the initial activation. Later on, more suggestions can be added either manually or through some kind of learning or observation process, e.g. machine learning.

Self-descriptiveness means that the robot 'presents appropriate information, where needed by the user, to make its capabilities and use immediately obvious to the user without unnecessary user-system interactions' [Int20]. This principle asks for presence and obviousness of information to guide the user and minimise the need for consulting online help [Int20]. Additionally to a tutorial explaining the functionality, this requires that the system is intuitive to use, which could be achieved by keeping the required interaction simple, e.g. posing simple yes/no questions regarding whether to do something or not. This is especially important when using a voice interface, as those can get confusing if they are too complex. Moreover, any offered suggestions for support have to be noticeable to the user, i.e. being presented in an attention-grabbing kind of way. Indicating the processing status, which is the second category of this principle, includes making it obvious when user input is needed. Hence, the robot should phrase any suggestions for support as questions, making it clear to the user that they have to answer in order for the robot to execute an activity.

The principle of *conformity with user expectations* implies the assistance robot behaving predictably and acting according to commonly accepted conventions [Int20]. This principle contains the factors appropriate system behaviour, consistency and changes in the context of use. Consistency implies predictability, which can be achieved by using consistent rules for making suggestions for how the robot can support the user. Appropriate system behaviour ties in with the principle of suitability for a task, in that any proactive suggestions the assistance robot makes must be suitable to the situation. This is especially important for any provided default suggestions as well as automatically generated suggestions. It might be useful to provide users with the opportunity to alter any suggestion rules that do not make sense to them. Lastly, in this thesis the context of use stays the same, namely proactive support. However, changes between proactive support and active user-initiated use could be considered further down the road.

Learnability involves discovery of information and controls that users are looking for, exploration of information and controls that users have discovered and retention of information about the system [Int20]. To ensure learnability, a short introductory tutorial which explains the basic functionality is proposed as it helps to facilitate the discovery of the proactive support feature. Moreover, in order to make the feature explorable without the need to rely heavily on the tutorial, the user interface should not be more complex than necessary as well as intuitive to use, as already mentioned in the context of self-descriptiveness.

The principle of *controllability* includes the possibility of interruption by the user, flexibility and individualization. This principle is essential to consider, especially as the concept in this thesis relates to proactive tasks. As proactive tasks are started without an explicit user command it is especially important to give the users a feeling of control. This could firstly be achieved by disabling the suggestion feature by default. That way, users consciously decide to use it and are not surprised when the robot starts making suggestions. On top of that, it must always be possible to interrupt the robot as described in the ISO standard. To allow for individualization it is imaginable that users can influence the suggestions made by the robot. If they do not like a certain suggestion or want the robot to make a specific one in certain situations they can manually alter the rules by which is decided what suggestions are made in which situations. Flexibility can be achieved by providing different means of interaction, such as a graphic user interface as well as a voice interface.

Use error robustness covers that the robot helps users to avoid errors and if they occur, tolerates them and assists in the recovery from an error [Int20]. In order to be error robust, an assistance robot should tolerate any kind of input and also missing input. When the received input can not be interpreted correctly, the robot could repeat its question, adding that it could not understand. Moreover, multiple input modalities could be provided. If there is no input when the robot expects it, for instance because the user is ignoring the robot or did not notice it, the robot should not proactively execute a complex task but rather act as if their offer for providing support was declined.

Lastly, *user engagement* entails an 'inviting and motivating manner supporting continued interaction with the system' [Int20]. If the robot offers to support the user during an ADL, this should happen in a way which would motivate the user to accept the offer. Other than wording the offers as questions, as previously mentioned, the robot's statements should be properly reviewed to ensure they are clearly phrased to prevent misunderstanding. In case the user acoustically could not understand the robot, the tutorial should educate the user on the possibility of asking the robot to repeat. Other than motivating the user, the principle of user engagement entails that the robot is trustworthy and that user involvement with the proactive support feature should be increased. Trust in the system can be gained by adhering to the previously mentioned principles. When users learn what to expect and accept the system, trust is built. Finally, increasing the user involvement can be made possible by allowing the users to personalise the system to their liking, e.g. by making the suggestion rules accessible as mentioned earlier.

2.2.1 Requirements

In the previous section the requirements for the concept developed in this thesis regarding how to proactively support elderly people during ADLs were derived from the interaction principles and the Technology Acceptance Model TAM in order to achieve a good usability. In this section, these requirements are compiled, characterized and their measurability is going to be explained. Regarding the measurability it can be noted that there are two types of requirements: Though all requirements have to be considered during the design process, some are fulfilled if they are included, e.g. provide a tutorial, while others need to be evaluated in a user study with a prototype to see if they have been achieved, e.g. if users are satisfied with the tutorial.

Provide value to the users Derived from the TAM aspect *perceived usefulness*, the need to provide value is essential for any system. If the users do not see any value in proactive robotic support during ADLs, not only will the acceptance of the feature be poor, but the feature will remain unused. It can be argued that the introduction of context-awareness for an assistance robot already provides additional value to users compared to a robot that does not consider the context. Moreover, the idea of proactive support suggestions also aims at providing additional value. It must be made sure that users perceive the suggestions made as valuable.

One can distinguish between the perceived usefulness and the actual usefulness. The perceived usefulness/value can be evaluated through a question in the user study evaluating the prototype, by asking the user if they think the feature will be useful to them. Another way to measure perceived usefulness is to observe how many people actually decide to use the feature in the long term. This measure can only be evaluated if a large number of users use the robot in a real life scenario. The actual usefulness however should be measured. For instance the increase in efficiency can be measured and compared to the efficiency when not using the feature. As efficiency or the time it takes to do a task can hardly be measured for a feature that proactively offers support, only the perceived value will be evaluated in this thesis.

Tutorial The need for a tutorial arose during the analysis of multiple interaction principles, namely *suitability for the user's tasks*, *self-descriptiveness* and *learnability*. A tutorial helps the user understand the system and enables them to explore it further. Users are also less likely to get confused when a context-based suggestion is made if they have been properly informed about the feature upon its activation (see next requirement). In terms of suitability for the user's tasks, a tutorial allows the robot to clearly communicate its function range which helps users decide if they deem the proactive support feature suitable for their needs.

In order to enable users to use the feature with minimal need for help, an introductory tutorial upon activation of the proactive support feature should be provided. Users should be able to go back to the tutorial at any time and the tutorial should include this information. Moreover, the tutorial should provide all information necessary to explore the options the feature provides while being as brief as possible. The existence of a tutorial is easily shown, while the quality of the tutorial should be evaluated in the user study.

Enable context-based support feature only upon activation In order to ensure the principle of *controllability*, users should consciously decide to activate context-based proactive robot support. Proactive support entails the robot offering support without a user prompt, which could surprise or even startle an unprepared user. Some users might also not appreciate this feature and only want the robot to communicate with them if they initiate the conversation. Moreover, while users might appreciate the idea of context-awareness in theory, it is possible that in practice the feature can be faulty. If the users are annoyed because the proactive support feature is often triggered in an inappropriate context, they might want the option to deactivate the feature. However, it must be made sure that users know they have this option, for instance by including this information in the tutorial. Upon the implementation of the system it can be shown that this requirement is fulfilled.

Interruption is always possible In order to ensure *controllability*, it must always be possible for the user to interrupt the robot. This requirements can be checked off if included.

Intuitive to use The proactive support feature should be intuitive to use, according to the TAM aspect *perceived ease of use* and the interaction principle *self-descriptiveness*. The aspect of explorability of the principle *learnability* can also be supported by an intuitive interface. To achieve this goal in the design process a simple interaction model can be considered as well as a minimalistic user interface. Whether the implementation of the goal was successful must be evaluated in the user study. For instance, the user could be asked if they were able to find all important features or settings without any problem, whether they had to search for anything for a long time or whether they got stuck at some point.

Make information obvious and engaging The interaction principles *self-descriptiveness* and *user engagement* imply that information should be provided in an obvious and attention-grabbing way so that users do not accidentally overlook them. It must also always be clear when user input is expected. This could for instance be achieved by phrasing the support suggestions as questions, for instance 'Do you want me to bring you a towel?'. Another possibility is phrasing the recommendation as a call-to-action, e.g. 'You can say: Bring me the towel.', which could lead to more user engagement with the robot. Moreover, the robot could include additional information about how the recommendation came to be in order to make the robot behaviour more transparent. For instance, the robot could say: 'I see you took a shower. Do you want me to hand you a towel?'. Which of these options users prefer must be evaluated in the user study, for instance by showcasing all options and asking which wording they prefer.

Furthermore, the robot's statements should be worded unambiguously to prevent misunderstandings. While the requirement to let the robot express its suggestions as questions instead of statements can easily be validated, it must be evaluated during the user study whether the users are overall satisfied with the way the recommendations are presented. A possible question for the questionnaire could be: 'Did you always understand what the robot wanted you to do?' or 'Did you like the way the robot worded its suggestions? If not, why?'.

Rule-based behaviour The principle of *conformity to user expectations* contains the aspect of consistency. Consistent context-aware behaviour can be achieved by implementing rules deciding in which context the assistance robot takes which action in order to offer support. The rules can either be derived analytically during the design process, input manually by users or created automatically by some kind of machine learning algorithm. The existence of rules must be an outcome of the design process and can be checked off. In order to prove that this requirement was really fulfilled however, it is useful to evaluate if the actual goal of the rule-based approach was fulfilled. The goal is to reliably make consistent suggestions. This could be evaluated by showing the users a test case that should yield a similar result as a previous one and ask them if they found the robot acted predictably.

Default suggestion rules In order to facilitate the initial activation of the proactive support feature and provide a ready to use system, default suggestion rules should be provided. Those rules decide what recommendation can be made under which context circumstances and can be derived analytically. The need for default rules is outlined in the principle of *suitability for the user's task*. More suggestions could be added later on, either manually or through a machine learning algorithm. In case an artificial intelligence approach is used, default rules can address the cold start problem, i.e. that not enough data has been collected upon activation of the feature which can be used to train a decision model. Until that is the case, default rules can be used while data is being gathered. The default values must be an outcome of the design process and can be checked off if they exist.

Appropriate suggestions To *conform to user expectations* the proactive support offered by the robot should include suggestions suitable for the context. This also ties in with the need to provide value to the users. While the connections between observed context and offered support must be chosen wisely during the design process, only the user evaluation can show whether users perceive the offered support as appropriate to their needs in the situation. A possible question for the user study could be 'Did you always find the suggestions made appropriate for the situation?'.

Customizable suggestion rules To allow for individualisation as outlined by the *controllability* interaction principle and increase *user involvement* (see *user engagement*), the users should be able to influence the rules deciding over what suggestions for support are made in which situation. This also allows the users to alter the robot's behaviour for it to *conform to the user's expectations* and leads to more transparency, which might increase the user acceptance.

Implementing adaptability is an important feature for a context-aware assistance robot. It gives users control, for instance when the robot misjudges the situation and makes a non-suitable suggestion. Moreover, while a suggestion may be appropriate in theory, the user might still dislike it and wants to disable this suggestion. Adapting the decision process should be made as easy as possible for users and not require any technical knowledge. The requirement can be checked off if it is included, however, the evaluation of user satisfaction with this aspect might be included in the user study.

Optimisation Process for the Decision Process Other than allowing the user to adapt the rules, it is beneficial if the robot automatically optimises the rules based on observations made about the user. Even though default rules are provided, it is unlikely that what designers and developers came up with works perfectly for every individual user. Adaptivity, just as adaptability, answers the need for individualisation and in the end provides a personalised, and hence likely better, user experience. The main goal is an optimisation process is to overcome the provided default rules, for instance by observing the correlation of the users actions and the context to create new rules.

Tolerate any kind of input During the implementation process it must be made sure that the robot is *use error robust*, which means it can handle any kind of user input, even missing input. This has more to do with the overall system usability than the fact that this is a context-aware system. User input for the context-aware recommendation feature is required when the robot made a suggestion and the user either declines or accepts. The user might also ignore the robot.

If input can not be properly evaluated the robot should ask the user to repeat. Additionally multiple input modalities could be provided to broaden the possibilities to provide acceptable input. If there is no input when expected, the robot should not automatically start the proposed activity, as the user would probably not appreciate the robot autonomously doing things the user does not expect. However, it makes sense for the robot to repeat the suggestion after a short time period, as it is possible the user simply did not notice the recommendation. The robot could also provide assistance if the user does not respond, for instance by telling the user what they can say in order to accept a suggestion.

The error robustness depends on the final implementation and implemented input modalities and must be evaluated in a user study. To test the robustness, test cases covering all types of possible input must be designed and tested. If all tests are successful, the requirement is fulfilled.

2.3 Summary

In this chapter, the domain of context was analysed regarding the use of context information for this thesis and requirements resulting from the goal for a good user experience were compiled. Firstly, the context categories introduced in the previous chapter were evaluated regarding what they mean for assistance robots and a list of context information available to assistance robots in general was compiled. Secondly, from this list the context information relevant for this thesis was filtered. Lastly, a brief outlook for the next chapter was given, regarding how context information can be used.

In the second part of this chapter, the requirements for the concept developed in the next chapter have been developed. As they are a recognised standard to evaluate usability the interaction principles were taken as a starting point, as was the Technology Acceptance Model. The elements of TAM and the interaction principles were analysed regarding their relation to context and the goal of this thesis. From that, a list of requirements emerged that have to be considered during the design and development process and during the final evaluation of the prototype for this thesis.

3 Developing a Concept for Robotic Support Using Contextual Information

In the previous chapter the requirements for the concept in this thesis as well as the relevant context information this concept should consider were laid out. In this chapter, that concept is going to be developed and described.

The goal of this thesis is to propose a concept for providing elderly people with context-related support during their daily activities. It has already been suggested that the robot can offer to execute activities to help the user with their daily tasks. Those suggestions should be based on the current context. Usually, the user interacts with the robot by giving direct commands. In the concept in this thesis the robot will take the initiative and proactively offer support, trying to anticipate the user's needs. The robot should be able to autonomously detect situations where help can be offered. It should be noted, that while the goal of this thesis is for an assistance robot to provide suggestions to support the user based on the current context, this does not include emergency scenarios. Although it is imaginable that the detection of emergencies relies on similar techniques, handling emergencies is a separate issue not considered in this thesis.

In order to offer context-based support, the basic approach proposed in this thesis is that the robot gathers information about its current context and uses this as input for a classifier. This classifier creates a recommendation based on the provided context input. In the concept for the recommendation process proposed and described in detail in this thesis, the classifier will use a static rule based approach, as described in the requirements derived in the previous chapter. Furthermore, an optimisation process for the decision process based on a dynamic machine learning approach is going to be proposed and described on a high level. Additionally, in this chapter a default rule set based on the identified relevant context information and the researched suggestions for how assistance robots can support elderly people in their daily lives is going to be provided. With the default rule set the robot can immediately start making suggestions. Lastly, some considerations for how the proactive recommendations should be phrased are going to be presented.

The requirements for the recommendation system that is going to be developed in this chapter have been listed in Section 2.2.1. Most of the requirements presented earlier are going to be considered and fulfilled at different points of the concept development process. Some requirements however, can only be implemented in a prototype while others are quite abstract and are hard to check off, though they should always be kept in mind. It needs to be shown in a user study if these requirements have been achieved. Figure 3.1 organises the requirements according to where they are going to be addressed.

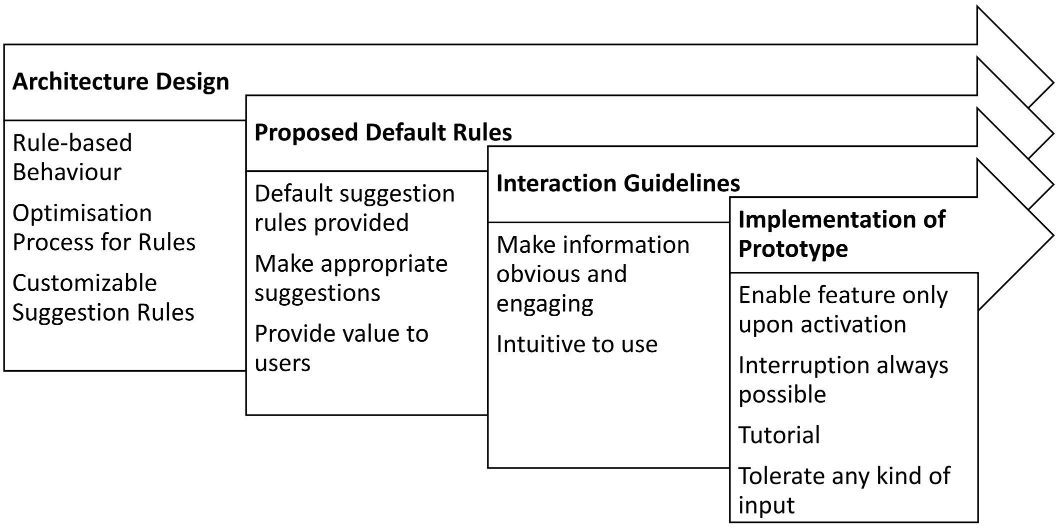


Figure 3.1 – The requirements for the recommendation system

3.1 Architecture

The requirements identified for this part of the concept all revolve around the rules deciding in which context what suggestion is made to the user. This signifies that those rules play a central role in the design process for this concept. There are two distinct processes to be identified from the requirements: Firstly, the recommendation process, where the recommendation module uses current context information and the supplied rule set to create support recommendations for the user. This process should fulfil the requirement of rule-based behaviour.

Secondly, there is the process of adapting the rules to better fit the user's life and preferences. This process has two components, according to the remaining two requirements. Firstly, the users themselves can customise the rules, for instance by telling the robot to no longer make a certain suggestion. Secondly, an optimisation process should exist where the robot itself can adapt the rules, for instance through the observation of the user's reaction to suggestions made based on existing rules, or create new rules based on observations of patterns of context and user behaviour. This calls for an machine learning approach such as deep learning.

Going forward, both processes are going to be described. However, solely the concept for the recommendation process is going to be developed in detail and demonstrated in the prototype. The task description asks for a systematic concept for capturing and processing the required context as well as offering relevant support, which is covered by the recommendation process. The optimisation process would be the next step towards a context-aware assistance robot that learns about the user's needs and preferences. Sufficiently developing the optimisation process would go beyond the scope of this thesis, which is why the proposed concept for the optimisation process will only be described superficially.

Recommendation Systems Most internet users have been in contact with recommendation systems, whether it is Netflix offering films users might like based on the ratings they provided for previously watched items, Amazon suggesting what one might want to buy next based on what other people with a similar purchase history bought or social networks suggesting new profiles to befriend based on the user's friends' social connections.

Burke states that the term Recommender System (RS) describes 'any system that produces individualized recommendations as output or has the effect of guiding the user in a personalized way to interesting or useful objects in a large space of possible options' [Bur02]. De Gemmis et al. assert that '[n]owadays, those systems can be seen as decision support tools, because they help people to make better choices in their everyday life: what products to buy, what documents to read, which people to have in their social networks' [GLP18].

While the systems mentioned previously match this assessment closely, the recommendation system in this thesis differs from them as it does not directly help the user to narrow down the choices available in a decision making process. Instead, it matches the first part of Burke's definition of recommender systems in that it outputs recommendations that are individualised in the way that they are based on the current context. Over time, the individualisation can also relate to the user and their preferences as the optimisation process adapts the decision process to output suggestions better suited for the user. As the recommender system in this thesis differs from other commonly used recommendation systems helping users narrow down their choices, it is difficult to profit from the research in that area.

Nevertheless, a recommender system has three parts, as every system has according to the input–process–output (IPO) model. Firstly, data must be accumulated in order to create an input for the recommender system. In the case of this thesis this is information about the current context coming from many different sources. Secondly, the recommender must process the input context data and calculate an output (see Figure 3.2). The output of this thesis is a concrete suggestion for how the robot can support the user. Lastly, the robot must communicate the calculated output to the user, i.e. make a suggestion. In the following section, these three process parts are going to be presented in detail for the recommendation process.

Figure 3.2 – The recommender derives a support suggestion from the current context

3.1.1 Recommendation Process

In Figure 3.3 an overview of the recommendation process is depicted. To give a quick overview before going into more detail, the first step is to collect the context data in a *context database*. From there, the current context data is periodically retrieved by a context assembly module which then assembles an object containing the current context. A possible realisation for this object could be a data exchange format such as JSON or XML. This object is provided as input for a classification module which uses rules in order to derive a recommendation from the context. The derived recommendation is sent to an output module which records the recommendation in a log file and communicates the suggestion to the user.

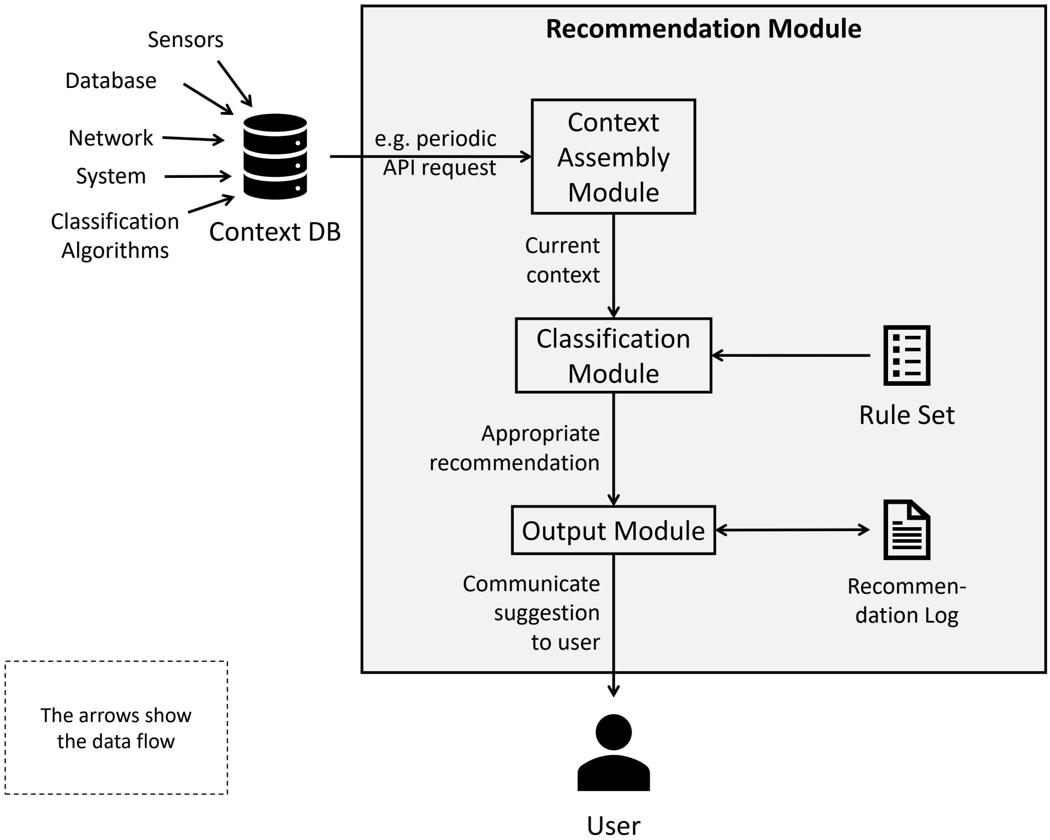


Figure 3.3 – An architecture for a context-aware recommendation system.

Input

In order to derive a recommendation, context information to base the recommendation on must first be gathered. Context information can come from many different sources. Environmental context for instance can be perceived via sensors such as cameras or microphones, the current time can come from the system and network information gives an overview of accessible devices. All these context information should be accumulated in one *context database* so it is all in one place to be easily accessible for the recommendation module. Furthermore, it must be made sure that it is easy for other data-collecting modules to provide input for the database, for instance through the provision of an interface.

The raw origin context data may not always be usable as is for further processing. For instance, raw video data must be processed first in order to recognise present users or nearby objects. Additional transformation steps would have to be executed by the recommendation module if only raw sensor data would arrive in the context database. This would not only blow up the recommendation module, it would also negatively impact the scalability. If a new kind of context information should be added that requires processing of the raw data first, this processing step would need to be integrated into the recommendation module, which could require a lot of effort. To avoid that, it will be assumed that the data in the context database is ready to be used to derive recommendations. It can contain data coming directly from sensors, e.g. information about the noise level from a loudness meter, as well as preprocessed data, such as detected objects.

The Database: For the context database in this thesis, a relational database was chosen instead of a non-relational database. Non-relational databases do not have a schema and consist of only one document instead of of multiple connected tables. They are well-suited for persisting large amounts of sensor data, which, as already explained, is not relevant for this thesis, as all sensor data must be classified to obtain concrete context information before entering the context database. As a database schema and the possibility of having multiple connected table are required to enable the recommendation module to retrieve the current context in a structured way, a relational database was selected.

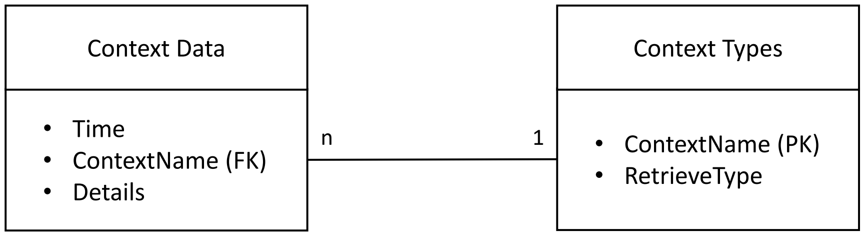


Figure 3.4 – The database schema for the context database

The context database contains two tables, the database schema is depicted in Figure 3.4. The first table will be called *context data table* and contains entries each representing a single piece of context information. The entries in this table come from many different sources, such as external sensors, other databases, services or from the robot itself. Every entity that wants to provide context information simply adds a new entry for the current context information it can provide. This should happen regularly, optimally as often as possible, so that the information is always up to date. This table has three columns: one contains the *Time* of when the entry was written to the database, one contains the identifiable *ContextName* of the type of context this entry belongs to, and the last column contains the *Details* about the context. This table does not contain a primary key. How these entries would look like for each kind of context used in this thesis will be explained in the second part of this section.

