Online platform for supporting the development of assistive technology tools for disabled people

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Abstract

Assistive technology is important for disabled people and can help them be active in society and improve their wellbeing. However, designing assistive technology products is difficult and needs to consider different requirements and constraints. In this report, we aim to investigate the design of an online platform for supporting the development of assistive technology tools for disabled people. For this we aim to address the following research questions: (RQ1) What are the key stakeholder requirements of an assistive technology platform for disabled people? (RQ2) How to develop an eye controlled telecommunication robot? (RQ3**)** What is the conceptual design and requirements for a platform dedicated to assistive technology for people with disabilities?

To answer these research questions we have first performed a literature review to gain more insight into the stakeholders, the design approaches, and the available platforms. Based on a stakeholders analysis and the design approaches we have provided a first conceptual design of a platform that will enable the development and usage of modules for the development of assistive technology products. A systematic method has then been proposed to develop the platform and use it for the development of assistive technology tools. Subsequently, an ideation process has been performed that includes the conceptual design of the platform and the design of two separate cases studies.

The first case study considers the design of the Eye Controlling interface for the earlier developed Bluebot Robot. This case study has only been reported from the ideation perspective and we did not elaborate on this in the implementation phase. The second case study defines the Parrot Robot that can be carried on the shoulder of a person and remotely controlled by a disabled person who can only use his eyes. This case study is used from the ideation up until the implementation phase. In the implementation phase, we have composed the Parrot Robot out of existing reusable components. In this way, we have shown how a typical platform with assistive technology components can be reused to develop a robot like the Parrot Robot. From the evaluation of the robot we can conclude that it is a practical alternative to a more expensive autononomous robot that will require still a lot more time to be completed.

Acknowledgments

I would like to thank Andrei Fokking and his father Arie Fokking for providing this important and interesting research topic, and their collaboration for the interview. Due to post-COVID symptoms I had some delay with the activities. I would like to thank my supervisors Edwin Dertien and Femke Nijboer for their patience, help and support for improving and finalizing this report.

Chapter 1 – Introduction

Like many industrial domains, the healthcare business is also being transformed by digitalization. Different digital solutions, such as electronic health records, AI-powered medical devices, remote patient monitoring, and smart software platforms, can select and perform faster and more accurate diagnoses and better treatment procedures. Unfortunately, the current digital solutions have targeted the broader public and often do not focus on accessibility for disabled people. As such, disabled people are less supported by the available tools, although these people often need more support. Developing digital healthcare solutions dedicated or accessible for disabled people is often not trivial and requires additional cost and effort. Moreover, expert knowledge on the needs of disabled people is required to develop the tools that meet the concerns of disabled people.

For disabled people and elderly people performing activities of daily lives (ADLs), independently or even with assistance can often be challenging. ADLs include mobility, eating, bathing, dressing, toileting, and personal care. Assistive technology can reduce the effects of disabilities that limit ADLs. Assistive technology (AT) is defined as "any item, piece of equipment, software program, or product system used to increase, maintain, or improve the functional capabilities of persons with disabilities." [1]. An assistive product is "any product (including devices, equipment, instruments, and software), either specially designed and produced or generally available, whose primary purpose is to maintain or improve an individual's functioning and independence and thereby promote their wellbeing" [1].

With AT, disabled people can achieve greater independence to perform ADLs they were formerly unable to accomplish easily. To this end, AT enhances existing tools and technology needed to accomplish such tasks. For example, wheelchairs can provide mobility, dedicated devices can support eating, or AT can provide voice recognition to support the writing process in schools. People who mainly need AT are people with disabilities, the elderly, people with non-transferable diseases like diabetes and heart stroke, people with psychological wellness conditions, and people with steady functional weakening [2]. Equipping those in need with assistive technology is necessary to bring them back to society physically and emotionally. Thanks to AT, people with disabilities will have the chance to participate in social life and feel more secure.

The context of this research is related to the 25 year person, AnF-Son, who is coping with a locked-in syndrome (LiS) [3]. LiS is a rare and serious neurological disorder that damages the brainstem, usually from a stroke. Although people with LiS have total paralysis but still have consciousness and their normal cognitive abilities. Most people with LiS can only communicate with eye movements. This is also the case for AnF-Son. Currently, he is using a wheel chair combined with a specialized computer called Tobii. Besides his daily needs, with the help of Tobii and the intelligent user interface, AnF-Son can additionally perform tasks such as drawing and playing an instrument on his computer [4]. AnF-Son has a helpful father who is actively pursuing assistive technology solutions to further ease the life of his son. He is now thinking for helping a broader number of disabled people and as such aims to develop a platform for AT.

In this report, we provide the results of an interview with a platform kickstarter (AnF-Son's father) on assistive technology (see Appendix A). Based on the interview we have provided the following research questions:

RQ1. What are the key **stakeholder requirements** of an assistive technology platform for disabled people?

RQ2. How to develop an eye controlled **telecommunication robot?**

RQ3. What is the conceptual design and requirements for a **platform** dedicated to assistive technology for people with disabilities?

To answer these research questions we have first performed a literature review to gain more insight into the stakeholders, the design approaches, and the available platforms. For answering RQ1 we have provided a systematic stakeholder analysis and prioritized these stakeholders.

RQ2 deals with the design process of assistive technology for disabled people by reconstructing the idea of a robot called "Bluebot" into the so-called “Parrot Robot”. Parrot Robot is built for AnF-Soni, who wishes to control the robot remotely with his eyes. The goal of this robot is to replace this person in social contexts. For this, we describe

RQ3 focuses on designing a reusable software and hardware ecosystem platform that can be used to develop modules dedicated to the healthcare of disabled people. The platform can be used by both developers who can add modules, and users who can download and install the modules. A cloud-based solution will be provided that will thus reduce the cost of installing, using, and maintaining the required modules. The design of a platform dedicated to the healthcare of disabled people requires a dedicated approach independent of existing platforms that do not consider the specific concerns of disabled people. On the other hand, the concerns of different disabled people can be different and thus also require special solutions for different disabilities. In this report the requirements for the platform have been derived from the answers of the interview, the (re)design of the Bluebot and Parrot Robot, and the personal experiences with Parrot Robot.

The remainder of the report is organized as follows. In section 2, we provide the background results of the literature review. Section 3 describes the research method. Section 4 describes the ideation process of both the platform and specific