The second table contains all context types known to the robot and is going to be called *context types table*. For each type of context the identifiable *ContextName* is provided as the primary key which can be used to reference entries from the context table. In the context data table the ContextName field act as a foreign key. On top of that, a second column *RetrieveType* specifies how the recommendation module should retrieve this kind of context from the context data table. In this thesis, the values `LIFO` and `Last ... Minutes` are going to be used in this column, though other types are possible. If another type should be added, the developer must implement the method of retrieval in the context assembly module.

The type LIFO (last in first out) refers to context types where it suffices to only retrieve the latest entry. This is the case when there can only one thing be true at any time. For instance, if evaluating the presence of users, either there is at least one user present or there is not. In that case, only the most recent piece of information matters.

The other possibility is that more than one piece of recent context information should be considered. The robot can for instance detect multiple objects in its environment at the same time, but each object would be a separate entry. Hence, every object detected recently, e.g. in the last couple of minutes, should be included in the current context.

This leads to the question of how old context information can be to be still considered current or recent context. The time period should not be too long, as in that case the derived recommendation may be no longer fitting. If the time period is too short, it could happen that only little information was added in that time which might make it harder to match more complex recommendation derivation rules. For this concept a time frame of five minutes is proposed, hence the RetrieveType `LastFiveMinutes`, though it would have to be evaluated in practice if that time frame both satisfies the users as well as leads to good recommendations.

It must be kept in mind that it is not necessarily the goal of this thesis to create a robot that reacts to current circumstances in real time, for instance answering the doorbell, but to proactively suggest activities based on the circumstances, such as offering to make tea when the user has a visitor. These suggestions aim to enrich the user's life but are not time sensitive and can be neglected in favour of more important tasks. However, the suggestions should still be relevant by the time they are offered. While for some kinds of context the exact time frame is negligible, for instance when basing a recommendation on the current date or part of the day, for others five minutes could be too long, such as when the robot reacts to an ADL.

The time frame also depends on how frequently the context information is provided by all the different sources. If one source provides information very rarely, this type of context will not be considered in every recommendation creation cycle. Potentially it might be helpful to synchronise the schedules between when a lot of new information comes into the database and when the robot retrieves the current context. Defining the acceptable time frame for each type of context information and developing a useful schedule for retrieving the information is beyond the scope of this thesis, as a lot depends on the actual conditions of the participating real life devices. The time frame of five minutes has been chosen as an example value but there is no claim that this is a value that works for every kind of context.

If context information has been in the database for long enough it becomes outdated and is no longer useful. In order to not keep data unnecessarily long in the database and potentially take up a lot of disc space, a retention period for the context data table can be set up, which means the data will be deleted after in has been in the database for a certain amount of time.

Lastly, the question remains where to deploy the database. The most important criterion when choosing a location is that the database must be easily accessible for all parties involved, such as the robot and any external device that provides context information. If allowed by the robot's architecture, it is preferable to run the database on the robot's operating system. That would mean no additional devices/servers are required, which makes the feature easier and cheaper to implement. Furthermore, there would be no connectivity issues, as the robot would always have access to the database. If other devices temporarily can not access the database the type of context provided by them can not be used to derive recommendations but the feature itself remains usable. However, if that is not possible, the database could be deployed on an external server. In his thesis, Hauptvogel showed how to have smart home sensors send their data to a database deployed on a smart home hub which is running on a Raspberry Pi 3 [Hau20]. A similar setup could be used if an external database is necessary.

The types of context in the context database: In the previous chapter, context information considered relevant for this thesis was identified (see Figure 2.1). Hereafter, how database entries for the identified relevant context might look like and how it can be gathered.

Present users: There are two possibilities for using the user presence context. The robot could sense the mere existence of (an) unspecified user(s) in its periphery or it could recognise a specific user. In the latter case, it is imaginable to let knowledge about the user and their preferences influence the decisions made. For instance, over time decision models customised for each known user could be created in the optimisation process. As it has been already explained going into too much detail for the optimisation process is out of scope for this thesis. Nevertheless, this possibility should be considered in future research. In this thesis, the simpler first case is assumed, i.e. that the robot simply knows if at least one user is present. Furthermore, to limit the complexity of the prototype in this thesis the multi-user case will be ignored and only the presence of one user will be considered.

Making a suggestion when no user is there to perceive it would not make much sense, hence this information is crucial for the robot to make suggestions. Recognising a user's presence requires a recognition algorithm processing the data collected from the robot's sensors, such as cameras or motion sensors. This must be done before writing to the context database. The context data table expects an entry in this category in the form of `[Timestamp | 'UserPresence' | (present|none)]`. The context types table entry for the user context looks like this: `['UserPresence' | LIFO]`. The RetrieveType LIFO (Last In First Out) was chosen, because there can be only one current entry. It must be noted, that for LIFO entries the time stamp must also be regarded. Even though only the last entry matters, it should not be outdated. Which amount of time is acceptable to have passed since the last entry was written must be determined in practice.

Nearby objects: In order to detect objects that could be relevant for an assistance robot the gathered sensor data, e.g. video material, must be processed by object detection and classification algorithms before it can enter the context database. The context data table expects an entry in this category in the form of `[Timestamp | 'Object' | Name of Object]`. The context types table entry for the user context looks like `['Object' | LastFiveMinutes]`, because multiple objects can be detected in the robot's periphery at the same time.

Situational events such as ADLs: Detecting situational events such as ADLs is quite complex. Hence, a preprocessing and classification step is necessary here as well. In his thesis, Hauptvogel presented a concept for detecting user activities in a smart-home environment [Hau20]. Smart Home sensors were used to observe the environment, this data was then send to a smart home hub which saved the sensor data to a time series database. In the next step, a hybrid approach based on machine learning and propositional logic was used to classify the activities and the identified ADLs were stored in a relational database. They propose a notification service to access this database and communicate the data to other systems. This interface can be used to bring ADL data into the context database. The context data table expects an entry in this category in the form of `[Timestamp | 'ADL' | Name of ADL]`. The context types table entry for the user context looks like `['ADL' | LIFO]`, because the robot should only react to the most recent ADL as reacting to an older ADL or even multiple ADLs might confuse the user.

Location of robot, user or ADL: This type of context has three components, the location of the robot, the user(s) or a detected ADL. Those three entities can be located in the same place at the same time, but they do not necessarily have to be. The robot can easily be in another room than the user, and if an ADL is detected that does not mean that all users are in the same location as where the ADL was detected. The robot's location can be retrieved via self-localising mechanisms that are usually used for navigation purposes. Localising users and ADLs might be achieved through external sensors in the environment.

However, considering all three of these locations and any possible combinations makes considering this type of context quite complex. It has already been established that this thesis will not consider a multi-user scenario, hence it can be assumed that the user and ADL are in the same location. Adding the assumption that the robot follows the user around to always be able to provide support, the user, robot and ADL are in the same location for the prototype in this thesis. Future research can evaluate which options present themselves when considering the three locations as separate information.

The context data table entry should look like this: `[Timestamp | 'Location' | Name of Room]`. The name of the room was chosen as it is a general enough description of a location without being too general. Using rooms naturally only works indoors where the robot can identify them, however, this thesis does not consider the outdoors. The context types table expects an entry in this category in the form of `['Location' | LIFO]`. As one can only be in one location at a time, the LIFO retrieve type must be chosen.

Time of day: This type of context information is obtained easily through accessing the system time. While every database entry should have a timestamp, it is not necessary to store the current time in the context database. When preparing the current context to match the rules it is possible to pre-classify the time into time intervals such as morning, noon or evening. The other possibility, which should be preferred, is that the rules are created in a way to consider time intervals, i.e. time between 14:00 and 16:00. This way, the rules are more flexible.

Historic information about tasks and routines: While historic information is crucial to optimising the context-related support offered on the long run, it is the opposite of current context and not suited well to trigger a support suggestion. Hence, this type of context will be ignored for now, but becomes very relevant in the optimisation process.

Accessible devices, their abilities and availability: It is necessary for the robot to know if a device is available before suggesting an action that involves it. For instance, if the robot knows a vacuum robot is available, this enables the suggestion to send the vacuum robot to clean up. Even though the abilities of the device do belong to this type of context, they are not relevant for the concept in this thesis. This information is important when designing the decision rules, but in order to make a suggestion the robot does not need to know what the device can do. Hence, only the availability of devices used in the suggestion rules will be entered into the context database. If a device is available, the context data table expects an entry in this category in the form of `[Timestamp | 'Device' | Name of Device]`. The context types table entry for the user context looks like `['Device' | LastFiveMinutes]`, because there can be multiple devices at the same time.

Non-physical contents such as sounds: Just as other environmental conditions perceived by sensors, sound data has to be classified in order to be usable for the recommendation system. There are multiple ways to classify this type of data imaginable, for instance specific sounds could be recognised or the volume level could be measured. If certain sounds are identified this could trigger a support suggestion. On top of that, the noise level could influence how suggestions are made. This last point could be considered in further research, while this concept focuses on identified sounds as context. The context data table expects an entry in this category in the form of `[Timestamp | 'Sound' | Name of identified sound]`. The context types table entry for the user context looks like `['Sound' | LastFiveMinutes]`, because multiple sounds can be perceived at the same time or close to each other. It can be assumed that users would accept the

Timestamp	ContextName (FK)	Details
15:39:46	Sounds	Doorbell
15:37:38	Device	Coffeemaker
15:37:34	Device	Vacuum
15:35:03	UserPresence	present
15:34:48	Object	Cup
15:34:24	Object	Book
15:34:13	ADL	Reading
15:33:54	Location	Living Room
15:32:39	Device	Coffeemaker
15:32:35	Device	Vacuum
15:30:05	UserPresence	present
15:29:59	Sounds	Music
15:29:27	ADL	Cooking
15:28:52	Location	Kitchen
15:27:36	Device	Coffeemaker
15:26:22	Object	Bag
15:25:57	Location	Hallway
15:25:05	UserPresence	present
15:22:37	Device	Coffeemaker
15:20:06	UserPresence	none
15:17:36	Device	Coffeemaker
15:15:03	UserPresence	none
15:12:38	Device	Coffeemaker
15:10:04	UserPresence	none

Table 3.1 – The *Context Data* table filled with sample data

robot reacting to a sound even when in the meantime another sound was present.

An example for how the context data table could look like can be found in Table 3.1. The entries in the example table describe a scenario where the robot is home alone at first, the only device available is the coffee maker. Then the user comes home, puts their bag away in the hallway and proceeds to the kitchen to make themselves a cup of coffee while listening to music. Afterwards they go to the living room where they connect the vacuum robot to the charging station, making it available again. The user sits down with their cup of coffee and a book, when suddenly the doorbell chimes.

The Context Assembly Module: In order for the data to be processed it must be transported from the database to the processing unit. This could be done via a context assembly module that periodically gets the data from the database, for instance via a SQL query, and provides the result as properly formatted input for the module deriving a suggestion from the current context. The service would first retrieve the whole *context types* table (see Listing 3.1).

```
SELECT *
FROM ContextTypes
```

Listing 3.1 – SQL for retrieving the context types

Context Name (PK)	RetrieveType
UserPresence	LIFO
Object	LastFiveMinutes
ADL	LIFO
Location	LIFO
Device	LastFiveMinutes
Sounds	LastFiveMinutes

Table 3.2 – The context types considered in this concept

In Table 3.2 the context types described above are accumulated. For every entry in this table, i.e. for every known context, the *context data* table would be queried. How this query looks like depends on the *retriveType* defined in the *context types* table.

For LIFO entries, only the latest entry of this context type is retrieved, if it was added within the defined 'current context' period (see Listing 3.2). In this thesis, this period is defined as five minutes, hence the entry would have to be younger than five minutes. It should be evaluated in practice if this period matches the user expectations or if a different time frame is more suitable.

```
SELECT *
FROM ContextData
WHERE ContextName = "Name of Context"
AND Time > GETDATE() - 5Minutes
AND most current entry
```

Listing 3.2 – Pseudocode for retrieving the entries for a LIFO context type

For the `LastFiveMinutes` type, all entries added in the 'current context' period for this category are retrieved (see Listing 3.3). If other RetrieveTypes are added by the developer, the method for retrieval must be implemented accordingly.

```
SELECT *
FROM ContextData
WHERE ContextName = "Name of Context"
AND Time > GETDATE() - 5 Minutes
```

Listing 3.3 – Pseudocode for retrieving the entries for a LastFiveMinutes context type

The context assembly module regularly makes a call to the database to retrieve the current context. As the time frame for context to be considered current was defined as five minutes, the module should retrieve the context every five minutes. From the gathered current context a currentContext object is built that can then be used as input for the classification module.

The use of the JSON datatype is proposed as it is a common data exchange format without much overhead. This means it should be widely supported, also it is easily human-readable (compared to for instance XML) which could be helpful for developers. Instead of a JSON Array a JSON Object was chosen, because the order of the entries can neither be ensured nor does it matter. An entry for a context information in the currentContext JSON looks like this: ‘ContextName’: ‘Details’ . An example for a currentContext object can be found in Listing 3.4.

```
{
  "UserPresence": "present",
  "Object": "Book",
  "Object": "Cup",
  "Location": "Kitchen",
  "Device": "Vacuum",
  "Device": "Coffee Maker",
  "Time": "14:07:48"
}
```

Listing 3.4 – Example for a currentContext JSON Object

Processing

When the context assembly module provides the current context as input in the form of a JSON object, the next step is to derive a recommendation. This must be done via a decision process that takes the currentContext object as input and provides an appropriate suggestion as output (see Figure 3.5).

Derived from the requirements developed in the previous chapter, a rule-based approach is going to be proposed in this concept. The classifier module uses a decision making process in order to derive suggestions from a set of context information. In this concept, the decision making process is rule-based, but other decision making processes are also possible. This will be discussed in more detail in the optimisation process. Deriving the recommendations from static rules has the advantage that the robot’s behaviour is consistent and hence transparent to the users.

The rule set contains default rules in order to enable the user to immediately start using the feature. This addresses the cold start problem, which is inherent to recommender systems. The cold start problem relates to the challenge that the system cannot yet draw any conclusions when it is first started as there is insufficient information. In the case of this thesis that means that the robot could not yet gather any information about the context or user behaviour history to create any recommendation rules.

Hence, default rules are going to be proposed as an initial means to make decisions. A selection of concrete default rules is going to be proposed in Section 3.2. Over time it is desirable that the decision process is optimised in order to better fit the user’s preferences as more and more data becomes available. A possible optimisation process is going to be proposed in Section 3.1.2.

If current context input is provided, the module tries to find a match between the precondition of a rule and a subset of the context information provided. As there can be a plethora of context information included in the current context it is unlikely the full context set will completely match a rule. However, it should be made sure that the conditions for the recommendations are specific enough as to not be triggered constantly. If a rule is too simple, for instance only relies on the fact that the user is in the kitchen, the user might be annoyed to be offered support every time they enter the kitchen. On top of that, if an offer for support is declined, the context might not immediately change. In that case, the robot should not immediately make the same suggestion

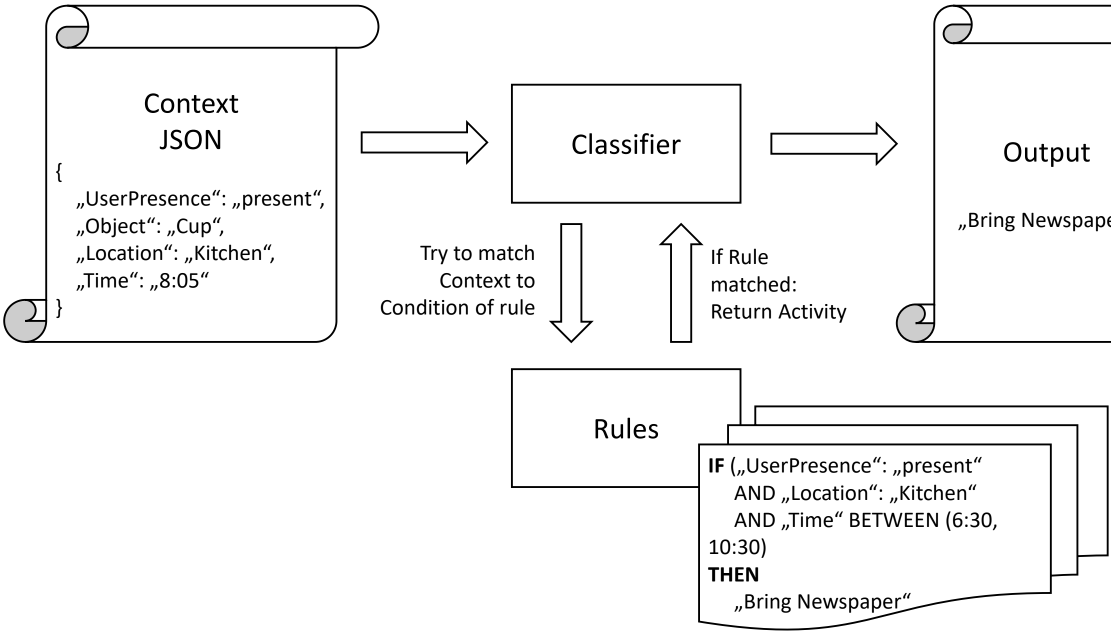


Figure 3.5 – The process for deriving a suggestion from the current context object using rules

again. The output module described in the next section is responsible for making sure the same suggestion is not immediately made again.

If there are multiple rules that match the current context, the recommender must chose one of them. The simplest solution is to to choose the first match found, but it is also imaginable to include a ranking for the rules that can be adapted in the optimisation process. A simple starting ranking could be giving the rules a random order, another option is that the recommender could always try to choose the rule that matches the largest subset of the current context in order to make situation-specific recommendations. Furthermore, the classifier could assign a likelihood to a rule referring to how likely this is a good suggestion for the user.

For the prototype in this thesis the simplest case of taking the first match found will be implemented, to keep the complexity of the prototype manageable. As the prototype default rules are going to be hand-picked, rules can be chosen that do not have matching preconditions. That way, there are not default suggestions that are never proposed because of a simple static recommendation ranking or selection process. However, in further research the issue of ordering the recommendations needs to be addressed.

The default rules proposed in this concept are structured as first order logic statements in the form of `IF context THEN recommendation`. That way, the connection between the cause and resulting action, i.e. the triggering context and derived recommendation, is more obvious to the user and the robot's behaviour appears more transparent. When a match is found, the classification module must output the data in order for the robot to communicate it to the user. How exactly that must be done depends on the implementation of the robot and its activities. For the prototype in this thesis, the classification module outputs the identifier of an activity that is going to be suggested (e.g. Id or unique name).

Output

Once a recommendation has been created, the robot must communicate it to the user. The output module receives the identifier of the recommended activity the classification module proposed as input. How exactly the recommendation is put out can depend on the robot, its available modalities and the users preferences. For the concept and prototype in this thesis it is assumed that the robot is able to output a simple string via a display or speech.

The input must contain all necessary information to build a string that can be output to the user via the robot's text-to-speech functionality. Which information is crucial depends on how the robot words its suggestions. The possibilities are discussed in more detail in Section 3.3. Some options would only require the name of the activity, as the user will directly give a command if inspired by the robot to do so. If however the user is only required to say yes to execute the proposed activity, information on how to do that is required. As it must be evaluated in the user study which option users prefer, for the concept and prototype in this thesis it is not going to be considered how exactly the proposed tasks are going to be executed after the recommendation was made. This thesis only aims at deriving a context-based recommendation.

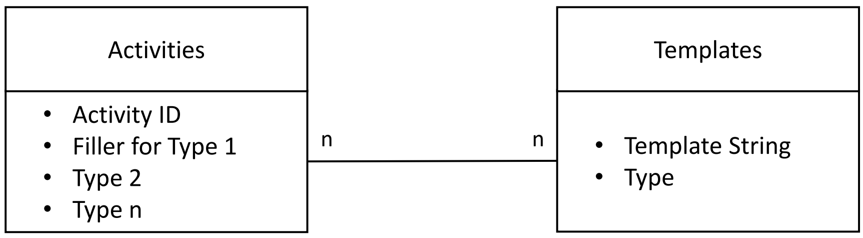


Figure 3.6 – The database schema for the creation of output strings

To create a text string that sounds like natural language a template approach is proposed. The basic idea is that a selected template is filled with a string, depending on which activity should be proposed, to create the output. As the English language and the selected templates permit this, going forward it is assumed that this only required the concatenation of two strings: the template as the first part and the activity specific filler as the second part. Other languages or more complex templates may require the use of a template language for encoding the template.

In the proposed concept in this thesis there are two tables in a database (see Figure 3.6), either the context database or another internal database. The *template table* contains the templates (see Table 3.3). Each entry has a template string and a type. The type defines how a string to complete the template would have to look like. For instance, if the template is 'Do you want me to ...' the term 'hand you the towel?' would complete it. For the template 'Would you like it if I ...' the string 'handed you the towel?' would have to be used. The names of the types can be arbitrary.

In the second table, the *activity table*, each activity that can be recommended has an entry (see Table 3.4). It includes a field for the identifier of the activity and a field for every possible type from the template table. For the activity 'Handing a towel' the two previously mentioned strings are stored in the field for the corresponding type.

When the output module receives the id of an activity to recommend, it will first look up the activity in the activity table. It arbitrarily chooses a type that is defined for this activity and gets a

TemplateString	Type
'Do you want me to'	1
'Would you like it if I'	2
'Can I'	1
'Should I'	1

Table 3.3 – An example for the templates table

corresponding template from the template table. By arbitrarily choosing a template there is variety in the way the robot phrases its suggestions, which more closely resembles natural behaviour. Lastly, the two components are concatenated which creates the output string.

ActivityID	Type1	Type2
'SetTable'	'set the table?'	'set the table?'
'HandTowel'	'hand you the towel?'	'handed you the towel?'
'PlayMusic'	'play music?'	'played music?'
'MakeCoffee'	'make coffee?'	'made coffee?'

Table 3.4 – An example for the activities table

How exactly the template looks depends on how the recommendations should be worded, which is going to be discussed in Section 3.3. If more information is needed for the template or if more complex templates are required, the template mechanism proposed here needs to be adapted. If a new template should be added, the developer must simply add the new template and its type to the template table. If the template requires a new type, a new field for this type must be added to the activity table and the strings for the activities must be entered manually.

It has already been mentioned that before putting out the recommendation, the output module should make sure that the same recommendation is not made again immediately because the context stayed the same. One way to honour that is to keep a *recommendation log* where the robot records all the recommendations it makes to the user. The log contains a time stamp, the full context set that triggered the recommendation, the derived recommendation and the user's reaction to the recommendation (accept or decline). If the recommender finds that a rule is triggered but the same recommendation was just made, it should refrain from making it again immediately after. How much time should have passed in order for users to find it acceptable to hear the same recommendation again should be evaluated in a real time scenario. For the prototype in this thesis it will be assumed that the robot will not make the same suggestion twice in a row, as the user study can only focus on certain test cases where there is not enough time to mirror a real life scenario. Furthermore, the recommendation log can later be used in the optimisation process to improve the decision process.

An entry in the recommendation log database should have the following form: `[Timestamp | Triggering Context (JSON) | Recommendation (Activity ID) | Reaction (accept/decline/ignore)]`. The robot writes an entry to the log, which can be a database table in the context database or in a separate database, when the recommendation is made to the user. When the reaction is observed, the entry is updated with a reaction in the previously empty field. How exactly the robot observes the reaction and updates the entry will not be explained here, as what happens after the recommendation is made is out of scope for this thesis. The workflow of the

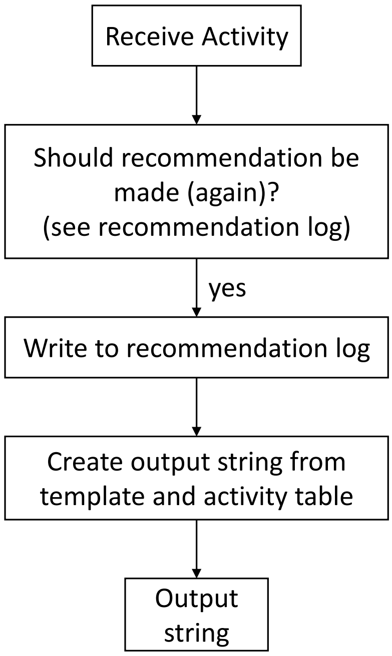


Figure 3.7 – The workflow of the output module

output module considered in this thesis is depicted in Figure 3.7.

Another detail that should be considered in further research is the fact that the proactive recommendations should not interfere with the execution of user commands or other more important proactive tasks. Considerations regarding the prioritisation of robotic activities were made in a previous work by this author [Zie21]. The proactive support suggestions in this thesis would fall under the category of circumstantial tasks proposed in this thesis.

3.1.2 Optimisation Process

The second process represented in the recommendation module is the optimisation of the decision making process. The provided default rule set should transform over time into a decision making process that provides the most value to the particular user(s) by adapting to the observation of their overall behaviour and their reactions to recommendations made based on the default rules.

A process that adapts itself falls under the category of the artificial intelligence approach of machine learning. This concept proposes that during the cold start phase the default rules are used to provide recommendations, while data is collected to fuel a machine learning algorithm that can adapt the decision making process to the user. Firstly, a decision tree model should be trained to mirror the default rules, i.e. make the same suggestions under the same context circumstances as the default rules. If the model can sufficiently mirror the decisions made by the static rule set, it can replace the rule set as a classifier (see Figure 3.8).

The next step would be to adapt the decision model to better fit the user's habits and prefer-

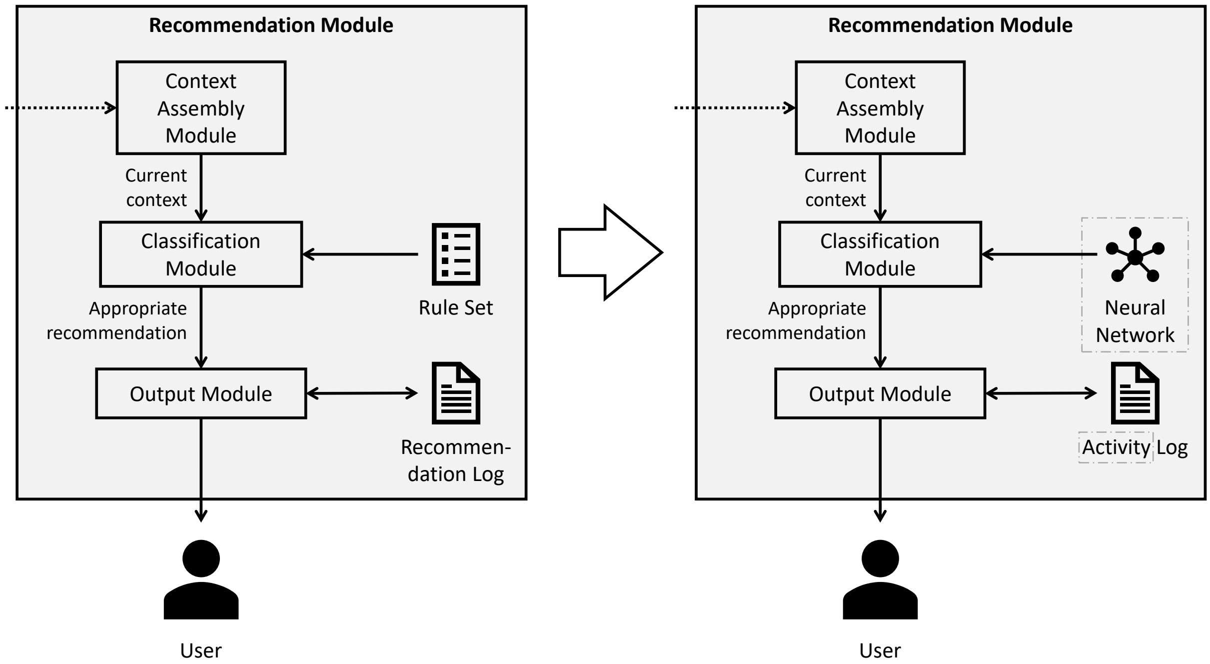


Figure 3.8 – Switching from a rule-based to a ML-based classification approach

ences. In order to do that, the recommendation module could try to find patterns in the user's behaviour and in their reaction to the existing suggestion rules. It must be noted, that this process assumes that the robot only deals with one user. If there are multiple users, adapting to all their needs at the same time would not result in a personalised decision model. However, if the robot can recognise the users it can have a decision model for every user that is stored with the corresponding user profile.

In order to implement to the optimisation process, a deep learning approach is proposed. This means that an artificial neural network is created that takes the currentContext as an input and suggests an activity as an output. The neural network is created by a deep learning algorithm which trains a neural network based on training data (see Figure 3.9). The training data contains sample input and expected output. The training algorithm then creates the parameters for the neural network based on these training data.

In this concept three influences for the training data are going to be proposed. This is not to say that there might not be other ways of customising the decision model.

Evaluate User Reactions on Recommendations The first approach is based on finding patterns in the user's reaction to the suggestions made. The information to base this on can be found in the recommendation log mentioned earlier. When a recommendation is made a new entry is created. When the user receives the recommendation that entry is updated to include the user's reaction to the recommendation. A deep learning algorithm can recognise the correlation of full context, triggered rule and evoked user reaction. If a user always declines a certain suggestion, after a certain amount of times this suggestion can be deactivated. To take the example of grocery bags, the user might want to put away the groceries themselves without the robot's help.

If the user only accepts when another context information is present that is not yet included in the decision tree conditions, the condition can be adapted to include it to only offer this sugges-

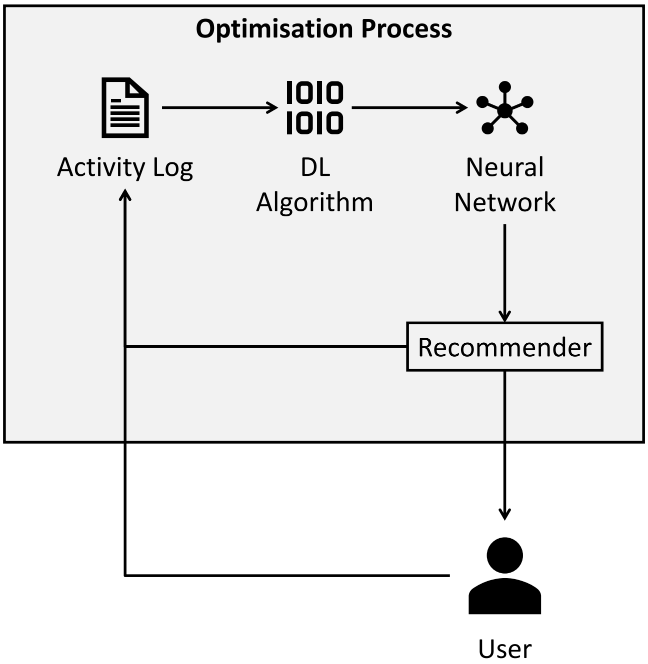


Figure 3.9 – The proposed optimisation process

tion when the user would accept it. For instance, the user might decline the offer to help with the groceries in the morning, because the still feel energized enough to do it themselves. However, in the afternoon they gladly accept because they would rather want to relax. The robot could recognise this pattern and stop suggesting to help with the groceries in the morning.

If the user regularly declines a suggestion in a specific context but consistently asks the robot to do something else immediately after, the neural network might be adapted to include the action that user actually wants to be executed in that situation. Maybe the user does not want help putting away the groceries, but instead is thirsty after shopping and would like a glass of water. If the robot learns that fact they can anticipate the user's request. Finally, it is imaginable that if a rank is implemented, each time a robot accepts a suggestion the rank of that recommendation improves and vice versa. That means the suggestion is more likely to be made again to the user.

Observe User Routines The second approach to customise the decision model is based in the context history and the command history. For this reason, a command log should be kept including all commands the user gave to the robot, including a time stamp and the full context at the time the command was given. A deep learning algorithm can find patterns based on which commands are usually expressed under which circumstances. When in the presence of a specific context a certain directive is always given, the robot could try to anticipate the user's command. The robot might notice that the user always requests hot tea if the outside temperature is under 15°C, it is the afternoon and the user just re-entered the house. To provide the user with a valuable service the robot could predict the user's request and proactively offer them a valuable service.

Direct User Control Lastly, the decision model could also be adapted by the user in order to give them more control over the suggestions made. If the robot makes a suggestion they do not like, they can tell it to stop making that suggestion.

Training data: The training data is collected in an *activity log* table. In this table, data about the user's routines, the recommendations made and the reaction to these recommendations is stored. The schema of this table looks like this: `[Timestamp | Context | Recommendation/Action | Reaction]`. It was mentioned earlier that the recommendation log, where every recommendation made is documented, can be used in the optimisation process. The data from the activity log can go into the activity log as is or the recommendation log could be adapted (renaming of fields) to be used as the activity log. Secondly, the activity log contains all the commands the user gave, including the time and the current context at that time. Keeping a separate command log is not necessary. For the reaction field a positive reaction can be entered, as the user made the command themselves and thus should appreciate the action in that context. Lastly, if a user manually tells the robot to stop making a suggestion, this is recorded in the reaction field. A difference should be made between when the user declines a suggestion, as they might generally appreciate it but for an unknown reason might not in that moment, and when the user consciously opts out of a suggestion. The first case should only be considered after a certain amount of negative reactions was recorded, while the latter should take effect immediately. How exactly this can be implemented should be the focus of further research concerning the optimisation process.

3.2 Default Rules

The existence of a default rule set has been requested by the requirements developed in the previous chapter. Default rules enable users to immediately use the proactive support feature without encountering the cold start problem commonly occurring for machine learning applications. The optimisation process described in the previous section is a kind of machine learning process, as the robot itself creates, deletes and adjusts suggestion rules with the recommendation module.

The need for default rules being shown, the other requirement for these rules is them being appropriate and providing value to the user. This implies that the suggested default rules should be logical, i.e. they make sense in the given context, and valuable, i.e. they provide the user with an additional service that benefits the user. In this section, suggestions for default rules are going to be made based on the earlier identified relevant context and the research presented in Section 1.2.2 regarding how assistance robots can support elderly people in their daily lives.

In order to propose rules that provide value it is necessary to further define the target demographic for this concept. There are many possible stakeholders that might interact with an assistance robot, for instance the primary users, which have already been identified as the target demographic for this thesis, care personnel or relatives. Even with elderly people identified as the target group there is a broad range of independence that affects which robot suggestion are perceived as useful. People requiring a lot of assistance in their daily live, for instance due to conditions such as dementia, may appreciate the robot offering to show how an action is done or provide help washing themselves, while the same suggestions might even offend a person living independently at home with no assistance. Though assistance robots can offer value in all of these scenarios, this thesis will focus on elderly people (over the age of 65) that live independently in their own home and require minimal physical assistance. The goal of the assistance robot is to let them maintain their independence and to enable them to keep living like that for longer.

In the following list the context information relevant for the concept identified earlier (see Figure 2.1) are going to be repeated.

List of relevant context

- present users
- nearby objects
- situational events such as ADLs
- location of robot, user or ADL
- time of day
- historic information about tasks and routines
- accessible devices, their abilities and availability
- non-physical contents

Going forward, default rules are going to be proposed considering the relevant context and the suggestions for robotic support by Esposito et al. [Esp+16] and Ziemann [Zie21] (see Appendix A.1.1 and A.1.2). The two lists do not only differ in size but also in focus. Esposito et al. focus more on broad categories that match the general goals of the employment of an assistance robot, such as social interaction, information, physical support, health or mobility. They offer suggestions based on these categories of robot usage. The list provided in an earlier work of this author is based on concrete ADLs. In a survey participants were asked to provide suggestions for robotic support for different ADLs which resulted in the aforementioned list. As ADLs were already categorised as context (situational events), the suggestions made in combination with the ADL they were proposed for already loosely resemble rules for context-based support. Hence, this list will be mainly considered when proposing default rules.

It must be mentioned, that the default rule set that is going to be proposed will not be exhaustive by any means. Which rules are considered useful is always a biased decision and one person can never find an optimal rule set that works for most people as a baseline on their own. Hence, the proposed list should only be considered a starting point for further refinement of default rules. Moreover, it has already been mentioned that the target user group greatly influences the optimal default rule set. On top of that, which suggestions can be made also depends on the capabilities of the assistance robot and the external devices available. This limitation is ignored for now and an ideal assistance robot with all abilities that are reasonable and desirable is assumed.

```
1  ADL 'Showering' detected (e.g. user location + bathroom humidity sensor) → Offer to hand towel
2  ADL 'Cooking' detected → Offer to set the table
3  ADL 'Eating' detected → Offer to play music
4  ADL 'Waking up' detected (e.g. user location + time + alarm) → Offer physical help getting out of bed
5  ADL 'Getting out of bed' detected (e.g. user location + time) → Offer to prepare clothing
6  ADL 'Going to bed' detected (e.g. user location + time) → Offer to dim the lights
7  ADL 'Taking medication' detected → Offer to document that medication was taken
8  A certain level of dirtiness is detected → Offer to clean up, send the vacuum robot
```

```
User detected in the kitchen with grocery bags → Offer to put away groceries
ADL 'Getting the Mail' detected → Offer to read out mail
User is detected using the computer → Offer dictating function
ADL 'Exercise' detected → Offer to provide instruction for further exercises
ADL 'Exercise' detected → Offer to eliminate tripping hazards
ADL 'Leaving the House' detected → Offer to accompany user
Newspaper detected in the morning → Offer to read newspaper aloud
```

Listing 3.5 – Possible default rules

3.3 Phrasing Proactive Recommendations

There are certain requirements for the proactive support suggestion system that relate to how the robot interacts with the user, namely that information should be obvious and engaging and the whole system should be intuitive to use. While in the concept described earlier, suggestions are constructed as yes/no questions with no additional explanation, it should be discussed whether a different wording might be beneficial.

Firstly, there is the question whether the robot should offer support using a call-to-action (CTA), i.e. the robot prompts the user to ask a question, or whether the robot should ask a simple yes/no question. A dedicated CTA could be more engaging as it activates the user to communicate with the robot. The downside, however, is that it requires a longer answer from the user compared to the robot directly asking if it should do something. The upside is that users might find it less intrusive as they get to have the choice to phrase the command the way they want it or even make a different request. Gollasch and Weber [GW21] conducted a study examining the preferences of elderly people for using voice assistances. Assuming many users prefer talking to an assistance robot as a mode of communication, the findings of this study can also be applied for this thesis. They found that users prefer simple dialogues and recommend the use of yes/no questions. Hence, this option is to be preferred.

Secondly, it could be beneficial for reasons of transparency to explain to the users why the robot makes a concrete suggestion. The upside is that users might have a greater sense of control, as they understand better why the robot does what it does. The downside is that explaining that the robot offers a towel because the humidity is high in the bathroom takes longer than just offering the towel. If users must listen to the explanation every time a suggestion is made, they might get annoyed. If explanations are given, they should be worded as simple and short as possible, and it should be considered to not give them each time a suggestion is made, but only if they provide value.

There is also the question of implementability, especially for computer-generated suggestions. How to construct a phrase offering support without explanation why has been described earlier in this chapter. Providing a phrase for the context explanation however might be more tedious, especially considering that the same suggestion might be made for different reasons in different scenarios. For this thesis, the simple approach without explanation was chosen and will be implemented in the prototype. Whether users have a need for additional explanations should be examined in future work, for instance using a fully functioning assistance robot in a real life scenario.

3.4 An Example for Deriving a Suggestion from the Current Context

After the concept for this thesis has been thoroughly described in the previous sections, in this section an example for how this workflow could look in action is going to be presented. As the goal of this thesis is to support elderly people during ADLs, a scenario related to a concrete ADL was chosen for this example.

The context the robot reacts to might be the ADL 'Cooking' in the evening. The associated rule will lead the robot to propose to set the table.

Firstly, the context information is accumulated in the context database. The triggering entry for this example might look like this: `[18:37 | ADL | Cooking]`. From the database the context assembly module retrieves the full current context, which contains the aforementioned entry as well as other possible entries, for instance related to available devices, the location or the presence of the user. In order to retrieve the current context entries, firstly all entries from the context types table are retrieved (see Listing 3.1). Then, for each context type the current entries are retrieved using the specified retrieve type. Lastly, the entries are accumulated in a JSON Object as in Listing 3.4. In this example the JSON object would have an entry in the form of
`{'ADL': 'Cooking', 'Time': '18:40'}`.

The current context JSON object is then given to the classifier as input. The classifier has access to a set of rules and tries to find matches between the conditions of those rules and the current context object. In the case of this example, the rule could look like this:
`IF (ADL == Cooking) AND (Time BETWEEN 17:30 AND 19:30) THEN "SetTable"`.
The entry mentioned earlier matches the first part of this condition and the current time matches the second part. Hence, the output of the classifier would be the 'SetTable' activity.

This information is then passed to the output module. This module would firstly check the recommendation log for whether the exact same recommendation has already been made recently. If that is not the case or enough time has passed to make it conceivable for the user to tolerate the recommendation being made again, the activity is put in the recommendation log. This entry would look like this:
`[18:40 | 'ADL': 'Cooking', 'Time': '18:40' | "SetTable" | ""]`.
The context JSON was abbreviated in this example and would likely contain more current context data than just the one relevant for the suggestion.

Following that, the output string is created by firstly looking up the activity Id ('SetTable') in the activity table (see Table 3.4). A defined template type is chosen at random, for instance type 1. Then, a random template for this type is chosen from the templates table (see Table 3.3), for instance 'Can I'. The template string and the corresponding type string from the activity table ('set the table?') are concatenated. The resulting string, 'Can I set the table?' is lastly output by the robot.

3.5 Summary

In this chapter, a concept for making suggestions for how an assistance robot can proactively support elderly people based on context information has been proposed. There are two parts to the concept.

Firstly, the basic process, called the recommendation process, for how the concept data gets evaluated in order to derive a suggestion was explained. The context data is stored in a database and periodically requested by the context assembly module. This module then builds a JSON object containing the current context retrieved from the database which serves as the input for the classification module. Using a rule set containing default rules the classification module tries to find a match between a rule condition and the current context. If an activity to recommend can be derived, its identifier is passed on to the output module which builds an output string that can be communicated to the user. The recommendation process is going to be implemented in the prototype.

Secondly, a concept for an optimisation process was explained on a high level, as this process is not going to be implemented in the prototype. It was proposed to train a neural network based on the default rules and when it can sufficiently mirror the decisions made by the rule, the rule set as a classifier is exchanged with the neural network. To optimise the neural network there could be an activity log that records all the recommendations made and the resulting user reaction, as well as the user's commands to the robot and the context at that time. A training algorithm would use these data as training data to periodically create a new neural network better adapted to the user's preferences.

Moreover, default rules have been proposed and recommendations for how the suggestions can be phrased were made. Lastly, using the scenario of the robot offering to set the table when it perceives the cooking activity an example run trough the previously described workflow was laid out.

4 Demonstrating the Concept

In the previous chapter a concept for creating context-based support suggestions was presented. To prove the technical feasibility of this concept, a prototype was created implementing the proposed architecture for the basic recommendation process. As mentioned in Chapter 3, the optimisation process was excluded from the prototype as sufficiently developing it is beyond the scope of this thesis.

The Assistance Robot Loomo Platform The task description for this thesis demands the realisation of the concept using the Android-based robot Loomo (see Figure 4.1). The robot by Segway-Ninebot was first shown in 2016[1] and is commercially available since 2018[2].

Loomo's hardware consists of a Segway/Ninebot self-balancing transporter combined with an Intel Atom-based computing unit and various sensors and actuators to perceive and interact with the environment, such as an Intel RealSense ZR300 depth-sensing camera as well as ultrasonic, infrared distance and touch sensors[3]. The robot is equipped with a 4.3 inch LCD screen and is 65cm tall. At around 2000€[3] it is relatively affordable compared to other assistance robot technologies.

Figure 4.1 – The self balancing transporter and personal robot Loomo[3]

The operating system is based on Android 5.1 and a free Android SDK[4] is available for creating extensions and accessing the sensors and actuators. Developers can create Android apps for the

[1] https://techcrunch.com/2016/01/07/segway-has-created-a-robot-that-connects-to-your-two-wheeled-scooter/
[2] https://www.intelrealsense.com/loomo/
[3] https://store.segway.com/segway-loomo-mini-transporter-robot-sidekick
[4] https://developer.segwayrobotics.com/developer/documents/segway-robots-sdk.html

robot to extend its function range.

The purpose of the prototype is to demonstrate that the architecture depicted in Figure 3.3 succeeds at generating a support suggestion from a collection of context data using a rule-based approach. The prototype will use dummy context data to trigger specific rules and the output will be displayed in text form. This does not require actually controlling the robot, hence, it is not necessary for the prototype to be executed on the Loomo robot. The mininum SDK version for this prototype app is 21. As the Loomo robot uses API Level 22 (Android 5.1), the app is compatible with the Loomo platform but can also be installed on any other compatible Android device.

4.1 Context Database

Data Storage in Android Android offers the possibility to use SQLite databases in apps to persist data. The database can be accessed by using the SQLite APIs directly, however, the Android documentation does not recommend this approach. Instead, the developers propose the use of the Room persistence library[5], which 'provides an abstraction layer over SQLite to allow fluent database access while harnessing the full power of SQLite'. Moreover, they mention that the use of Room has the benefits of compile-time verification of SQL queries, convenience annotations minimizing repetitive and error-prone boilerplate code as well as streamlined database migration paths.

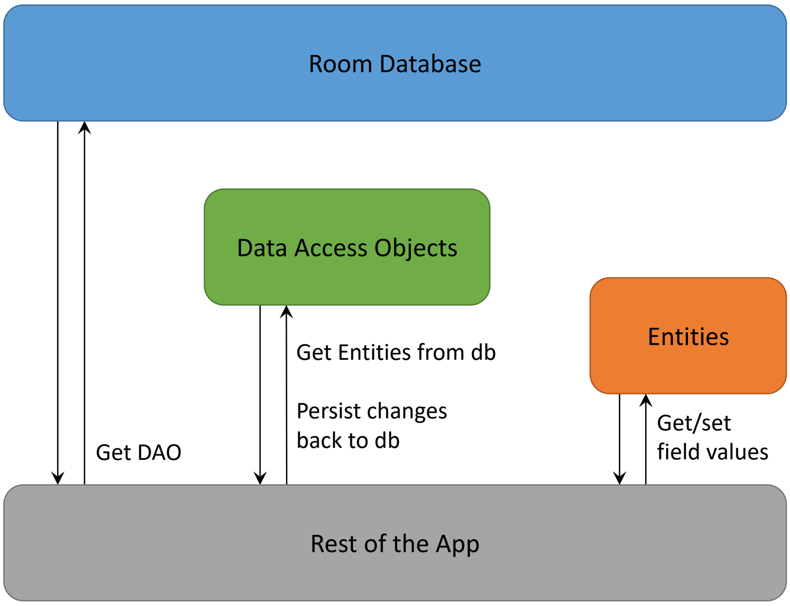


Figure 4.2 – Diagram of Room library architecture (based on Room developer guide diagram[5])

The data model described in the concept matches a relational database model. SQL is usually used with relational database management systems and using the Room library is recommended and well documented by the Android developers. Hence, the approach of using the Room library to access a relational context database was chosen. Going forward, the basic architecture of

[5]https://developer.android.com/training/data-storage/room

a Room database is going to be explained, in order to enable readers to better understand the architecture of the prototype.

There are three major components to a Room database setup (see Figure 4.2). Firstly, the *database* class contains the database and serves as the main access point for the underlying connection to the persisted data. Secondly, there are *data entities*, annotated classes representing the tables of the database. Lastly, Data Access Objects (DAOs) are interfaces providing methods for querying, updating, inserting and deleting data in the database.

In order to retrieve data from the database, an instance of the database is needed. To prevent creating multiple instances of the database, the Android documentation[6] strongly recommends the use of the Singleton pattern. Moreover, the DAO holding the required database access methods needs to be instantiated. To access the data in the database, one of the DAO methods that are associated with an SQL query needs to be executed. It must be noted, that Room does not allow accessing the database in the main thread, as this could potentially lock the UI. Instead, it is recommended to run database operations in a background thread.

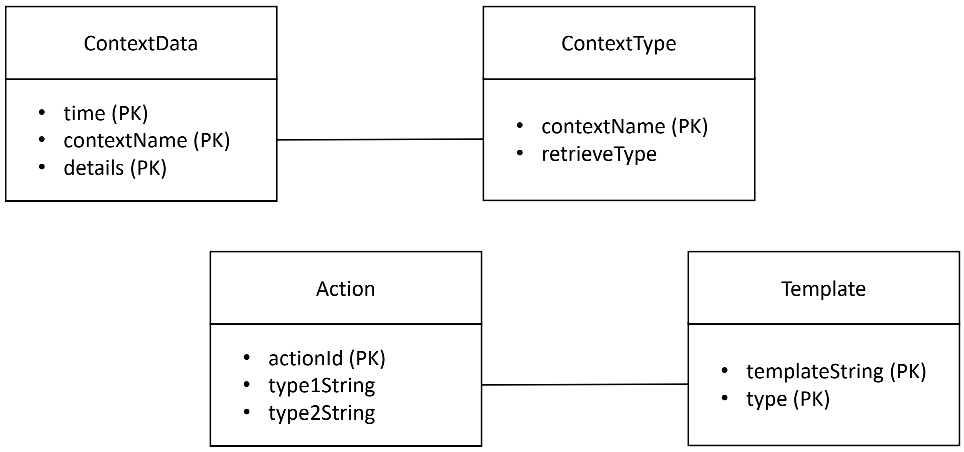


Figure 4.3 – Entities of the context database

Context Database The context database in this prototype consists of four tables (see Figure 4.3) as described in the concept. In order to derive a recommendation, the *ContextData* and *ContextType* tables are required. While the *ContextType* table is filled upon the creation of the activity, the *ContextData* table can be filled with different sets of data through the UI of the *MainActivity*, depending on which scenario the user selects.

Moreover, the database contains the *Template* and *Action* tables to create an output string in the output module. The *Action* table is referred to as *Activities* in the concept and contains information about the activities that can be recommended. As the term 'activity' refers to the Android application component providing a UI, a different term was chosen to use in the code so as to not confuse the two.

The data that is inserted into the tables is stored in csv files, which makes it easy to access and alter the data during the development stage. There is one csv file for the tables ContextType, Action and Template respectively, as well as one file for each scenario (see Section 4.3) to insert

[6] `https://developer.android.com/training/data-storage/room#database`

into the ContextData table. The CSV*Utils* class contains the `getObjectListFromCSV()` method, which reads the contents of the specified csv file, converts each entry to the corresponding object and returns the list of objects to be inserted into the database.

To access the data, two DAOs were created to better separate concerns. The *ContextDao* (see Listing 4.1) contains all queries necessary for accessing the *ContextData* and the ContextType table, while the *OutputDao* can be used to interact with the *Template* and *Action* table. All classes, their attributes and methods can be found in Figure 4.5.

```java
@Dao
public interface ContextDao {
    @Query("SELECT * FROM context_data_table")
    List<ContextData> getAllContextData();
    @Query("SELECT * FROM context_type_table")
    List<ContextType> getAllContextTypes();

    @Insert(onConflict = OnConflictStrategy.REPLACE)
    void insertAllContextTypes(List<ContextType> contextTypes);
    @Insert(onConflict = OnConflictStrategy.REPLACE)
    void insertAllContextData(List<ContextData> contextData);

    @Query("SELECT * FROM context_data_table WHERE contextName = :contextName ORDER BY time DESC")
    List<ContextData> getContextDataLIFO(String contextName);
    @Query("SELECT * FROM context_data_table WHERE contextName = :contextName")
    List<ContextData> getContextDataLastFiveMinutes(String contextName);

    @Query("DELETE FROM context_data_table")
    void deleteAllContextData();
    @Query("DELETE FROM context_type_table")
    void deleteAllContextTypes();
}
```

Listing 4.1 – ContextDao code snippet

4.2 Components of the Prototype

The prototype app consists of four activities (see Figure 4.4). The *MainActivity* corresponds to the context assembly module and is the entry point for the app. Upon creation of the activity, the DAOs and database are initiated and the database tables *ContextType*, *Template* and *Action* are filled with data which is read from a csv file using the CSV*Utils* `getObjectListFromCSV()` method.

From the *MainActivity* the user can navigate to the ViewDatabaseActivity by pressing the *View Database* button, where the content of the ContextData table is displayed. By pressing or gesturing Back, the user returns to the *MainActivity* through the back stack[7].

The second workflow is going to be described in the next paragraphs. All components of the prototype can be found in the UML diagram in Figure 4.5.

[7] `https://developer.android.com/guide/components/activities/tasks-and-back-stack`

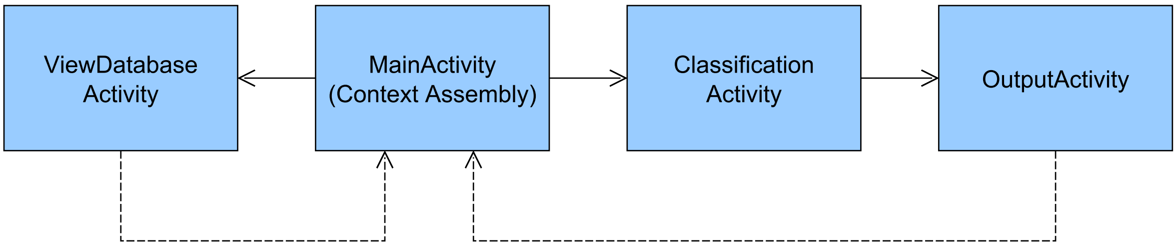


Figure 4.4 – Workflow for the prototype activities

Context Assembly The second workflow (see Figure 4.6) in the prototype app is the previously presented recommendation process. In the *MainActivity* the user has the choice between four scenarios, which are described in more detail in Section 4.3. When a scenario is selected, the *ContextData* table is filled with the corresponding data which is read from a csv file and the selected button is highlighted. The *ContextData* table can be cleared by clicking the *Clear Context Table* button.

Upon clicking the button *Trigger Recommendation*, a *CurrentContextAssembler* AsyncTask is created and executed. There, as described in the concept, all context types are retrieved from the corresponding table. Then, a date matching the dummy context data is assigned. In a real life scenario the current date would be used. Five minutes are subtracted from the date, as only data from the last five minutes are considered current in this prototype. In a real life scenario this value can be adapted and different time frames for different types of context might be chosen.

In the next step, the context data for each kind of context is retrieved from the corresponding table via a Room query. There is one query for each of the retrieval types in the ContextDao. Depending on the context type, only the most current result (LIFO) or all results (LastFiveMinutes) are added to the `currentContext` list. This list is then converted to a JSONArray containing each piece of context information (pair of contextName and details) as a JSONObject. It is not possible to format this data structure as a JSONObject containing the context pairs, as a JSONObject requires unique keys. As the same kind of context might be present multiple times with different details, the JSONArray format was chosen.

The last step involves switching to the *ClassificationActivity*, which is achieved via an Android Intent[8]. The `currentContext` JSONArray is converted into a String format and included as an Intent Extra.

Classification Activity The *ClassificationActivity* receives the current context as an Intent Extra and displays it in the UI. If no current context is provided, a Toast[9] message conveying this fact is displayed. If there is context information, a recommendation is created. As explained in the requirements for the concept this happens via a rule based approach.

The rules are implemented via a IF-THEN-ELSEIF approach. As the currentContext was handed over in a String format due to the restrictions of the Android Intent, the IF condition checks if this string includes each required piece of context as a substring. If a rule applies, i.e. if all context conditions are met, the attribute `actionId` is set to the id for the associated action for this rule.

[8] `https://developer.android.com/reference/android/content/Intent`
[9] `https://developer.android.com/guide/topics/ui/notifiers/toasts`

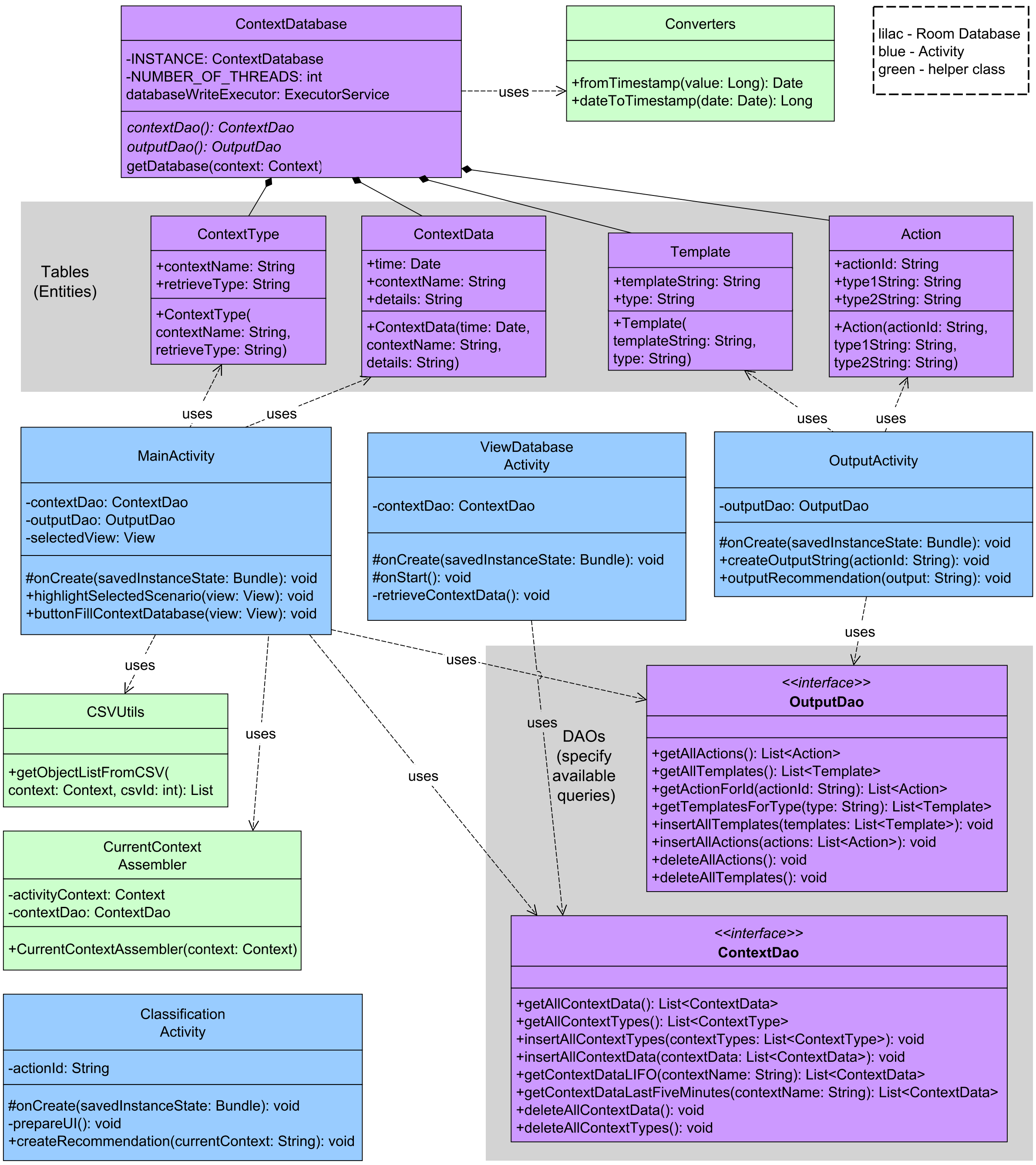


Figure 4.5 – An overview of the prototype classes

The triggered rule as well as the resulting recommendation (actionId) are displayed in the UI. This way, it is more transparent what happens in the background and why a specific recommendation is made.

When the user decides to proceed to the next step, creating the output string, they press the button *Create Output String*. Upon clicking that button, an Intent leading to the OutputActivity is created including the `actionId` as an Extra. After executing the Intent the activity is finished, which removes it from the activity stack. The reason for this decision is that when the user proceeds to the OutputActivity, the workflow is completed and it would not make sense to return to the classification activity. Moreover, the direction of the data flow is always clear.

If no recommendation can be made, i.e. no rule was triggered, a Toast message communicating this fact is displayed and the button usually leading to the next step displays the text '*Go Back*' and brings the user back to the main activity.

Output Activity The last step in creating a recommendation is communicating it to the user. First, the action id is retrieved from the Intent Extra. If an id is present, an output string is created according to the concept described in the previous chapter. First, the action matching the passed `actionId` is retrieved from the *Action* Table. As this prototype app contains two types of templates, the Action object has two attributes containing the template filler for each of these template types. A template type is chosen randomly, if the chosen template is not defined for the action, the other template is chosen. If no template is available, this fact is conveyed via the UI. By generating a random number the order in which the templates are checked for availability is chosen. The template acts as the second part of the final output string.

In the next step, a list of all templates for the chosen type is retrieved from the *Template* table. One of them is randomly chosen as the first part of the output string. Lastly, the two parts of the output string are concatenated and printed in the UI. When the user wants to return, pressing Back brings them back to the main activity as the classification activity has been removed from the activity stack.

It must be noted, that the method of choosing the template type first leads to imbalanced odds if more templates exist for one of the types. The templates associated with the less represented type have a higher chance to be selected.

In the concept, at this point it was envisaged that the derived recommendation is recorded in the recommendation log to avoid making the same recommendation twice in a row in a short amount of time and to have training data for the optimisation process. However, to test the logic implemented in the prototype the user might execute the same scenario multiple times in a row and would likely feel frustrated if that was forbidden by the recommendation log. The recommendation log logic is only the last part of the recommendation process, aimed at ensuring users would not be annoyed in a real life scenario. However, it is not crucial to deriving the recommendation, which is why it was excluded in order to facilitate the use of the prototype. Moreover, the optimisation process was excluded from the prototype, hence the recommendation log is not required there either.

4.3 Implemented Scenarios

Four scenarios were chosen to implement in the prototype, based on the suggestions made in the survey mentioned earlier [Zie21], where users were asked to give concrete suggestions for robot support. The scenarios and associated rule can be found in Table 4.1. For each scenario a csv file containing the context data that triggers the corresponding rule is included in the app. An example can be found in Listing 4.2.

In this section, an example for processing the *Cooking* scenario will be given (see Figure 4.6). When the scenario is selected by pressing the *Cooking* button, the corresponding context data is set as the content in the ContextData table. The data for this scenario (see Listing 4.2) contains

Scenario	Rule Conditions	Outcome
User puts away groceries	UserPresence:present && ADL:PutAwayGroceries && Object:Shopping Bags	HoldBags
User is cooking	UserPresence:present && ADL:Cooking	SetTable
User is eating	UserPresence:present && ADL:Eating	PlayMusic
User prepares to go for a walk	no rule available	-

Table 4.1 – Scenarios implemented in the prototype

three entries. When the currentContext object is assembled, only two of them are included. The reason for that is that the current time is assumed to be `‘05-07-2021 15:15:53’`, which leads to the exclusion of the third entry as it is not in the five minute time frame.

In the second step, the Classification activity displays the currentContext it receives. Moreover, the triggered rule and resulting activity recommendation is displayed. When the user chooses to continue, they are forwarded to the output activity where the output string is created.

Firstly a type of template is chosen at random and the corresponding string for the action is selected, for instance ‘set the table?’. Then a template string is selected at random for the selected template type, for instance ‘Would you like it if I’. The two strings are concatenated and printed in the user interface. In this example the output activity displays the message ‘Would you like it if I set the table?’.

```
timeStamp,contextName,details
05-07-2021 15:13:08,UserPresence,present
05-07-2021 15:13:52,ADL,Cooking
05-07-2021 15:02:49,ADL,Medication
```

Listing 4.2 – CSV for the Cooking Scenario

Evaluation of Requirements In Section 2.2.1 requirements for the concept have been developed. Some of these requirements can only be tested in a user study, while others can be checked off upon implementation. The latter include:

- Architecture Design
  - Rule-based Behaviour
  - Optimisation Process for Rules
  - Customizable Suggestion Rules
- Proposed Default Rules
  - Default suggestion rules provided
- Implementation of Prototype

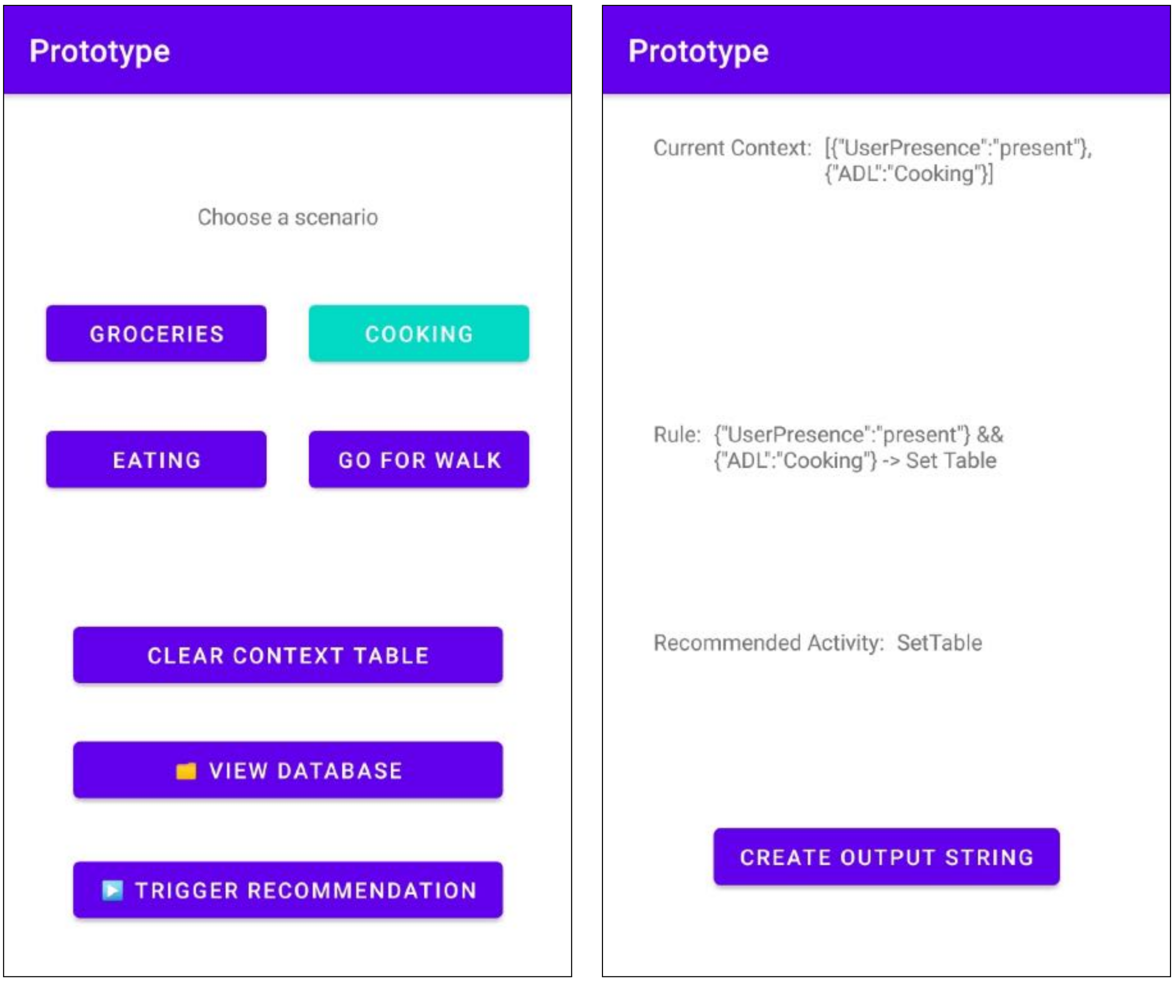


Figure 4.6 – Activity layout for the main activity and the classification activity of the prototype app

- Enable feature only upon activation
- Interruption always possible
- Tutorial
- Tolerate any kind of input

It must be noted that not all of these requirements could be fulfilled as only a prototype to prove the feasibility of the core concept was implemented. Due to the fact that the optimisation process was left out, some requirements can not be checked off, namely the need for an *optimisation process for rules* and *customizable suggestion rules*. Moreover, the prototype only shows the feasibility of the concept but is not equal to a fully functioning feature that is part of a fully functioning robot. For this reason, it is difficult to fulfil the requirements of *enabling the feature only upon activation* and *tolerating any kind of input*. On top of that, no *tutorial* has been provided as the setup process, that would have been required in a real world scenario, is not part of the prototype.

The remaining requirements however have been fulfilled. The *rule-based behaviour* described in the concept has been implemented using IF-THEN-ELSEIF conditions. *Default suggestion rules* have been provided for the implemented scenarios. Finally, *interruption is always possible*, as by using the back button the user can always return to the main activity.

Overall, it can be said that the goal of this prototype, which was implementing a proof of concept to demonstrate the feasibility of the concept described in this thesis, has been achieved.

4.4 Summary

In this chapter, the prototype showcasing the feasibility of the concept developed in the previous chapter was presented. The assistance robot Loomo was briefly introduced and it was explained why the prototype in this thesis was implemented on the Android platform. The context database was implemented as a SQLite database using the Room persistence library and contains the four tables described in the concept. The modules of the concept were implemented as separate Android activities. The *MainActivity* acts as the entry point of the prototype app and holds the functionality of the context assembly module. The raw data is stored in csv files and inserted in the database upon the start of the app, except for the ContextData table, which is filled upon selecting a scenario in the *MainActivity*. When the user wants to trigger a recommendation, the current context is assembled and passed to the *ClassificationActivity*. There, the current context is matched with the implemented rules. The current context, the triggered rule and the recommended activity Id are printed in the UI. Lastly, the output string is assembled as described in the concept and printed in the UI.

Moreover, the scenarios implemented in the prototype have been listed including their corresponding rules and the outcome of the recommendation process and a sample walkthrough for the *Cooking* scenario was provided. Lastly, it was explained which requirements that have been developed for the concept in Section 2.2.1 can be fulfilled by the prototype.

5 Evaluating the Concept

In this chapter the technology acceptance for the concept developed in Chapter 3 is evaluated, while the feasibility of the concept was shown in Chapter 4. A study design is presented and the results of the conducted user study are going to be presented and evaluated.

5.1 Study Design

The goal of this evaluation is to examine the technology acceptance for the concept, i.e. if potential users from the target demographic (over the age of 65) accept the idea of a robot that autonomously provides support suggestions depending on the current context, e.g an ADL the user is currently executing.

In order to do that, the study design proposed for this thesis includes a questionnaire and a video showing different scenarios in which an assistance robot offers its support to a user. The study is conducted as a pilot study with a relatively small number of participants.

The questionnaire used is based on the Technology Usage Inventory (TUI) by Kothgassner et al. [Kot+13] and includes means of measuring Curiosity, Technology Anxiety, Interest, User-friendliness, Usefulness, Scepticism and the Intention to Use. According to the Technology Acceptance Model TAM (see Section 1.2.4), the most important factors influencing the attitude towards using (Intention to Use) are the perceived usefulness and the perceived ease of use (User-friendliness according to TUI). The hypothesis that is going to be examined in this user study reads as follows:

Hypothesis: After seeing the scenarios presented via video, most participants have an overall positive attitude towards and a rather high intention to use an assistance robot offering proactive context-based support.

5.1.1 Video and Scenarios

To enable the study participants to properly empathise with the situations, a short video has been filmed (see Figure 5.1). The reason why the scenarios were presented to the participants in video form was because it was easier logistically, it allowed more creative freedom and control over how the presentation looked like and the presented scenarios were consistent between participants. When selecting the situations, care was taken that the depicted scenarios cover a wide variety of areas of robotic applications in the daily lives of the elderly. To do this, inspiration was taken from the provided list of daily activities (see Section 1.1) and the accumulated suggestions for robotic support (see Section 1.2.2, as well as A.1.1 and A.1.2).

The robot used in the video is the Loomo robot[1] by Segway/Ninebot. It was controlled either by the associated app or by the follow mode. The voice of the robot was imitated by using Google's

[1]https://de-de.segway.com/products/segway-loomo-robot

Figure 5.1 – Stills from the video. Left: User prepares breakfast. Right: User is waiting for lunch time.

text-to-speech API[2]. To keep the scenarios as realistic as possible, only scenarios which the Loomo robot could actually execute were chosen. This excluded any action involving the robot to bring the user an item. Even though the Loomo robot can be equipped with a robotic arm, the robot available for filming was not.

The video, which is just under five minutes long, includes the following situations:

Breakfast The first scene shows the user entering the kitchen in the morning and sitting down at the kitchen table. He cuts up and starts eating a pear. The robot recognises the activity *breakfast* and asks the user if he would like to listen to the radio. The user accepts and a news piece is played. This scenario covers the area of Daily Activities, as well as the provisioning of information/entertainment.

Taking medication After finishing breakfast, the robot asks the user if he has already taken his medication. The trigger for this action could either be the fact that the user has just eaten breakfast or a previously set timed reminder. The user appreciates the reminder and takes his pills. Afterwards, when the robot perceives the medication being taken, it suggests to write down the medication intake for the user to which the user agrees.

Later in the video the user is startled and asks the robot if he has already taken his medication today. The robot answers positively that the user did. The scenario of taking medication is an important daily activity for most elderly people and relates to the area of health.

Birthday reminder To cover the area of socialisation, this scene shows the robot reminding the user of a friend's birthday, triggered by the current date. The robot offers to call the friend, to which the user agrees. Together they call Michael, who picks up and gets greeted by the user with a birthday song.

Lunch This scenario relates to the daily activity of food preparation. Based on the time of the day and the fact that the user has not eaten yet, the robot informs the user that it is lunch time and asks if it should suggest a recipe. When the user accepts, the robot suggests a recipe based on an ingredient in the smart fridge. The user asks if there is enough cheese for the casserole, which the robot confirms. The user goes to the kitchen and prepares the dish. While the dish is

[2] https://cloud.google.com/text-to-speech

in the oven the user is seen waiting in a time lapse. When the time is up, a beeping sound can be heard, but the user does not react. The robot perceives the sound as context information and when the user does not react, it offers to turn off the oven. The user wonders why he did not hear the oven and goes on to take out the casserole himself.

Encouragement to go for a walk and Getting help After the user has spent a significant amount of time on the couch the robot says it is time for getting some air and proposes going for a walk. The user hesitates at first but then accepts. Based on the outside temperature the robot suggests to wear a jacket. The robot and the user leave the house together.

In the next scene, the two of them can be seen finishing up their walk. The user turns to the robot and says: 'That was a nice walk!'. He then turns around, stumbles and falls. The robot perceives this, drives up and asks the user if he is okay and if it should get help, which the user declines.

The composite scenario portrayed here combines two areas of robotic application for the elderly. Firstly, the activation after a resting period belongs to the area of physical activity and exercise. Secondly, the emergency scenario showcased belongs to the area of safety.

Going to bed In the last scene a scenario relating to a resting activity (going to bed) is showcased. The user is going to bed and asks the robot to turn off the lights. With the help of the smart home environment the light in the room is switched off. As the robot realises the user goes to bed it suggests to play music to help the user fall asleep. The user declines and the robot wishes a good night.

It must be mentioned, that the interaction shown in the scenarios in the video is not fully technically accurate. Firstly, in reality the user would have to use a wake word when addressing the robot, which does not happen in the video. Secondly, the user does not always respond clearly with yes or no to the robot's suggestions. The user might say 'That would be nice.' or 'Thank you, I'm fine.' instead of yes and no. In real life, the robot could have difficulty understanding the user, if it can not interpret the user's statement. Lastly, the wording of the suggestions does not fully correspond with the way the concept explains how suggestion statements are created. In some cases, the suggestions contains additional information about the trigger of the suggestion, e.g. 'It's time for lunch. Should I suggest a recipe?' or 'Would you like to listen to music to fall asleep?'. When the user falls, the robot says 'Are you okay? Should I get help?', which requires the user to give a concrete command, as these two questions can not clearly be answered by a simple yes or no.

Even though there are some technical inaccuracies, this helps keep the video more entertaining and allowed for more creative freedom in the execution. The colloquial interaction portrayed should help to keep users engaged. If the robot would never give context to why it makes a suggestion and the user would always simply answer with yes and no statements, the participants would have a harder time understanding what is going on and feel less immersed in the situation. On top of that, while some of the participants have experience with smart home assistants, others did not. No prior experience, e.g. in interaction with voice assistance, should be required to participate in the study.

5.1.2 Questionnaire

The goal of this user study was to prove the technology acceptance (TA) for the concept developed in this thesis. The video that is going to be used to help participants get to know the technology better was described in the previous section. An established questionnaire designed to evaluate TA was chosen in favour of creating a questionnaire from scratch.

The Technology Usage Inventory (TUI) was developed by Kothgassner et al. [Kot+13], an interdisciplinary team of psychologists and computer scientists, to capture technology-specific and psychological factors that contribute to the actual use of a technology. The authors state that while the TUI can generally be used for adults 18 years of age and older, it is primarily intended for older adults (over 60 years of age), which matches the target demographic in this thesis of elderly people over the age of 65.

The TUI contains nine scales [Kot+13]:

- **Curiosity** - Measures a person's curiosity towards the evaluated technology.
- **Technology Anxiety** - Captures the evoking of anxious or emotional reactions through the use of technology in general, e.g. whether a person generally feels overwhelmed by technological devices of all kinds or is afraid of doing something wrong when using technologies.
- **Interest** - Measures a person's basic interest in technology and (new) technologies in general. It does not refer to a specific technology, but to how much technical knowledge a person has in general and to what extent they keep themselves informed and up-to-date about technological developments.
- **User-friendliness** - Assesses the perceived ease of use of a specific technology. It measures whether a person experiences the technology as user-friendly and easy to use.
- **Immersion** - Measures the feeling of immersion into a virtual world. Not applicable for every technology.
- **Usefulness** - Captures the perceived usefulness, i.e. whether a person considers the technology to be useful and purposeful and whether they believe that the technology can support them in some way in their daily lives or make certain tasks easier.
- **Scepticism** - Measures a person's level of scepticism/mistrust with regard to the use of the evaluated technology. Captures whether a person views the technology as risky, dangerous and detrimental to them.
- **Accessibility** - Measures the perceived accessibility/obtainability of the evaluated technology, i.e. whether they consider the technology to be financially affordable and easy to obtain.
- **Intention to Use (ITU)** - Captures the tendency to actually want to use the presented technology.

Translations As the original questionnaire is in German, the scale names had to be translated. While for most scales the translation is obvious, for some it is more difficult.

The term *accessibility* is the direct translation of the German term 'Zugänglichkeit' and is also mentioned by the authors in the description of this scale ('Diese Skala erfasst die wahrgenommene Zugänglichkeit bzw. Erhältlichkeit (engl. accessibility) einer ganz bestimmten Technologie'

[Kot+13]). However, in the context of human-computer interaction accessibility usually means that every user can use a technology regardless of their restrictions or disabilities. In the TUI the term accessibility is interpreted differently, referring to whether participants consider the technology to be financially affordable and easy to obtain. Using both meanings of the term accessibility in this thesis could potentially lead to confusion. As the common meaning is not used here and the TUI scale is only referenced briefly (see below), this translation was chosen despite the disparity, remaining true to the original questionnaire.

The term user-friendliness is a literal translation of its German equivalent (Benutzerfreundlichkeit). It could have also been translated as 'usability', which is a term commonly used in the area of human-computer interaction (see Section 1.2.5) and refers to the extent to which a system can be used to achieve a goal with effectiveness, efficiency and satisfaction [Int18]. In the TUI user-friendliness refers to whether the system is easy to use, which is similar to the definition for usability, but not a full match. As both terms are used in this thesis, using the translation 'usability' for the user-friendliness scale would lead to confusion. The meaning of this scale corresponds more closely to the meaning of the term 'ease of use', which is a crucial part of the Technology Acceptance Model (see Section 1.2.4) and refers to 'the degree to which a person believes that using a particular system would be free of effort' [Dav89]. The term 'ease of use' would therefore be a more accurate translation, but to make it clear whether the term refers to the TAM or the TUI, the decision was made to remain true to the original wording.

Questionnaire Structure Every scale consists of four items, except the scales for Accessibility, User-friendliness and ITU, which contain three items. This results in 30 items for the whole questionnaire. The authors offer the questionnaire in one piece, as well as separated into a pre- and a post-questionnaire. The pre-questionnaire includes the scales for Curiosity and Technology Anxiety, the post-questionnaire includes the remaining scales. This pre/post set-up is used in this thesis and the participants will watch the video in between filling out the two questionnaires. This way, the participants' general curiosity and technology anxiety can be estimated, which can help interpret their results for the technology specific scales.

For this thesis, not all scales are used. As the authors of the questionnaire mostly focus on virtual reality applications they included a scale to measure immersion. However, they state that when evaluating a technology not designed to evoke immersion this scale should not be provided. In the case of this thesis immersion does not play a role and is hence excluded.

Moreover, the accessibility scale is excluded. In the TUI, this scale refers to the (financial) obtainability. As the technology in question is still in the research phase and not readily available, it is impossible to say how much it would cost or how it could be obtained. Hence, participants can not give their opinion on the affordability and availability. Excluding these two scales leaves the questionnaire with 23 questions.

Concept Requirements In Section 2.2 requirements for the concept have been derived. While some of them have to be checked off upon implementation, others should be evaluated in a user study. Those requirements are:

- Provide value to the users, i.e. is the technology useful?
- Quality of a tutorial
- Intuitive to use

- Make information obvious and engaging
- Rule-based behaviour
- Appropriate suggestions

Some of the requirements correspond to one of the TUI scales. Providing value to users is covered by the Usefulness scale, while the User-friendliness scale covers whether a technology is intuitive/easy to use. The other requirements can not be evaluated in a meaningful way in this user study.

The quality of the tutorial can not be evaluated because there is no tutorial and the participants do not use the system themselves. As some creative liberties were taken with the wording of the suggestions, in order to make the video more interesting, evaluating whether participants thought the suggestions were worded in a obvious and engaging way would provide no value. The implementation of rule-based behaviour, i.e. predictability, can be checked off, as it is implemented in the prototype. Moreover, it would interrupt the flow of the video if participants were frequently asked if they expected a certain suggestion. On top of that, as only a subset of possible suggestion rules were showcased in the video, asking users what they think about this subset has no expressive power over the concept as a whole. For this reason, whether the suggestions were considered appropriate will not be evaluated in this user study.

This leaves the questionnaire untouched, which simplifies the evaluation of the results, as the evaluation methods developed by Kothgassner et al. [Kot+13] can be used as is. The only addition made to the questionnaire was a final open-ended question, regarding whether had any additional ideas or wishes for situation-dependent suggestions. As this question does not rely on a scale but is only intended to gather ideas, it does not interfere with the evaluation of the rest of the questionnaire.

An excerpt of the questionnaire can be found in Table 5.1. The full questionnaire can be found in the appendix (see A.2). It must be noted, that this is not the document the participants were given, as it includes explanations that were given verbally (printed in italics). The explanations were sometimes paraphrased and adapted to the individual participants. If the participants had any questions, they could be answered immediately.

Methodology The method detailed by Kothgassner et al. in their paper [Kot+13] was used to evaluate the questionnaire answers. Each participants questionnaire is evaluated separately. Firstly, for each scale the answer scores for the corresponding questions were summed up. For the analogous ITU scale, Kothgassner et al. instruct to measure the distance between the right endpoint of the line and the answer mark. As the participants have been asked to measure the distance from the left endpoint of the line and the answer mark the measurement written down on top of the answer scales must be converted to millimetres and subtracted from 100 in order to receive the correct values. These converted values were then added up to receive a value for the ITU scale.

After calculating the raw scale values, they are transformed into standardised values by looking them up in the attached transformation table (Appendix C in Kothgassner's paper [Kot+13]). For standardisation, the authors use the Stanine method, short for STAndard NINE, which uses a nine-point standard scale with a mean of five and a standard deviation of two[3].

[3] https://en.wikipedia.org/wiki/Stanine

		strongly agree 1	2	3	4	strongly disagree 5	6	7
1	I am curious about the use of this technology.							
2	I often worry that new technical devices might overwhelm me.							
3	I have long since wanted to work with assistance robots.							
4	When I am supposed to use a new technical device, I am suspicious at first.							
5	I am eager to learn more about this technology.							
6	I find it hard to trust technical devices.							
7	I have always been interested in using this technology.							
8	The idea of doing something wrong when using technical devices scares me.							

Table 5.1 – The pre questionnaire

5.2 Study Results

Five people participated in this pilot study. All of them were over the age of 75, two of them were male, three were female. Four of the five tests were conducted through video chat, while one could be conducted in person. For the video chat the participants were sent the questionnaire, which only included the relevant questions without the explanations, and a link to the video. They printed out the questionnaire themselves in preparation of the user study.

For the execution of the user study, after receiving a verbal introduction to the topic the participants were asked to fill out the pre-questionnaire. Then the five minute video was shown. Afterwards, the participants filled out the post-questionnaire with the additional open-ended feedback question. The filled out questionnaires can be found in the Appendix (see A.3).

5.2.1 Individual Results

Going forward, the participants are going to be referred to by the first letter of their name. The first two participants, A and E (see Figure 5.2), did the study at the same time. Each participant was asked to fill out the questionnaire for themselves, only taking their own opinions into account.

Participant A

Results: The pre-questionnaire showed that participant A had a relatively low score for Curiosity (3/9), while the Technology Anxiety score was rather high (7/9). In the post-questionnaire, they signalled a lukewarm interest towards and knowledge about technology and technological advances in general (4/9).

After seeing the video, the participants are able to give feedback regarding the presented technology. Participant A thought that an assistance robot providing context-dependent suggestions for support would be extremely useful to them (9/9) and signalled a very high intention to use (8/9). Their scepticism towards the technology was moderate (4/9), as was their impression of the user-friendliness (4/9).

Interpretation: According to Kothgassner et al. a high score for Technology Anxiety means that a person can generally feel overwhelmed by technical devices of all kinds and might oftentimes be afraid of doing something wrong when using technologies. On top of their rather high technology anxiety, participant A had a rather low interest and curiosity towards the assistance robot technology and technology in general. Despite this, after being presented the technology in question, the participant had a positive attitude towards it, signalling a high intention to use and very positive impression of the usefulness, as well as only moderate scepticism. Only their perception of the user-friendliness suggests there is room for improvement in this area.

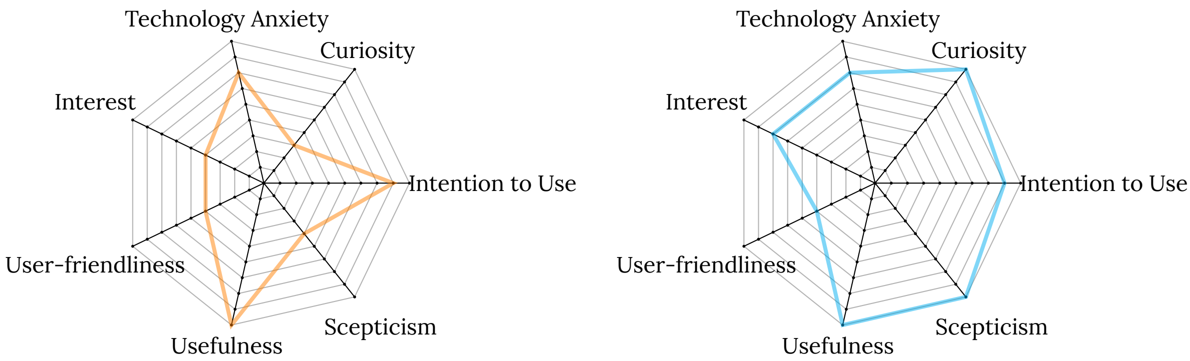


Figure 5.2 – Study results for participants A (left) and E (right)

Participant E

Results: Participant E received high scores on almost all scales. Their general interest in technology was rather high (7/9), while their curiosity regarding the presented technology was extremely high (9/9). However, they also showed a rather high score for general technology anxiety (7/9).

After seeing the technology presented in the video, E indicated that they found it extremely useful (9/9) and has a very high intention to use it (8/9). E expressed a medium satisfaction with the user-friendliness of the technology (4/9), however, they were very sceptic of it (9/9), despite their high intention to use.

Interpretation: It is unclear why they are so sceptic, a possible explanation lies in their general technology anxiety. They might imagine many hypothetical risks that can occur with this technology, but assume that in a ready-to-use robot many of those would have been eradicated.

Another possibility is that they did not fully understand or properly read all the questions. The Scepticism scale includes questions 12, 17, 23 and 29 and participant E gave all of them a rating of 7 (fully agree). While their answers to questions 12 ('I think that the use of this technology is always associated with a certain risk.') and 17 ('I think this technology holds risks for me.') can be attributed to the previous explanation of pessimism/realism, the others show inconsistencies with the rest of their answers.

This becomes obvious when comparing them to the questions belonging to the Usefulness scale. They gave a fully agree answer to questions 16 ('This technology would help me to perform my daily tasks more conveniently.') and 28 ('This technology would support me to achieve my everyday tasks.'). Question 23 ('This technology would disrupt my daily routine.') sounds quite similar, however it has a negative implication. It is possible that the participant did not realise this. Question 29 ('Using this technology would bring me more disadvantages than advantages.') is worded in a way where you have to think about it carefully to get it right. Another participant, R, whose interview could be conducted in person, also stumbled over this question. In this case, the supervisor could give guidance, however, E did not ask a question as they probably did not realise they understood the question wrong.

To conclude, the result for the Scepticism scale for participant E has to be taken with a grain of salt. However, ignoring the Scepticism scale, the results for this participant show that they while they were generally quite anxious regarding technology, they were also very curious and interested. As participant A, E had a very positive attitude towards the presented technology despite their technology anxiety (not taking the scepticism result into account).

Lastly, it goes to show that it is easier to scan the answers the participants give for inconsistencies when being in the same room as them. In the case of the remote participants, they were able to ask questions but their actual answers could only be looked at once the interview was over and they had sent over their questionnaires.

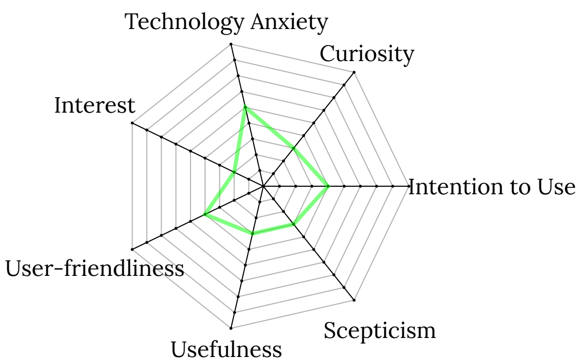


Figure 5.3 – Study results for participants H (left) and W (right)

Participant H

As the previous participants, H and W (see Figure 5.3) did the study at the same time.

Results: Out of all the participants, H was the least convinced of the technology presented. To start off, their curiosity regarding the assistance robot technology presented was rather low (3/9), as was their general interest in technology (2/9). Their technology anxiety was moderate (5/9).

Regarding the presented technology their scores were overall mediocre to low. They were the least sceptic out of all participants (3/9), their impression of the user-friendliness however correlated with that of the other participants (4/9). While all other participants found the technology presented extremely useful, this participant did not (3/9). Additionally, their intention to use was also quite low (4/9).

Interpretation: After filling out the questionnaire, they were asked why they were not convinced by the idea of an assistance robot providing situational support suggestions. Their main concern was that the robot would be very impractical in their small apartment and feared it would stand in the way. Moreover, they really liked using their Amazon Alexa device, which takes up very little space, and they did not think an assistance robot would provide any additional value to them personally.

It must be mentioned, that due to the capabilities of the robot used, in order to stay in the realm of what is possible, only scenarios that are similar to what a voice assistance can do, were shown in the video. A different robot, with the ability to actually bring the user items, maybe would have resulted in a different reaction. However, this kind of feedback is very valuable as many elderly people live in small apartments were a robot could be in the way. This type of concern should be kept in mind when designing an assistant robot for elderly people in order to provide value to their lives and increase the technology acceptance.

Participant W

Results: Participant W showed a rather high technology anxiety (7/9), but at the same time a similarly high curiosity towards the presented technology (7/9) and a moderately high general interest in technological developments (6/9). After seeing the video, W was unsure about the user-friendliness (5/9), as all participants were. Their scepticism was moderate to low (4/9). They concluded the technology to be extremely useful (9/9), however, their intention to use was only mediocre (5/9).

Interpretation: One possible explanation is that they read the scales wrong. Between the questionnaire and the analogous ITU scale the labels fully agree and fully disagree switch places. Assuming this was the case, W would land on a 6/9 score for intention to use, only slightly higher than their current score.

The other, maybe more likely explanation, is that they were influenced by the attitude of participant H, as they sat next to each other when filling out the questionnaire. Through questions asked and comments made after filling out the post-questionnaire, it became apparent that H was rather critical of the technology as explained above. Most of their concerns regarded the practicality of a robot in their and W's current living arrangements. It is possible, that W did not yet think of these concerns when filling out the post-questionnaire, but unconsciously took them into account when answering the ITU questions.

Overall, W's results show that they liked the general idea of an assistance robot. It is possible that if their impression of the user-friendliness was improved, for instance by letting them use the robot themselves, their overall intention to use would be higher.

Participant R

Results: The last participant, R (see Figure 5.4), did fill out the questionnaire alone. Their interview could be conducted in person, while the others were conducted via video chat. As for most others, their technology anxiety was rather high (7/9). Their curiosity towards the presented technology (4/9), as well as their general interest in technology (4/9) was mediocre to low.

R rated the assistance robot's presented feature as mediocre (5/9) and were not very sceptic of it (4/9). Moreover, they thought it was extremely useful (9/9). However, their intention to use was only slightly above mediocre (6/9).

Interpretation: The reason for this could lie in their general technology anxiety. On top of that, the video only showed a prototypical concept. Even though a user might find it useful, they can be hesitant in expressing their intention to use as they do not yet know what the actual usage and acquisition of such a device might entail.

If the participant were able to get a better idea of how interacting with the assistance robot would feel like, it is likely that their intention to use would increase, as other participants' results showed that it is possible to express a high intention to use despite having a high score for technology anxiety.

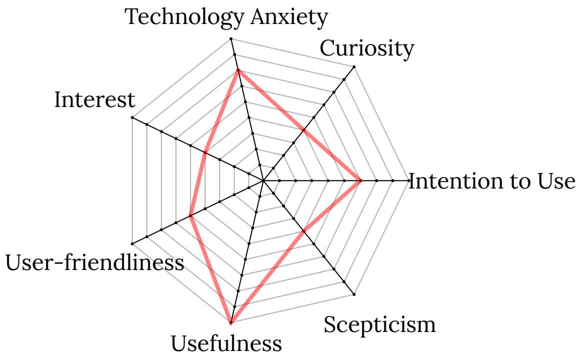


Figure 5.4 – Study results for participant R

Suggestions for Robotic Support The only question added to the questionnaire asked for suggestions for situations where an assistance robot might offer its services. The suggestions made by all participants are accumulated here:

- Reminder to take medication (W, A)
- Reminder to drink coffee at 16:00 (A)
- Save and remind doctor's appointments (A)
- Manage time while cooking (R)
- Encourage to take a walk (R)
- Support during sporting activities, e.g. demonstrate exercises (R)

Not all participants had suggestions, the identifier of each participant is listed next to the suggestions they made. Not all ideas are original, as some were shown in the video, but if participants put them down it signifies their importance. It seems the reminder to take medication as well as the encouragement to take a walk were especially well received.

5.2.2 Overall Results

The Stanine scores for all participants and scales can be found in Table 5.2. They are furthermore visualised in a spider web chart in Figure 5.5.

Overall, all participants showed a rather high level of *Technology Anxiety*, with most scores for this scale being 7/9 and one being 5/9. This was to be expected, as many elderly people experience some kind of fear regarding the use of technology [RS14]. It is also something to be kept in mind when interpreting the following results.

	H	W	A	E	R
Curiosity	3	7	3	9	4
Technology Anxiety	5	7	7	7	7
Interest	2	6	4	7	4
User-friendliness	4	5	4	4	5
Usefulness	3	9	9	9	9
Scepticism	3	4	4	9	4
Intention to Use	4	5	8	8	6

Table 5.2 – Study results for all participants (Stanine scores)

Regarding the *Curiosity* towards the specific technology presented as well as the *general Interest in technology*, a gender disparity can be observed. While the women (H, A and R) all had relatively low scores for both of these scales, the men (W and E) scored relatively high. This disparity is also not unusual, as women are often reported to be more critical of assistance robots [RW20] and less interested in new technologies than men [Kün15].

For the scales that directly relate to expressing an opinion concerning the technology presented the opinions were fairly unanimous, except for some outliers and the ITU scale. Starting off with the positive, all participants except one found the presented feature extremely *Useful*. Only participant H expressed their concerns, which mainly related to them being worried about the practicality of such a robot and them not seeing the additional value compared to their voice assistant device. Hence they did not find the feature very useful for their particular living situation.

Another positive result is that while all participants showed relatively high levels of technology anxiety in the pre-questionnaire, most of them signified a relatively low level of *Scepticism* after seeing the use cases in the video. As explained previously, the outlier E's answer has to be taken with a grain of salt, not only because it contradicts with E's other answers but also because it contradicts with the answers of the other participants.

It is remarkable that all participants were rather undecided about the *User-friendliness* of the presented feature. All Stanine values for this scale are 4/9 or 5/9. The reason for this is very likely that the participants were not able to use the feature themselves. Instead, they could only look at the video, which helped them to determine whether they find it useful or not, but hard to know how it would feel actually using the device themselves.

Lastly, the *Intention to Use* ranges from 4 to 8 point out of 9. As already explained, H's general attitude naturally leads to them having a lower intention to use, furthermore it can not be ruled out that W was unconsciously influenced by H's opinion when giving their answer. The other participants however showed a slight to strong intention to use, which implies the robotic feature shown left an overall positive impression.

5.3 Discussion

Before executing the user study it was hypothesised, that after seeing the video showcasing the scenarios, the participants would have an overall positive attitude towards the presented technology as well as a high intention to use. Overall, it can be said that the concept presented was indeed positively received by the participants, which were members of the target audience.

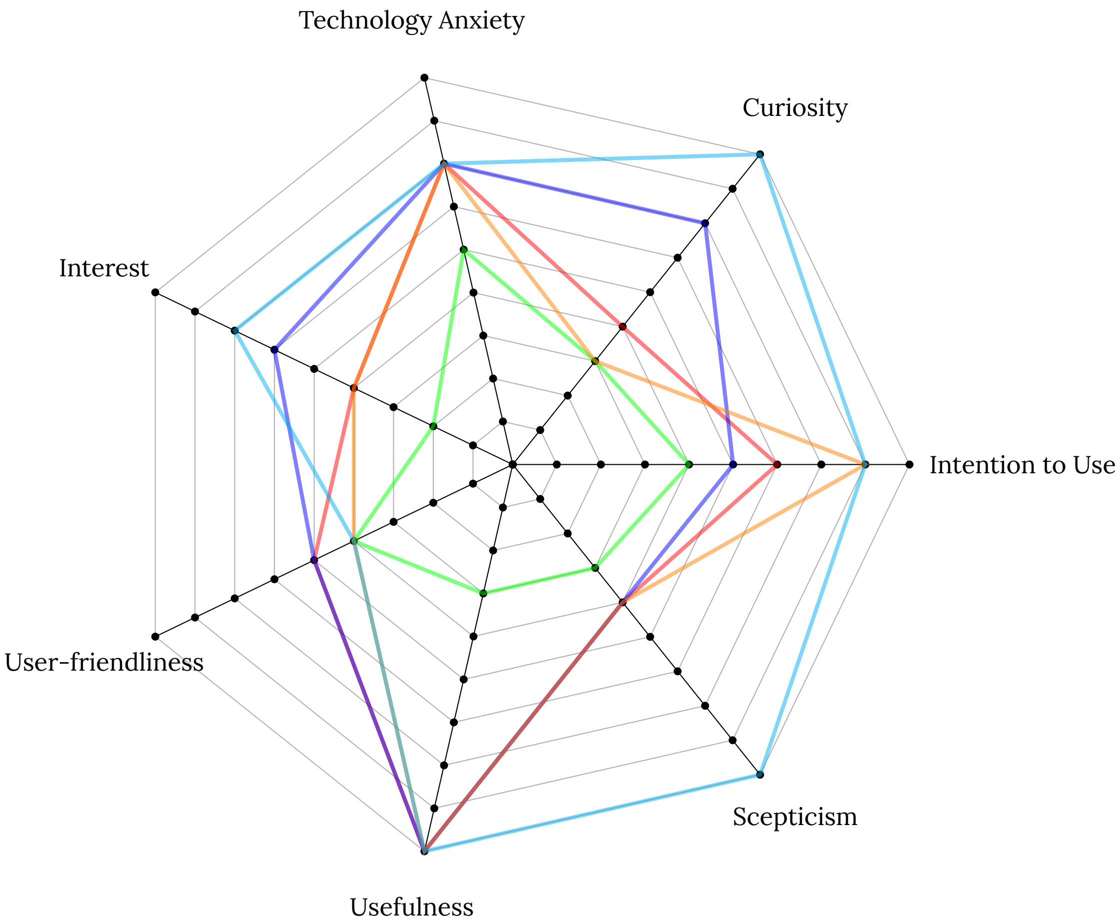


Figure 5.5 – Study results for all participants (A-orange, E-cyan, H-green, W-blue, R-red)

The most important scales are the User-friendliness, Usefulness and Scepticism scales, as well as the Intention to Use scale. The remaining scales, Technology Anxiety, Curiosity and Interest, do not directly relate to the technology shown but help to get an understanding to the participants general attitudes towards technology. As mentioned in Section 5.1.2, the scales Usefulness and User-friendliness furthermore directly relate to the requirements for this thesis' concept that have been derived in Section 2.2.

According to this user study, the concept fully accomplishes the requirement of providing value to users, as all except one participant received the highest possible score for the Usefulness scale. Seeing that one participant did not find the robot very useful for their specific living conditions does not change this conclusion. However, it is something to discuss and keep in mind for further research. Upon being asked why they do not find the robot useful, participant H expressed that their main concern was the practicability of a mobile robot in their small home. This realistic approach is quite insightful, as many elderly people live in rather small homes and it is conceivable, that other participants would have expressed the same concerns if they had interacted directly with the robot in their own homes. In the video for the user study, the Loomo robot was used. As it is based on a Segway platform, it takes up a lot of space. In order to address the concern of practicability it might be useful to rethink the image of what exactly an assistance robot looks like and examine how it can be made more practical for small homes.

The results for the User-friendliness scale were not as satisfactory as the results for the Usefulness scale. All scores are located in the middle of the scale, indicating that users are rather undecided about this factor. The reason for this is presumably that the participants were not able to use the robotic feature themselves and hence did not feel able to give judgement on the user-friendliness. Correcting this would require a fully functioning robotic prototype that participants could interact with. If such a robot existed, it is likely that even more of the requirements could be meaningfully evaluated, such as the tutorial and how users perceive the suggestions made.

Despite the relatively high technology anxiety in most participants, the majority expressed only a medium to low level of scepticism after seeing the video. Overall, taking into account the relatively low level of scepticism and high level of perceived usefulness, one can conclude that most participants had an overall positive attitude towards the presented technology. While the participants were undecided towards the perceived ease of use, they did not rate it negatively, which does not negate the conclusion that participants had a positive impression of the technology.

The second part of the hypothesis relates to the Intention to Use. The Intention to Use scale is crucial to determine if an assistance robot offering proactive context-based support suggestions would be a successful product. In this study, the results for this scale were leaning positive which can be counted a success for this thesis.

However, not all participants were fully convinced whether they would want to use the robotic feature presented. It can be hypothesised that a fully functioning robot prototype that users can directly interact with would greatly impact the perception of the User-Friendliness and thus the Intention to Use. If users feel like the interaction is intuitive, they are more likely to want to use such a robot. Moreover, some participants of the study were worried about the effort needed for owning such a robot, such as acquisition, maintenance, charging or storage of the robot, as well as the practicability of sharing a small home with a robot. All those factors have to be kept in mind when designing an assistance robot for elderly people. They also need to be made transparent to potential users for them to feel more at ease with the idea of actually owning such a robot.

Outlook As the study conducted for this thesis was designed and executed as a pilot study, the results are well suited to give a first impression of how the proposed feature is perceived by the target demographic. However, this study is not representative. In order to achieve representative and more significant results the study could be repeated at a larger scale.

In this section, some suggestions for improvements are made in order to achieve even more meaningful results. If the interviews are conducted remotely, it is more difficult to observe what answers the participants are giving than if the participant and supervisor are in the same room. When the supervisor can see the answer sheet, they can watch out for any inconsistencies or unusual answers and ask the participants to clarify whether they really answered the way they wanted to answer or whether they made a mistake or misunderstood the question.

While the TUI seems well suited to qualitatively evaluate the technology acceptance of elderly people, it does not give quantitative answers to why participants answered the way they did. In order to improve a system it is useful to know why people are dissatisfied. It might hence be a good idea to include more open ended questions at the end to better understand the users' feelings. Such questions could be along the lines of: 'What reservations do you have regarding the use of such an assistance robot?' or 'What could this assistance robot do better?'.

Lastly, it has already been mentioned that the results for the perceived ease of use (user-friendliness) show room for improvement. Before repeating this study at a larger scale, it should be reflected on how the ease of use can be better communicated and what can be done to improve it. Using a fully working robot that users can interact with would likely help the participants give better feedback.

5.4 Summary

In this chapter, a user study was conducted to prove the technology acceptance of the concept developed in this thesis. Firstly, the study design was presented. This includes a video, showcasing different possible scenarios of a user interacting with an assistance robot proactively offering situation-based support during the day. Moreover, the Technology Usage Inventory questionnaire developed by Kothgassner et al. [Kot+13] was slightly adapted to be used in this study by omitting the scales measuring immersion and accessibility.

The study was conducted with five participants, all over the age of 75. The participants were first given a verbal introduction about the subject of this thesis and the goal of this study. They were then asked to fill out a pre-questionnaire, containing questions affiliated with the scales for Curiosity and Technology Anxiety. Afterwards, they were shown the five minute long video and subsequently filled out the post-questionnaire containing the remaining questions associated with the scales Interest, User-friendliness, Usefulness, Scepticism and Intention to Use.

Overall, the participants had a relatively high level of technology anxiety, which is not unusual in elderly people. Furthermore, differences in curiosity towards assistance robots and general interest in technology could be observed between genders, which is also not unusual. Both were rather high for the male participants and lower for the female participants. Overall, the scepticism towards the presented technology was moderate, with one outlier which can be ignored. The most important measures are the usefulness, which for the most part received an extremely good rating, and the user-friendliness, which only received a mediocre rating. The reason for that is likely that participants did not directly interact with the robot themselves, but instead only watched a video. Lastly, the results for the Intention to Use are rather uniformly distributed on the scale. Considering the other results, this implies that while the overall impression was a positive one, not all participants are fully convinced yet. A fully working prototype that users can directly interact with in combination to transparency regarding how the whole process of acquiring and owning an assistance robot would look like can likely improve the intention to use.

6 Conclusion

In this thesis a concept for creating context-based support suggestions has been presented and evaluated regarding its feasibility and technology acceptance. In this chapter, a summary of the previous chapters is provided and the research question is going to be answered. Moreover, the proposed solution is going to be discussed and an outlook is given.

6.1 Summary

Background In the first chapter the concept of the Activities of Daily Living has been introduced and a list of activities taking place in the daily lives of elderly people was presented. The need for assistance robots in care was demonstrated and the term assistance robot as it is used in this thesis was further defined. Moreover, an overview of the current state of the art assistance robots in elderly care was provided and concrete suggestions for robotic support for elderly people were compiled. Furthermore, the acceptance of assistance robots in elderly care was examined and the Technology Acceptance Model TAM was introduced as a means for measuring acceptance. The terms *user experience* and *usability* were introduced and the connection to *technology acceptance* was made. The Interaction Principles were introduced as a means for supporting usability and consequently technology acceptance.

The topic of contextual information was introduced and the terms *context* and *context-awareness* were defined. Different types of contextual information have been characterised and related work using context information in the domain of assistance robots was presented.

Lastly, the concept of variability management was introduced to solve the problem of implementing adaptive assistance robots. The basic terminology from this domain was introduced and student works contributing towards an adaptive assistance robot were presented.

Analysis This chapter consisted of two parts. In the first part, the previously identified context types were analysed in view of what they include in terms of assistance robots and a list of generally available context information was compiled. From that list a list of context information relevant for this thesis was filtered. In the second part of this chapter, 12 requirements for the concept developed in this thesis were derived, taking the interaction principles and the TAM as a starting point.

Concept In the third chapter, a concept for providing context-based proactive suggestions has been proposed. The first part described the basic recommendation process, in which context data is evaluated to derive a suggested activity. Context data sources input their data into a context database which is regularly queried by the context assembly module. This module assembles an object containing the current context information which serves as the input for the classification module. Using a rule based approach this module derives an activity id from the current context input. The output module creates an output string for the suggested activity.

The second part of the concept concerns an optimisation process for adapting the classification mechanism to the user's preferences. This process has only been described on a superficial level, as sufficiently developing it was out of scope for this thesis. It was proposed to implement a machine learning approach using a neural network instead of a rule set and training it using data about the user's past commands and reactions to suggestions.

Lastly, some default rules have been proposed and recommendations for wording the suggestions were made. A sample run through for the recommendation process was provided.

Prototype To demonstrate the feasibility of the concept, a prototype was created in the form of an Android app. Each module was represented as an Android activity and the context database was implemented using the Room library to access a SQLite database. Four different scenarios were implemented in the prototype. Implementing the prototype showed that the concept is indeed feasible as described, with the exception of the data format chosen for the currentContext object the context assembly module creates.

Evaluation The user study conducted in this thesis aimed at evaluating the technology acceptance of the concept presented in this thesis. It was designed as a pilot study and conducted with five participants who were shown a five minute video and given a questionnaire. The questionnaire included scales for measuring the participants' curiosity towards the presented technology, their technology anxiety, their general interest in technology, their perception of the user-friendliness and usefulness of the technology shown as well as their scepticism and their intention to use. Overall, the participants gave positive feedback. Most found the presented robot extremely useful and had a rather high intention to use, however, their impression of the user-friendliness (ease of use) was mediocre, as they were not able to directly experience working with the system.

6.2 Answering the Research Question

The research question posed in the beginning was: *How can an assistance robot use contextual information to proactively support elderly people during* ADLs*?*

This thesis proposed to collect raw and preprocessed context data from different sources in a central database and use the most current data to suggest an activity the user might find helpful in the current situation. A technology-neutral concept has been proposed for deriving a support suggestion from the current context to implement this idea.

In order to determine whether the concept proposed offers a good solution to the problem posed in the research question, it is helpful to look at the results of the evaluation as well as the implementation of the prototype. Implementing the prototype on the Android platform showed that the concept is feasible which implies that it can be implemented on other platforms as well. While the success of the final system may also depend on other factors, such as which suggestions are made or how often an activity is suggested, the concept developed in this thesis succeeds at creating a suggestion based on context information.

Additionally, the pilot study conducted for this thesis aimed at examining the technology acceptance of members of the target demographic towards the proposed solution. The results showed that most participants found the idea of an assistance robot making context-based suggestions extremely useful and the intention to use was for the most part positive. Even though the study participants were not yet fully convinced of the user-friendliness (ease of use) of such a robot, which highly depends on the final implementation, the takeaway of the study is that the idea of a robot offering context-based suggestions for activities was perceived very positively and hence is a good answer to the research question.

6.3 Discussion

After stating in the previous section that the concept proposed in this thesis answers the research question, in this section the boundaries of this concept and its evaluation are going to be discussed.

Leaving out the Optimisation Process This thesis proposed a concept for deriving support suggestions from current context information. Based on the requirements developed, the concept consisting of two parts, the basic recommendation process and the optimisation process, has been created. However, only the recommendation process has been actually developed, while the optimisation process remained in the design stage. The reason was that sufficiently developing this part of the concept, as well as implementing and testing it, would have gone beyond the scope of this thesis. The considerations made while designing the optimisation process are therefore only theoretical and speculative and this part of the concept can not be regarded as as sound as the recommendation process which has been tested for implementability and technology acceptance. Nevertheless, in order to work towards a context-aware assistance robot the optimisation process must go through the same thorough testing process as the recommendation process.

Default Rules and Current Context While the recommendation process was thoroughly evaluated, not all parts of it were tested equally. This concerns for instance the aspects of the default rules and the processed context, as the focus in this thesis was on implementing the architecture of the concept and evaluating its acceptance in the target demographic.

While in Section 3.2 some possible default rules were proposed based on previous user feedback, these suggestions were not evaluated regarding whether they cover a broad enough range of suggestions and are suitable for as many users as possible. A final set of default rules that comes with a functioning assistance robot has to be carefully selected and evaluated with participants of the target demographic.

The available default rules also depend on the types of available context information. While in Chapter 2 potentially available context information has been compiled and context information considered relevant for this thesis was identified, which context information is available to create support suggestions highly depends on the actual conditions the robot is deployed in. It is possible that some of the relevant context is not available in real life or there might be context information available that has not been considered in this thesis. Fully designing the rule set can therefore only be done when more concrete information about the conditions of the assistance robot's deployment is available.

Another factor regarding context that needs to be examined further is how and when the current context information is retrieved. In this thesis, an approximate time frame of five minutes is assumed. The optimal time frames for each kind of available context should be refined in a real life scenario. Moreover, the mechanisms making sure the robot does not annoy the user with its recommendations by suggesting them too often should be considered in a real life scenario. Lastly, a smarter approach for deciding which recommendation to make when multiple recommendations are available than choosing at random could be developed.

Single User Considered in Optimisation Process The concept in this thesis proposed an optimisation process in order to adapt the decision process to the user's needs and preferences. So far, this process only considers adapting to one single user. While there certainly are many elderly people living alone, many are not. In those cases, implementing the optimisation process as described would lead to the many different opinions defeating the purpose of optimising the decision process, as reaching a general consensus is unlikely. Before deploying the optimisation process in a multi user scenario, this issue needs to be addressed. One possible solution could be to create a separate decision model for each user, which requires accurate user detection.

Prototype on a Single Platform The prototype succeeded at demonstrating the feasibility of the concept. However, as the prototype is only running on a single device the scenario is not fully realistic. In reality, many devices would be involved in the process, accessing the database to insert context data. The interaction between the different systems bears its own risks that have not been considered in this thesis. Properly evaluating that however would only be possible with a fully configured robot that is ready to be deployed in an existing smart home environment.

Expressiveness of the Evaluation The last step of this thesis included evaluating the developed concept regarding the technology acceptance. While the takeaway from this study was that the participants mostly found the proposed feature extremely useful and the intention to use was positive for the most part, some factors limit the expressiveness of the study.

Firstly, the study was designed as a pilot study with a small number of participants. This configuration is well suited for testing the study setup and the comprehensibility of the questionnaire and associated explanations, as well as for giving a first insight into the opinion of the target demographic. However, a pilot study can not be representative and conducting a representative study would have been beyond the scope of this thesis.

Secondly, the selection of participants was not fully representative for the target demographic. While both genders were equally represented, all were of similar age and socio-economic group. Moreover, the author knows all participants personally, which could have led to the participants being slightly biased to have a more positive attitude towards the presented technology than they maybe would have had had they not known the author.

Thirdly, by conducting the interviews it became apparent that the remote setup is not ideal for this study. While the participants are filling out the questionnaire the supervisor can not see which answers are given and potentially double check if the participants correctly understand the questions. Inconsistent answers only become obvious after the questionnaires are submitted.

Fourthly, it can not be rules out that the robot used in the video and its capabilities influenced the participants' impression. The robot shown had no arms and was hence not able to bring items or help with physical tasks. Moreover, it required some space to navigate which may not be ideal for small apartments. Implementing the concept for a robot with a wider range of abilities that can move well in small spaces may help to increase the technology acceptance.

Finally, the only way user could get an impression of the proposed technology was via a video. Deploying the feature on a fully functioning robot was out of scope for this thesis, however, directly interacting with a robot would enable the users to get a better impression of the ease of use of the technology and, if that impression is positive, increase the intention to use and the technology acceptance.

Overall, it can be said that the study conducted in this thesis fulfils the goal of getting a first impression of how the concept is perceived. Moreover, it provided the opportunity to gain insight regarding what to look out for when repeating this study at a larger, more representative scale.

6.4 Outlook

Overall, it can be concluded that there is a lot of potential in the area of context-based robotic support for elderly people. Shishehgar et al. stated that the area of robotic support during activities of daily life, which will enable older adults to remain in their homes, is not yet researched as thoroughly as other fields in robotic technology, such as using companion robots to address memory cognitive impairment problems [SKB19]. Moreover, the pilot study conducted in this thesis showed, that elderly people may find an assistance robot offering context-based support useful, if it is easy to use.

While this thesis provided a contribution towards such an assistance robot, in order to create a fulling functioning robot that is ready to be deployed in elderly people's homes, more research has to be conducted. In the previous section, some open issues were raised that need to be solved in further research.

Firstly, the second part of the concept developed in this thesis has only been designed on a theoretical level. Further research should refine this design in terms of best practices and state of the art technology. Moreover, the issue of handling the preferences of multiple users has to be solved. If the optimisation process is sufficiently developed, a prototype testing its feasibility and quality of retrieved suggestions should be created.

The second big step is to implement the proposed concept for a fully functioning assistance robot. This would enable many open issues to be addressed. It would allow a more accurate evaluation of the technology acceptance, as users could directly interact with the robot. Moreover, the robot could be connected to a smart home environment, which would allow testing the interaction between the different devices and concept components. It would also make it easier to finetune the retrieval of context data, the time frames in which each type of context is considered relevant and the timing of the output of suggestions. If the connected devices are known, it is easier to define the available context information and thus to create default rules utilising them. While it is helpful to know the available context information in order to design useful default rules, it is possible to create a well thought out rule set without a fully working assistance robot. Lastly, it allows doing long term trials to work out the fine details, such as the wording of the suggestions and whether the robot should give additional information as to why it recommends certain things in certain situations.

A Appendix

A.1 Suggestions for Robot Support

A.1.1 List by Esposito et al.

- **Social Interaction**
  - Communication with friends and family
  - Writing letters via speech control
  - Encourage social interaction (gamefication)
  - Contact with care staff, doctors etc.
- **Information**
  - Documentaries and news via audio/video
  - Speech controlled search function
  - Information about places to visit/visited
  - Reminding of tasks
- **Safety**
  - Monitoring risks and giving warning
  - Make older users feel safe in and outdoor home
  - Emergency calls
  - Domestic environment monitoring
- **Health**
  - Check health status
  - Monitored rehabilitation with gesture control
  - Documentation of care
  - Communication with medical doctors
  - Saving and updating patient profile
- **Leisure**
  - Games that encourage social interaction
  - Games for physical and mental training
  - Watch movies

- **Physical Support**
  - Collection and distribution of laundry and garbage
  - Check of stock amounts & date of expiry
  - Order goods to refill stocks / online shopping
  - Cleaning works
  - Support caregivers lifting patients out of bed
  - Support during walking or on stairs
  - Transport of heavy objects
  - Possibility to locate elderly when outside (e.g. family or care staffs)
  - Navigation
  - Providing a seat
  - Bringing and moving goods inside house
  - Open bottles and food packages
  - Controlling devices in smart home
  - Translating speech commands to control smart home devices
- **Mobility**
  - Support in personal mobility inside the house
  - Public transportation

A.1.2 Suggestions for Robot Support by Ziemann

- **Personal hygiene and Going to the toilet**
  - Help with transfer/Accompany the user
  - Remind user to wash themselves/go to the toilet regularly
  - Instruct user how to wash themselves
  - Hand user necessary items
  - Wash the user
- **Eating, Food preparation and Drinking**
  - Help with cooking, e.g. cutting food, hand over food, monitor cooking time of dishes, turn the oven on and off
  - Prepare food/drinks, set the table
  - Feeding the user, cutting food for the user
  - Remind users to eat/drinking
  - Accompany users to the dining hall
  - Deliver/Serve food
  - Keep the user company while eating (encourage eating)
  - Open containers that are hard to open (e.g. bottles, jars, ...)
  - Clear the table
- **Getting up in the morning and Going to bed**
  - Act as an alarm clock in the morning
  - Help with transfer, physically help with getting in an out of bed
  - Prepare clothes
  - Hand things
  - Aiding with falling asleep (e.g. turn off the lights, play music, read sth. aloud, ...)
- **Getting dressed and Taking medication**
  - Remind user to take their medication
  - Prepare a glass of water for taking the medication
  - Prepare the correct drugs in the prescribed dose (e.g. depending on the time in the day)
  - Hand over clothes
  - Put clothes on the user if the user has difficulty with that (e.g. shoes, socks, close buttons...)
- **Housework and Shopping**
  - Robot does housework, such as vacuuming, washing the floors, (un)loading the dishwasher/washing machine, ...

  - Robot turns on other technical devices, such as vacuum robot
  - Handing (difficult to reach) products in the store/cleaning supplies
  - Shopping assistance
  - Write shopping lists
  - Carry/Put away groceries
  - Help finds products at the store
  - Read labels
  - Robot delivers groceries
- **Appointments, Financial affairs and Office work/Paperwork/Mail**
  - Remind user of upcoming appointments, keep a calender
  - Read out forms and fill them out through voice recognition
  - Fetch mail (from mailbox)/take letters to the post office
  - Read out the mail and help with the reply
  - Dictating texts and entering them into a computer
  - Use the robot like a computer, e.g. for online banking, transactions
  - Robot accompanies the user to the bank, provides advice
  - Participants had some apprehensions, especially regarding banking activities, found data to be too sensitive
- **Exercise and Games**
  - Plays music
  - Encourages movement, motivates
  - Reminders for daily exercise
  - Personalized exercise program
  - Gives instruction for exercise, advice on correct execution, demonstrate movements
  - Eliminating tripping hazards
  - Accompaniment during walks, potentially providing physical assistance during walk
  - Games for mental fitness
  - Giving instructions for games, teaching new games
  - Play physical/digital (board) games with the user
- **Cultural activities and Religious activities**
  - Accompany user, e.g. to the theatre, etc.
  - Help get to a venue (Navigation, alternatives, price, distances,...
  - Provide accessibility information about venues (e.g. places to rest, toilets, ramps, elevators
  - Help paying for tickets

  - Provide information about art and artists at museums
  - Take care that nothing happens to the user
  - Make user not feel alone
- **Reading and Current news**
  - Robots reads printed text out loud (e.g. books, newspaper, magazines
  - Hold/fetch books/magazines/newspapers
  - Enlarge written text
  - Provide information about the latest news
- **Listening to the radio/to music, Watching TV and Other hobbies**
  - Read books
  - Turn on/off devices, adjust setting (e.g. volume, set program, ...)
  - Participate in board games
  - Crossword and Sudoku puzzles
  - Help with handicrafts
  - Do garden work
  - Accompaniment to hobbies
- **E-mail Correspondence and Writing text messages**
  - Read out e-mails
  - User dictates e-mails, robot sends them
  - Open e-mail program, help with reading and replying
- **Phone Calls (Audio) and Video calls**
  - The robot is the phone
  - The robot hands the phone to the user
  - The robot helps the user use the phone (e.g. instructions, dialing, ...)

A.2 Survey Questionnaire with Explanations

This section includes the questionnaire used for conducting the user evaluation. The parts in italics were only communicated verbally and were not printed in the version the participants were given. It must be noted that the questionnaire is in German, as the interviews have been conducted in German.

Nutzerstudie

In dieser Studie geht es um soziale Assistenzroboter, die Nutzende bei ihren täglichen Aufgaben unterstützen sollen. Solche Roboter sind in der Regel mobil, interagieren mit den Nutzenden und können Aufgaben für die Nutzenden erledigen, zum Beispiel indem sie Informationen bereitstellen oder Objekte anreichen. Das Ziel von Assistenzrobotern ist die Verbesserung der Lebensqualität, dabei gelten sie aber nicht als medizinisches Werkzeug.

In meiner Arbeit geht es darum, wie man Kontextinformationen nutzen kann, um Unterstützungsvorschläge zu generieren. In anderen Worten, der Roboter soll von sich aus Vorschläge machen, die zur aktuellen Situation passen.

Im Folgenden sind Sie zunächst angehalten, einen kurzen Vor-Fragebogen auszufüllen. Danach werden Ihnen einige Anwendungsszenarien in Videoform gezeigt, um Ihnen die Technologie in Aktion zu zeigen. Zum Schluss gibt es nochmal einen abschließenden Fragebogen, den Sie im Hinblick auf die gezeigten Szenarien beantworten sollen.

Die zu beantwortenden Fragen beziehen sich einerseits auf die Technologie, mit der Sie sich gerade auseinandergesetzt haben und andererseits auf Ihre Einstellungen zu Technologien im Allgemeinen. Bitte lesen Sie sich jede Aussage sorgfältig durch. Entscheiden Sie dann, wie sehr die jeweilige Aussage auf Sie zutrifft und machen Sie ein Kreuz an der entsprechenden Stelle (siehe Beispiel). Sie haben die Möglichkeit zwischen sieben Abstufungen zu wählen:

Beispiel: *Trifft nicht zu* … *Trifft zu*

1	2	3	4	5	6	7
			X			

Bitte lassen Sie keine Antwort aus. Wenn Sie Schwierigkeiten haben, eine Aussage zu beantworten, dann wählen Sie jene Antwortmöglichkeit, die am ehesten auf Sie zutrifft. Es gibt keine richtigen oder falschen Antworten. Bitte antworten Sie spontan und arbeiten Sie zügig.

Prä-Fragebogen

		Trifft nicht zu						Trifft zu
		1	2	3	4	5	6	7
1	Ich bin neugierig auf die Verwendung dieser Technologie.							
2	Ich mache mir oft Sorgen darüber, dass mich neue technische Geräte überfordern könnten.							
3	Ich wollte mich schon früher mit Assistenzrobotern beschäftigen.							
4	Wenn ich ein neues technisches Gerät verwenden soll, bin ich erst mal misstrauisch.							
5	Ich bin bestrebt, mehr über diese Technologie zu erfahren.							
6	Mir fällt es schwer technischen Geräten zu vertrauen.							
7	Mich hat die Verwendung dieser Technologie schon immer interessiert.							
8	Die Vorstellung, bei der Verwendung technischer Geräte etwas falsch zu machen, macht mir Angst.							

Video:

Im Folgenden sehen Sie ein 5-minütiges Video, in welchem ein Tagesablauf eines Nutzers mit dem Assistenzroboter Loomo gezeigt wird. Der Roboter sammelt ständig Informationen über seine Umgebung und generiert daraus immer wieder Unterstützungsvorschläge für den Nutzer. Dabei ist er mit anderen Geräten in der Wohnung vernetzt, zum Beispiel mit dem Kühlschrank, dem Ofen oder den Lichtschaltern. Über diese Verbindung kann er sowohl Informationen abrufen (z.B. Inhalt des Kühlschranks) und zum anderen auf die Funktionen der verbundenen Geräte zugreifen (z.B. Licht ausschalten).

Hinweis zu den Videos (nur für technisch versierte ProbandInnen):

Die Art und Weise wie der Nutzer mit dem Roboter interagiert entspricht teilweise nicht ganz dem wie es in der Realität wäre. Eine korrekte Interaktion ähnelt mehr dem Umgang mit einem Sprachassistenten wie Alexa oder Siri. Der Grund dafür ist, dass so die Szenarien interessanter gestaltet werden konnten, als wenn der Nutzer immer nur mit ja oder nein antwortet und man sich so hoffentlich auch ohne Erfahrung im Umgang mit ähnlichen Geräten (z.B. Sprachassistenten) gut in die gezeigten Situationen einfühlen kann.

Konkrete Abweichungen von der Realität:

- *Wenn der Nutzer den Roboter anspricht, muss er eigentlich ein Erkennungswort verwenden, damit der Roboter sich angesprochen fühlt.*
- *Der Nutzer antwortet dem Roboter teilweise zu ungenau, in der Realität ist es besser klar mit Ja oder Nein auf einen Vorschlag zu antworten.*
- *Die vom Roboter gemachten Vorschläge enthalten teilweise Zusatzinformationen dazu, warum ein Vorschlag gemacht wird. Das ist so nicht im technischen Konzept vorgesehen und nicht trivial umzusetzen.*

Post-Fragebogen

		Trifft nicht zu						Trifft zu
		1	2	3	4	5	6	7
9	Im Laufe meines Lebens habe ich mir viel technisches Wissen angeeignet.							
11	Die Anwendung dieser Technologie würde vieles komfortabler machen							
12	Ich denke, dass die Nutzung dieser Technologie immer mit einem gewissen Risiko verbunden ist.							
13	Die Anwendung dieser Technologie ist leicht verständlich.							
14	Wenn ein neues technisches Gerät auf den Markt kommt, informiere ich mich darüber.							
16	Diese Technologie würde mir helfen, meine täglichen Aufgaben bequemer zu erledigen.							
17	Ich denke, dass diese Technologie Gefahren für mich birgt.							
18	Die Anwendung dieser Technologie ist insgesamt einfach.							
20	Ich versuche immer aktuelle Informationen über neue technische Entwicklungen zu bekommen.							
22	Könnte ich mir diese Technologie leisten, würde ich sie mir anschaffen.							
23	Diese Technologie würde meine Alltagsroutine stören.							
24	Die Anwendung dieser Technologie ist kompliziert.							
26	Ich informiere mich über technologische Entwicklungen.							
28	Diese Technologie würde mich dabei unterstützen, meine alltäglichen Aufgaben zu erfüllen.							
29	Die Anwendung dieser Technologie würde mir mehr Nachteile als Vorteile bringen.							

Sie sehen untenstehend drei Fragen mit jeweils einer Antwortlinie **(10cm)** darunter. Die Antwortlinie entspricht einem Kontinuum mit den Endpunkten „trifft zu“ (volle Zustimmung) und „trifft nicht zu“ (volle Ablehnung). Sie können Ihre Antwort auf jedem beliebigen Punkt dazwischensetzen. Dazu machen Sie bitte bei jeder Frage ein Kreuz auf der Antwortlinie an der Stelle, die Ihrer Antwort entspricht.

Beispiel:

trifft zu |———x———————| trifft nicht zu

A Würden Sie diese Technologie nutzen?

trifft zu |——————————| trifft nicht zu

B Würden Sie sich diese Technologie anschaffen?

trifft zu |——————————| trifft nicht zu

C Würden Sie Zugang zu dieser Technologie haben wollen?

trifft zu |——————————| trifft nicht zu

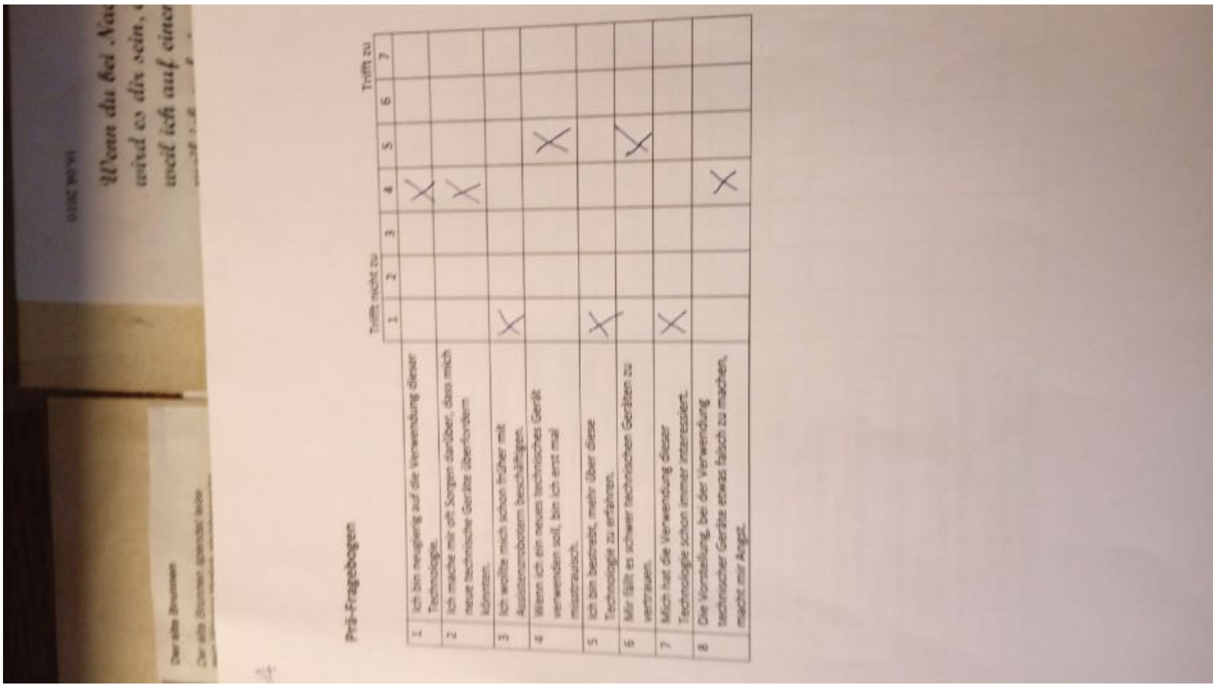
Letzte Frage:

Können Sie sich Situationen vorstellen, in den Ihnen der Roboter selbständig seine Hilfe anbieten könnte? Wo wünschen Sie sich Unterstützung von einem Assistenzroboter?

Beispielszenarien:

- *Besuch ist da oder kommt bald*
- *Bestimmte Tageszeiten, morgens, mittags, abends*
- *Bestimmte Tage/am Wochenende*
- *Bei bestimmtem Wetter*
- *Bei einer bestimmten Lautstärke*
- *Ausübung von Hobbies*
- *Beim Benutzen des Computers*
- *…*

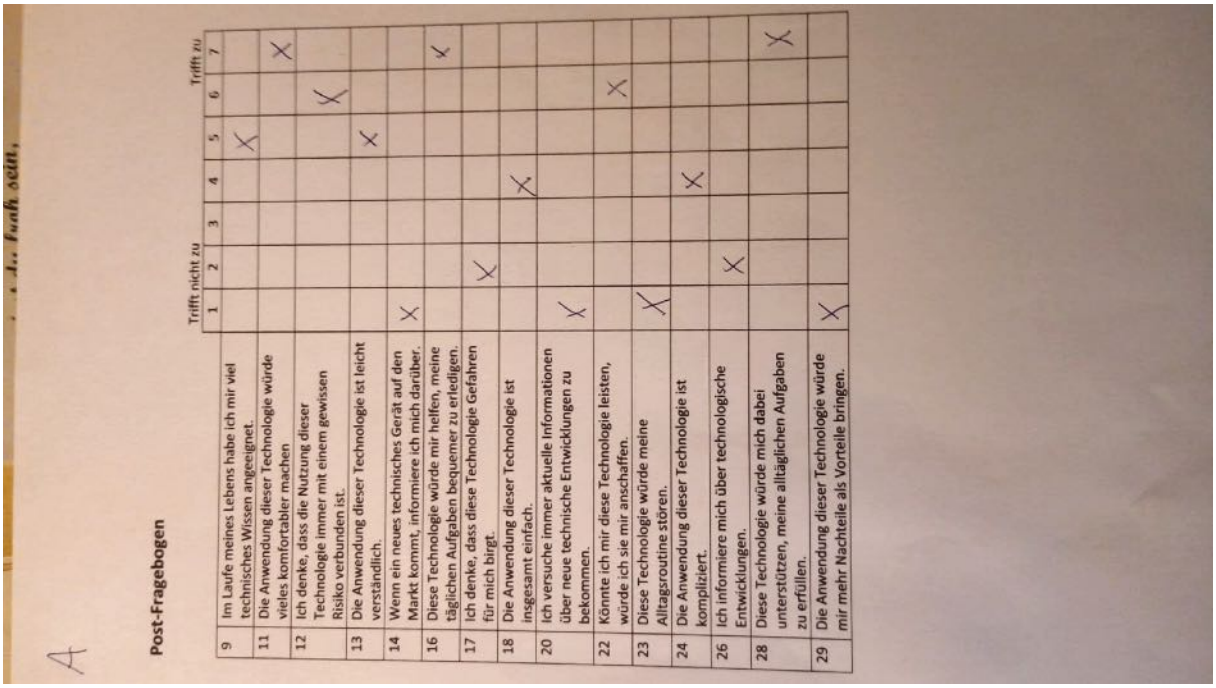
A.3 Survey Results



Prä-Fragebogen

		Trifft nicht zu 1	2	3	4	5	6	Trifft zu 7
1	Ich bin neugierig auf die Verwendung dieser Technologie.				X			
2	Ich mache mir oft Sorgen darüber, dass mich neue technische Geräte überfordern könnten.				X			
3	Ich wollte mich schon früher mit Assistenzrobotern beschäftigen.	X						
4	Wenn ich ein neues technisches Gerät verwenden soll, bin ich erst mal misstrauisch.					X		
5	Ich bin bestrebt, mehr über diese Technologie zu erfahren.	X						
6	Mir fällt es schwer technischen Geräten zu vertrauen.					X		
7	Mich hat die Verwendung dieser Technologie schon immer interessiert.	X						
8	Die Vorstellung, bei der Verwendung technischer Geräte etwas falsch zu machen, macht mir Angst.				X			

Figure A.1 – The completed pre questionnaire from participant A

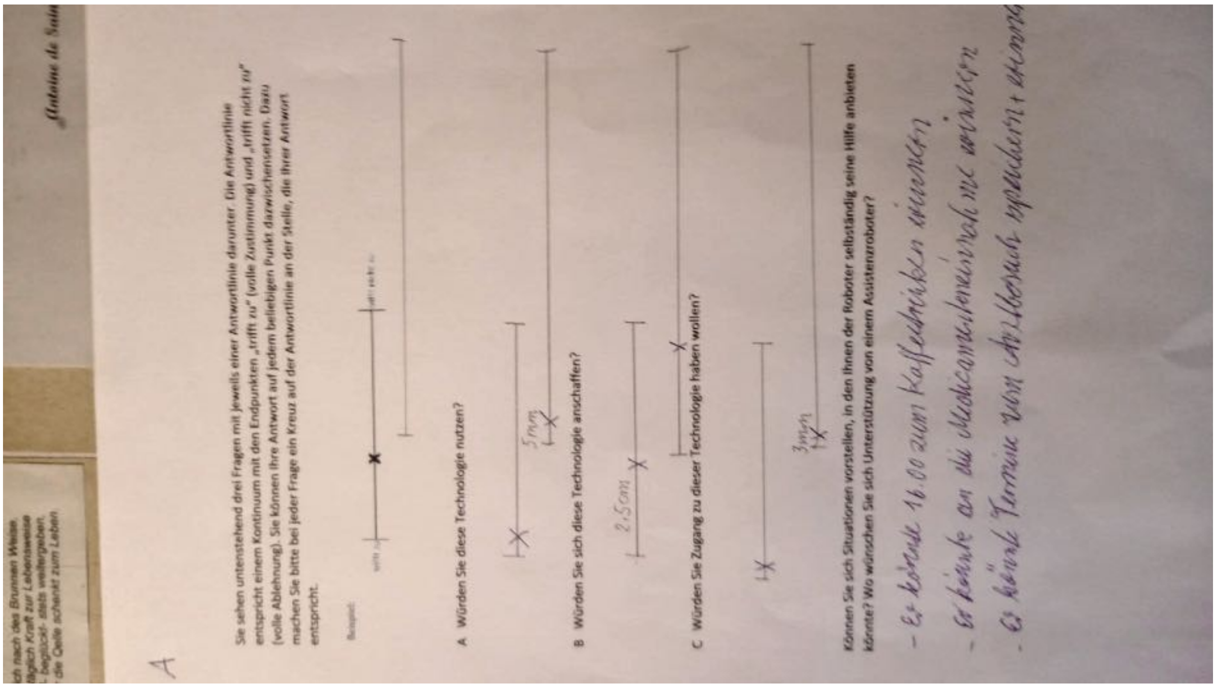


A

Post-Fragebogen

		Trifft nicht zu 1	2	3	4	5	6	Trifft zu 7
9	Im Laufe meines Lebens habe ich mir viel technisches Wissen angeeignet.					X		
11	Die Anwendung dieser Technologie würde vieles komfortabler machen							X
12	Ich denke, dass die Nutzung dieser Technologie immer mit einem gewissen Risiko verbunden ist.						X	
13	Die Anwendung dieser Technologie ist leicht verständlich.					X		
14	Wenn ein neues technisches Gerät auf den Markt kommt, informiere ich mich darüber.	X						
16	Diese Technologie würde mir helfen, meine täglichen Aufgaben bequemer zu erledigen.							X
17	Ich denke, dass diese Technologie Gefahren für mich birgt.		X					
18	Die Anwendung dieser Technologie ist insgesamt einfach.				X			
20	Ich versuche immer aktuelle Informationen über neue technische Entwicklungen zu bekommen.	X						
22	Könnte ich mir diese Technologie leisten, würde ich sie mir anschaffen.						X	
23	Diese Technologie würde meine Alltagsroutine stören.	X						
24	Die Anwendung dieser Technologie ist kompliziert.				X			
26	Ich informiere mich über technologische Entwicklungen.		X					
28	Diese Technologie würde mich dabei unterstützen, meine alltäglichen Aufgaben zu erfüllen.							X
29	Die Anwendung dieser Technologie würde mir mehr Nachteile als Vorteile bringen.	X						

Figure A.2 – The completed post questionnaire from participant A



A

Sie sehen untenstehend drei Fragen mit jeweils einer Antwortlinie darunter. Die Antwortlinie entspricht einem Kontinuum mit den Endpunkten „trifft zu“ (volle Zustimmung) und „trifft nicht zu“ (volle Ablehnung). Sie können Ihre Antwort auf jedem beliebigen Punkt dazwischensetzen. Dazu machen Sie bitte bei jeder Frage ein Kreuz auf der Antwortlinie an der Stelle, die Ihrer Antwort entspricht.

Beispiel:

A Würden Sie diese Technologie nutzen?

5mm

B Würden Sie sich diese Technologie anschaffen?

2,5cm

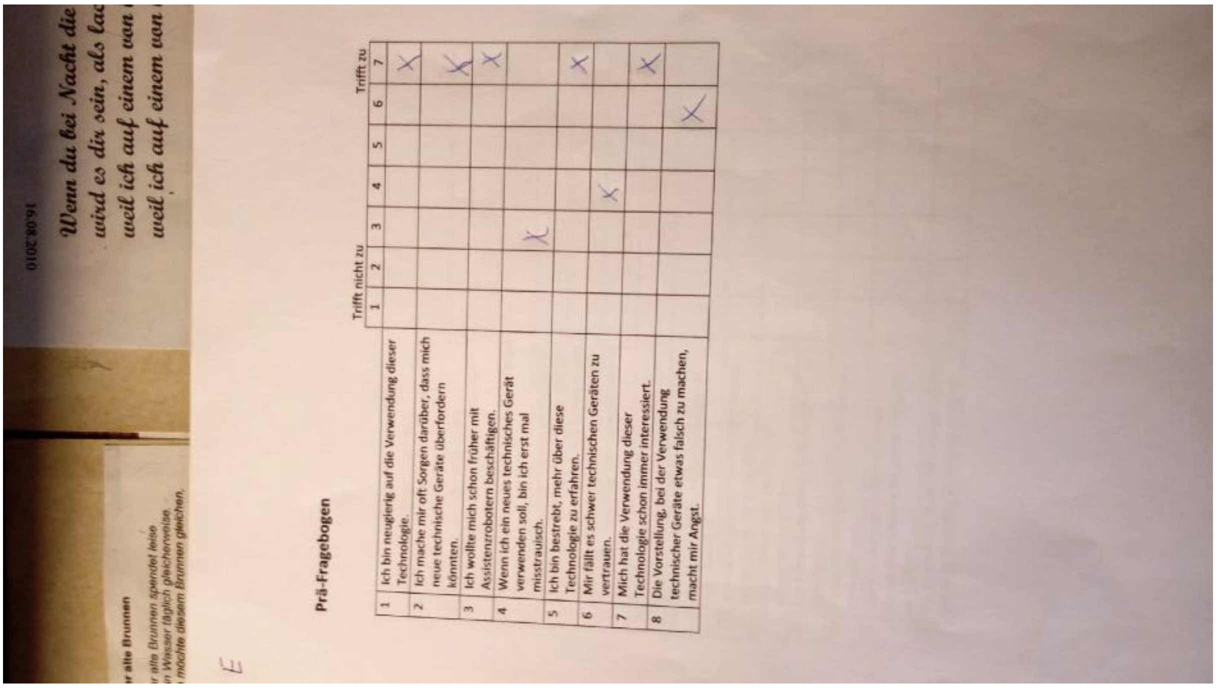
C Würden Sie Zugang zu dieser Technologie haben wollen?

3mm

Können Sie sich Situationen vorstellen, in den Ihnen der Roboter selbständig seine Hilfe anbieten könnte? Wo wünschen Sie sich Unterstützung von einem Assistenzroboter?

- Es könnte 16.00 zum Kaffeetrinken erinnern
- Er könnte an die Medicamenteneinnahme erinnern
- Es könnte Termine zum Arztbesuch speichern + erinne

Figure A.3 – The completed ITU questionnaire from participant A



E

Prä-Fragebogen

		Trifft nicht zu 1	2	3	4	5	6	Trifft zu 7
1	Ich bin neugierig auf die Verwendung dieser Technologie.							X
2	Ich mache mir oft Sorgen darüber, dass mich neue technische Geräte überfordern könnten.							X
3	Ich wollte mich schon früher mit Assistenzrobotern beschäftigen.							X
4	Wenn ich ein neues technisches Gerät verwenden soll, bin ich erst mal misstrauisch.			X				
5	Ich bin bestrebt, mehr über diese Technologie zu erfahren.							X
6	Mir fällt es schwer technischen Geräten zu vertrauen.				X			
7	Mich hat die Verwendung dieser Technologie schon immer interessiert.							X
8	Die Vorstellung, bei der Verwendung technischer Geräte etwas falsch zu machen, macht mir Angst.						X	

Figure A.4 – The completed pre questionnaire from participant E

Figure A.5 – The completed post questionnaire from participant E

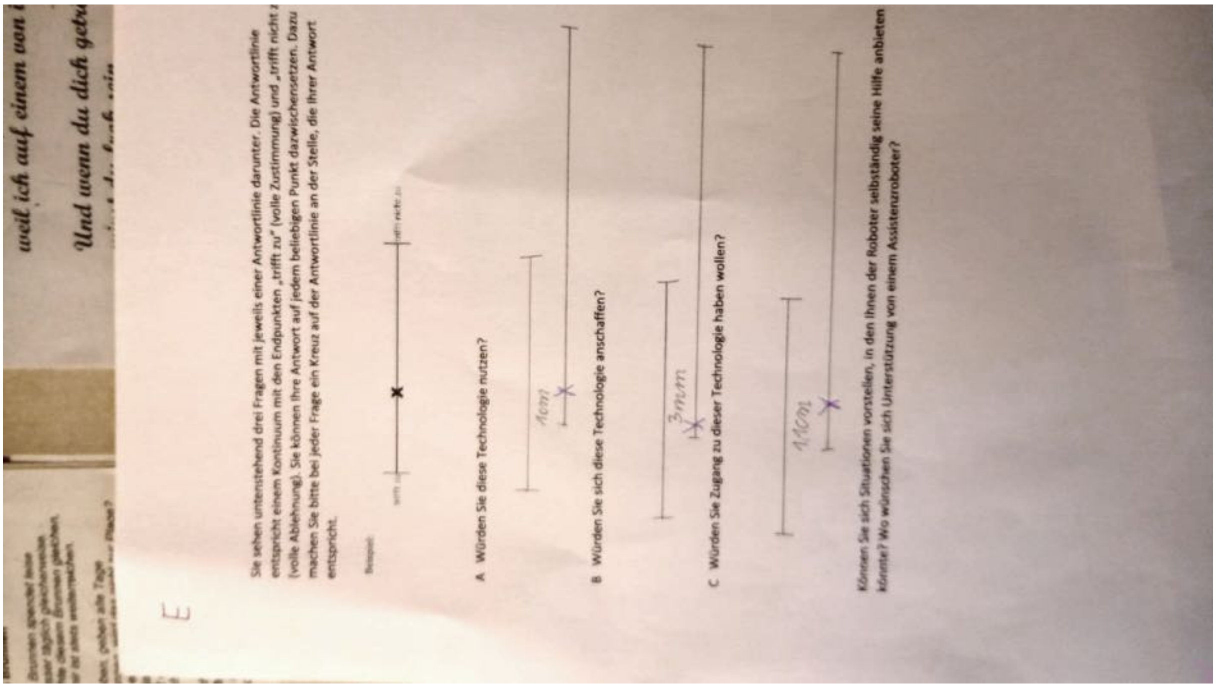
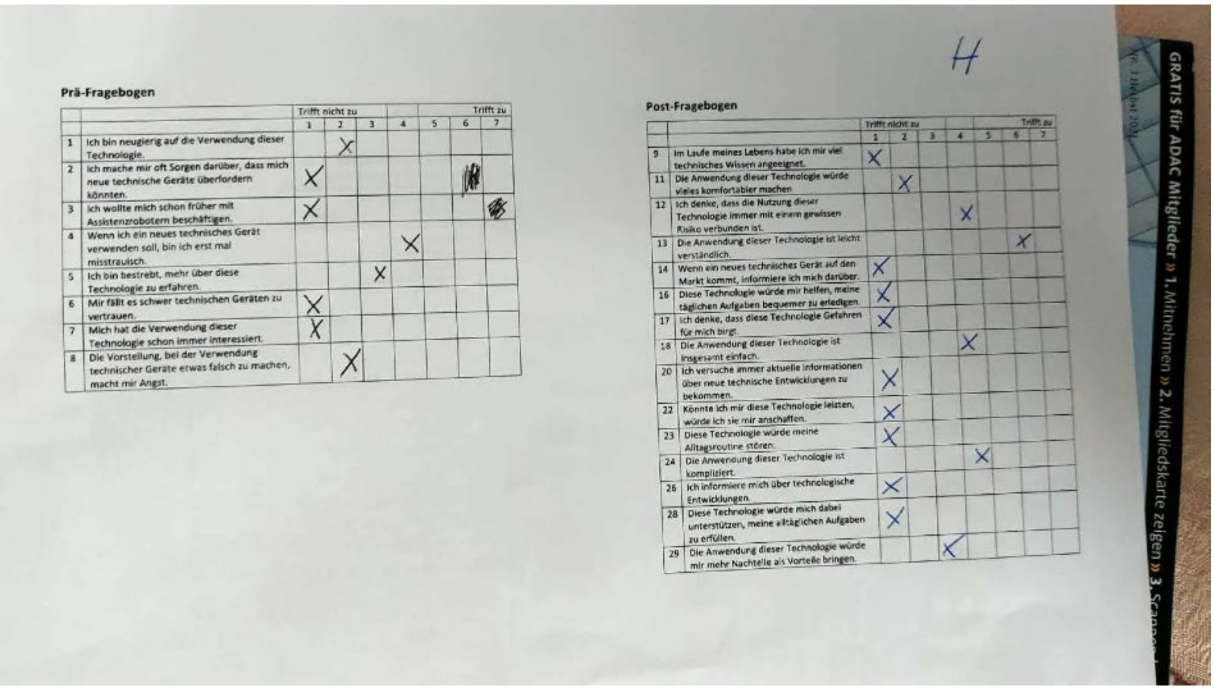


Figure A.6 – The completed ITU questionnaire from participant E



Prä-Fragebogen

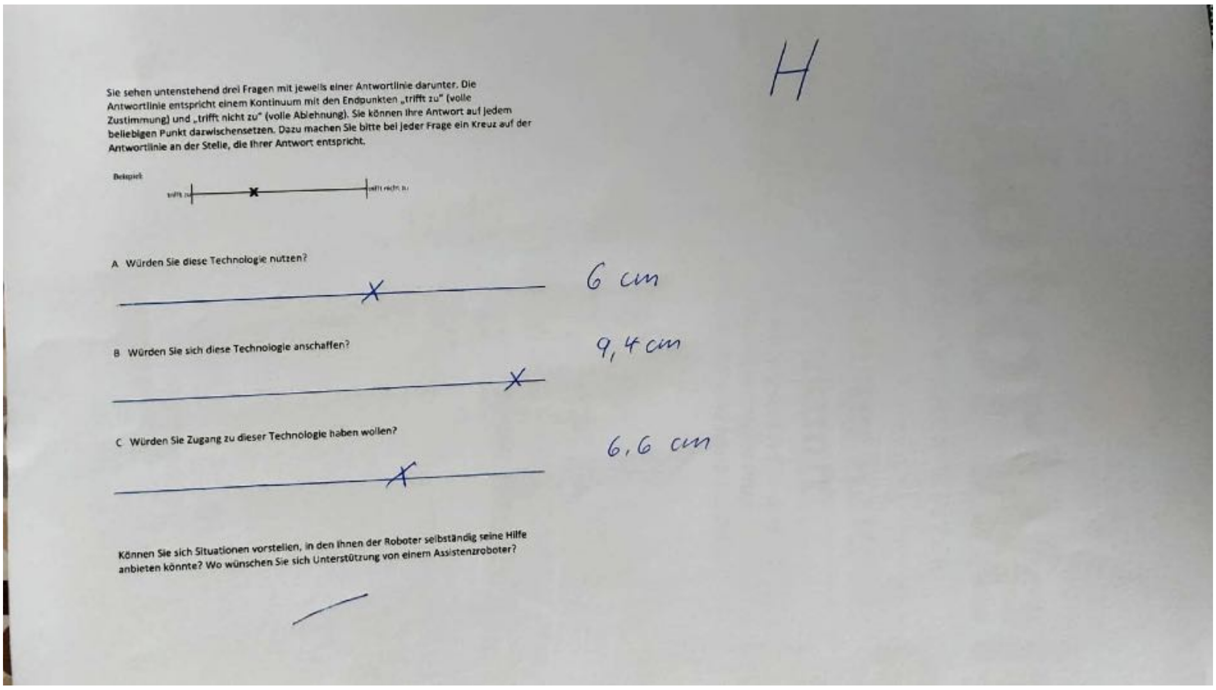
		Trifft nicht zu						Trifft zu
		1	2	3	4	5	6	7
1	Ich bin neugierig auf die Verwendung dieser Technologie.		X					
2	Ich mache mir oft Sorgen darüber, dass mich neue technische Geräte überfordern könnten.	X						
3	Ich wollte mich schon früher mit Assistenzrobotern beschäftigen.	X						
4	Wenn ich ein neues technisches Gerät verwenden soll, bin ich erst mal misstrauisch.				X			
5	Ich bin bestrebt, mehr über diese Technologie zu erfahren.			X				
6	Mir fällt es schwer technischen Geräten zu vertrauen.	X						
7	Mich hat die Verwendung dieser Technologie schon immer interessiert.	X						
8	Die Vorstellung, bei der Verwendung technischer Geräte etwas falsch zu machen, macht mir Angst.		X					

H

Post-Fragebogen

		Trifft nicht zu						Trifft zu
		1	2	3	4	5	6	7
9	Im Laufe meines Lebens habe ich mir viel technisches Wissen angeeignet.	X						
11	Die Anwendung dieser Technologie würde vieles komfortabler machen		X					
12	Ich denke, dass die Nutzung dieser Technologie immer mit einem gewissen Risiko verbunden ist.				X			
13	Die Anwendung dieser Technologie ist leicht verständlich.						X	
14	Wenn ein neues technisches Gerät auf den Markt kommt, informiere ich mich darüber.	X						
16	Diese Technologie würde mir helfen, meine täglichen Aufgaben bequemer zu erledigen.	X						
17	Ich denke, dass diese Technologie Gefahren für mich birgt.	X						
18	Die Anwendung dieser Technologie ist insgesamt einfach.				X			
20	Ich versuche immer aktuelle Informationen über neue technische Entwicklungen zu bekommen.	X						
22	Könnte ich mir diese Technologie leisten, würde ich sie mir anschaffen.	X						
23	Diese Technologie würde meine Alltagsroutine stören.	X						
24	Die Anwendung dieser Technologie ist kompliziert.					X		
26	Ich informiere mich über technologische Entwicklungen.	X						
28	Diese Technologie würde mich dabei unterstützen, meine alltäglichen Aufgaben zu erfüllen.	X						
29	Die Anwendung dieser Technologie würde mir mehr Nachteile als Vorteile bringen.				X			

Figure A.7 – The completed pre and post questionnaire from participant H



H

Sie sehen untenstehend drei Fragen mit jeweils einer Antwortlinie darunter. Die Antwortlinie entspricht einem Kontinuum mit den Endpunkten „trifft zu" (volle Zustimmung) und „trifft nicht zu" (volle Ablehnung). Sie können Ihre Antwort auf jedem beliebigen Punkt dazwischensetzen. Dazu machen Sie bitte bei jeder Frage ein Kreuz auf der Antwortlinie an der Stelle, die Ihrer Antwort entspricht.

Beispiel

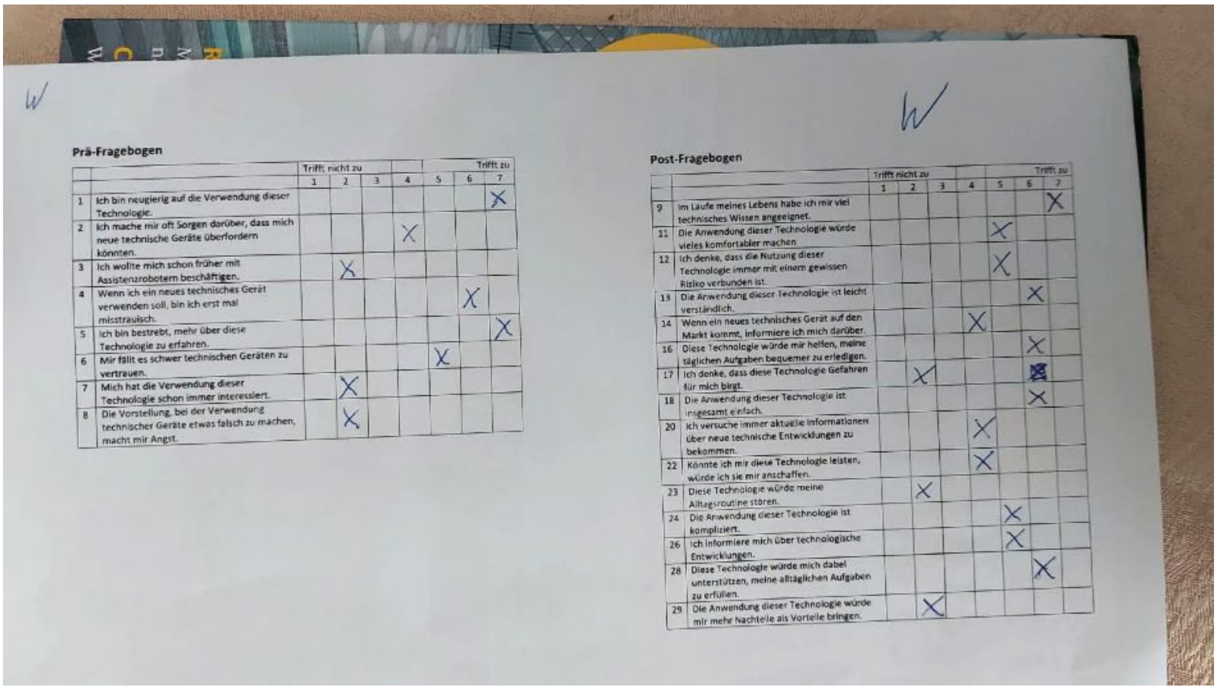
A Würden Sie diese Technologie nutzen? 6 cm

B Würden Sie sich diese Technologie anschaffen? 9,4 cm

C Würden Sie Zugang zu dieser Technologie haben wollen? 6.6 cm

Können Sie sich Situationen vorstellen, in den Ihnen der Roboter selbständig seine Hilfe anbieten könnte? Wo wünschen Sie sich Unterstützung von einem Assistenzroboter?

Figure A.8 – The completed ITU questionnaire from participant H



W

Prä-Fragebogen

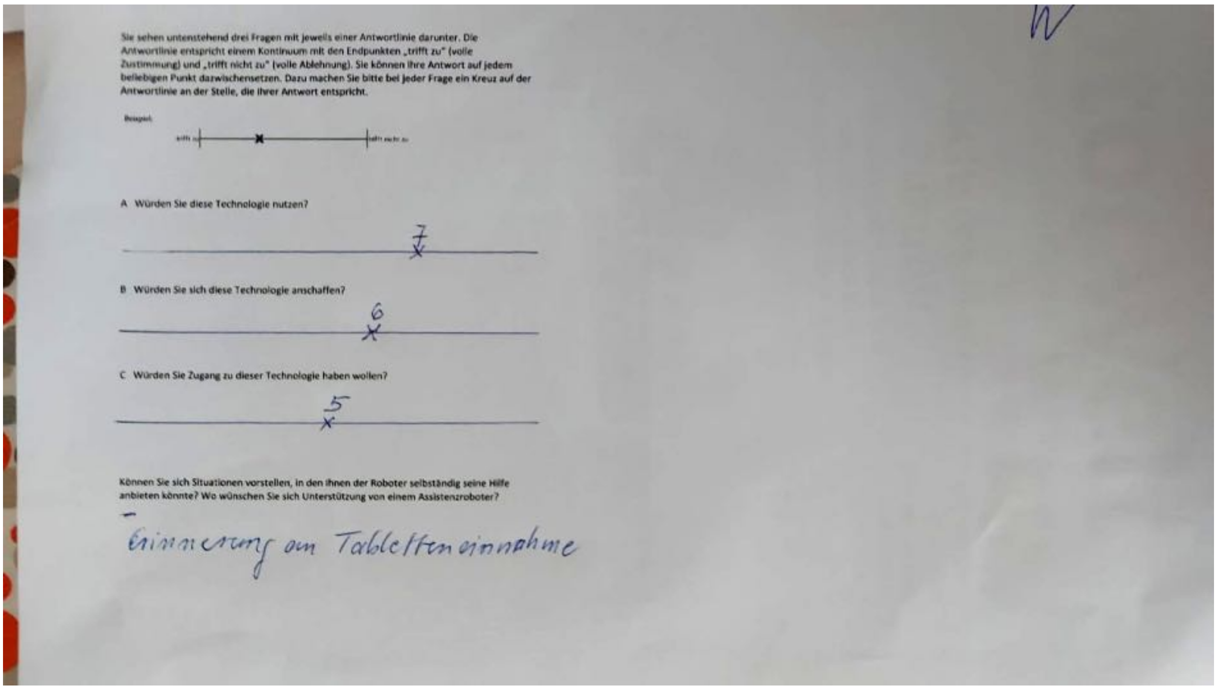
		Trifft nicht zu						Trifft zu
		1	2	3	4	5	6	7
1	Ich bin neugierig auf die Verwendung dieser Technologie.							X
2	Ich mache mir oft Sorgen darüber, dass mich neue technische Geräte überfordern könnten.				X			
3	Ich wollte mich schon früher mit Assistenzrobotern beschäftigen.		X					
4	Wenn ich ein neues technisches Gerät verwenden soll, bin ich erst mal misstrauisch.						X	
5	Ich bin bestrebt, mehr über diese Technologie zu erfahren.							X
6	Mir fällt es schwer technischen Geräten zu vertrauen.					X		
7	Mich hat die Verwendung dieser Technologie schon immer interessiert.		X					
8	Die Vorstellung, bei der Verwendung technischer Geräte etwas falsch zu machen, macht mir Angst.		X					

W

Post-Fragebogen

		Trifft nicht zu						Trifft zu
		1	2	3	4	5	6	7
9	Im Laufe meines Lebens habe ich mir viel technisches Wissen angeeignet.							X
11	Die Anwendung dieser Technologie würde vieles komfortabler machen					X		
12	Ich denke, dass die Nutzung dieser Technologie immer mit einem gewissen Risiko verbunden ist.					X		
13	Die Anwendung dieser Technologie ist leicht verständlich.						X	
14	Wenn ein neues technisches Gerät auf den Markt kommt, informiere ich mich darüber.				X			
16	Diese Technologie würde mir helfen, meine täglichen Aufgaben bequemer zu erledigen.						X	
17	Ich denke, dass diese Technologie Gefahren für mich birgt.		X				~~X~~	
18	Die Anwendung dieser Technologie ist insgesamt einfach.						X	
20	Ich versuche immer aktuelle Informationen über neue technische Entwicklungen zu bekommen.				X			
22	Könnte ich mir diese Technologie leisten, würde ich sie mir anschaffen.				X			
23	Diese Technologie würde meine Alltagsroutine stören.		X					
24	Die Anwendung dieser Technologie ist kompliziert.					X		
26	Ich informiere mich über technologische Entwicklungen.					X		
28	Diese Technologie würde mich dabei unterstützen, meine alltäglichen Aufgaben zu erfüllen.						X	
29	Die Anwendung dieser Technologie würde mir mehr Nachteile als Vorteile bringen.		X					

Figure A.9 – The completed pre and post questionnaire from participant W



W

Sie sehen untenstehend drei Fragen mit jeweils einer Antwortlinie darunter. Die Antwortlinie entspricht einem Kontinuum mit den Endpunkten „trifft zu" (volle Zustimmung) und „trifft nicht zu" (volle Ablehnung). Sie können Ihre Antwort auf jedem beliebigen Punkt dazwischensetzen. Dazu machen Sie bitte bei jeder Frage ein Kreuz auf der Antwortlinie an der Stelle, die Ihrer Antwort entspricht.

Beispiel:

trifft zu ——x—————— trifft nicht zu

A Würden Sie diese Technologie nutzen?

7

B Würden Sie sich diese Technologie anschaffen?

6

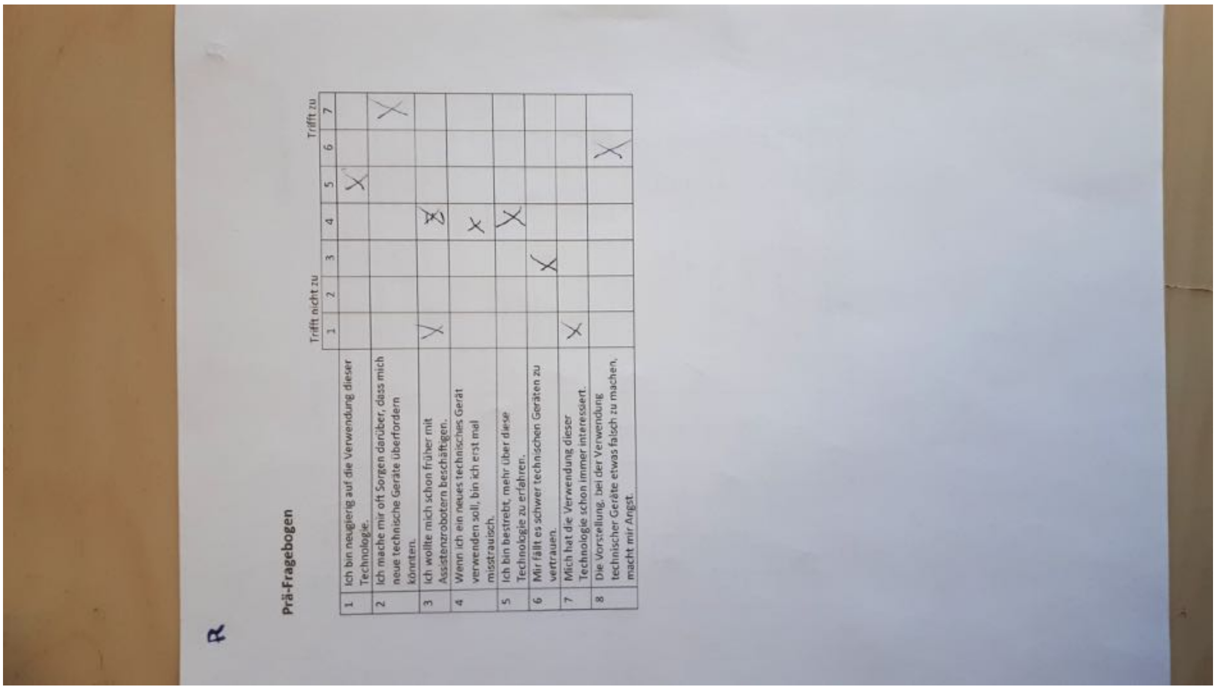
C Würden Sie Zugang zu dieser Technologie haben wollen?

5

Können Sie sich Situationen vorstellen, in den ihnen der Roboter selbständig seine Hilfe anbieten könnte? Wo wünschen Sie sich Unterstützung von einem Assistenzroboter?

– Erinnerung an Tablettenеinnahme

Figure A.10 – The completed ITU questionnaire from participant W

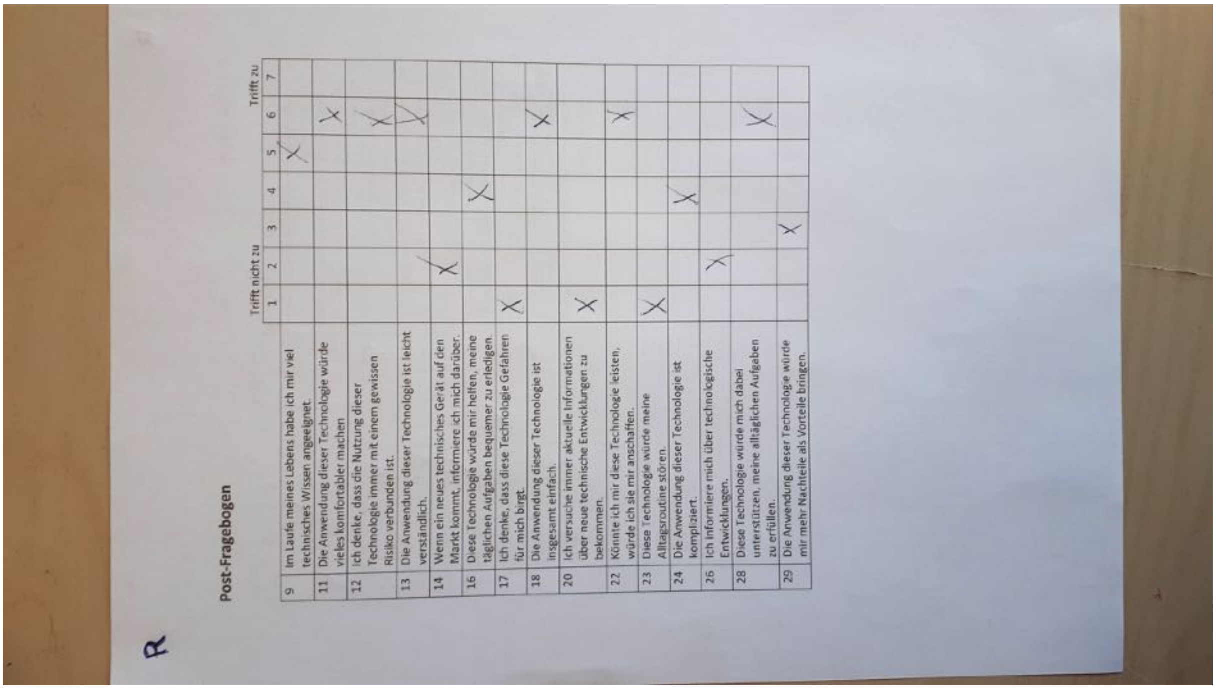


R

Prä-Fragebogen

		Trifft nicht zu 1	2	3	4	5	6	Trifft zu 7
1	Ich bin neugierig auf die Verwendung dieser Technologie.					X		
2	Ich mache mir oft Sorgen darüber, dass mich neue technische Geräte überfordern könnten.							X
3	Ich wollte mich schon früher mit Assistenzrobotern beschäftigen.	X			X			
4	Wenn ich ein neues technisches Gerät verwenden soll, bin ich erst mal misstrauisch.				X			
5	Ich bin bestrebt, mehr über diese Technologie zu erfahren.				X			
6	Mir fällt es schwer technischen Geräten zu vertrauen.			X				
7	Mich hat die Verwendung dieser Technologie schon immer interessiert.	X						
8	Die Vorstellung, bei der Verwendung technischer Geräte etwas falsch zu machen, macht mir Angst.						X	

Figure A.11 – The completed pre questionnaire from participant R

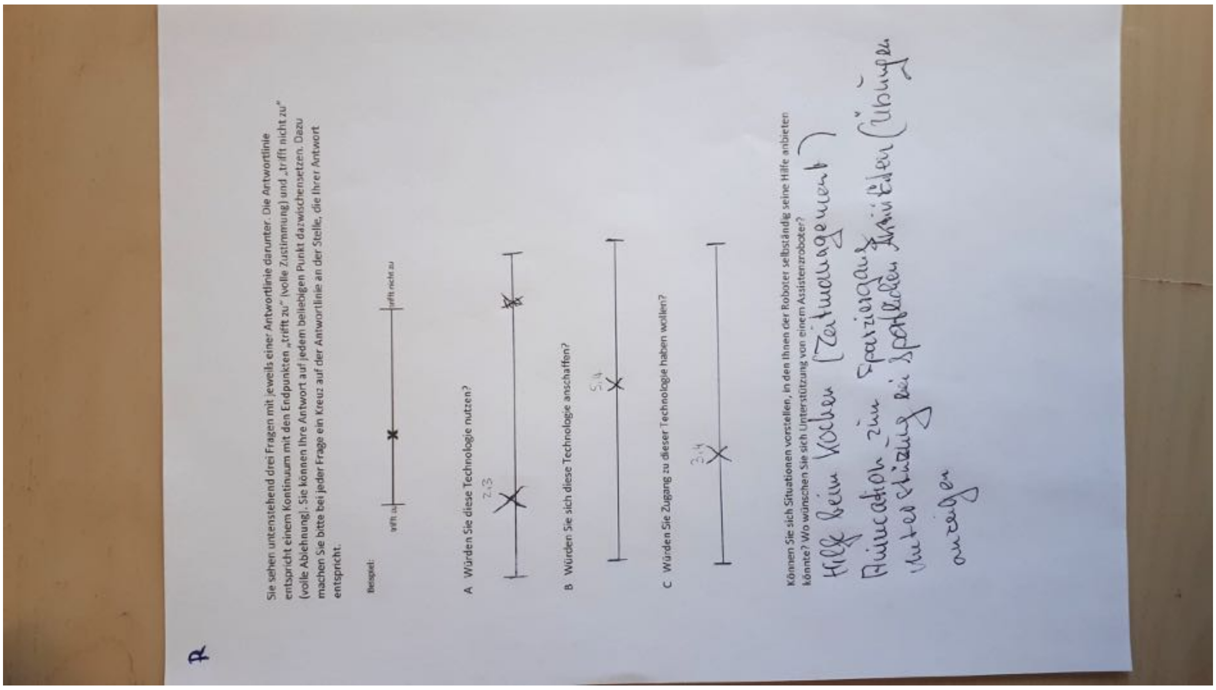


R

Post-Fragebogen

		Trifft nicht zu 1	2	3	4	5	6	Trifft zu 7
9	Im Laufe meines Lebens habe ich mir viel technisches Wissen angeeignet.					X		
11	Die Anwendung dieser Technologie würde vieles komfortabler machen						X	
12	Ich denke, dass die Nutzung dieser Technologie immer mit einem gewissen Risiko verbunden ist.						X	
13	Die Anwendung dieser Technologie ist leicht verständlich.						X	
14	Wenn ein neues technisches Gerät auf den Markt kommt, informiere ich mich darüber.		X					
16	Diese Technologie würde mir helfen, meine täglichen Aufgaben bequemer zu erledigen.				X			
17	Ich denke, dass diese Technologie Gefahren für mich birgt.	X						
18	Die Anwendung dieser Technologie ist insgesamt einfach.						X	
20	Ich versuche immer aktuelle Informationen über neue technische Entwicklungen zu bekommen.	X						
22	Könnte ich mir diese Technologie leisten, würde ich sie mir anschaffen.						X	
23	Diese Technologie würde meine Alltagsroutine stören.	X						
24	Die Anwendung dieser Technologie ist kompliziert.				X			
26	Ich informiere mich über technologische Entwicklungen.		X					
28	Diese Technologie würde mich dabei unterstützen, meine alltäglichen Aufgaben zu erfüllen.						X	
29	Die Anwendung dieser Technologie würde mir mehr Nachteile als Vorteile bringen.			X				

Figure A.12 – The completed post questionnaire from participant R



R

Sie sehen untenstehend drei Fragen mit jeweils einer Antwortlinie darunter. Die Antwortlinie entspricht einem Kontinuum mit den Endpunkten „trifft zu" (volle Zustimmung) und „trifft nicht zu" (volle Ablehnung). Sie können Ihre Antwort auf jedem beliebigen Punkt dazwischensetzen. Dazu machen Sie bitte bei jeder Frage ein Kreuz auf der Antwortlinie an der Stelle, die Ihrer Antwort entspricht.

Beispiel:

trifft zu — trifft nicht zu

A Würden Sie diese Technologie nutzen?

2,3

B Würden Sie sich diese Technologie anschaffen?

5,4

C Würden Sie Zugang zu dieser Technologie haben wollen?

3,4

Können Sie sich Situationen vorstellen, in den Ihnen der Roboter selbständig seine Hilfe anbieten könnte? Wo wünschen Sie sich Unterstützung von einem Assistenzroboter?

Hilfe beim Kochen (Zeitmanagement)

Animation zum Spaziergang

Unterstützung bei sportlichen Aktivitäten (Übungen anzeigen)

Figure A.13 – The completed ITU questionnaire from participant R

List of Abbreviations

ADL	Activities of Daily Living
AAL	Ambient Assisted Living
API	Application Programming Interface
BADL	Basic Activities of Daily Living
DAO	Data Access Object
IADL	Instrumental Activities of Daily Living
ITU	Intention to Use
LIFO	Last In First Out
TA	Technology Acceptance
TAM	Technology Acceptance Model
TUI	Technology Usage Inventory
UI	User Interface
UX	User Experience

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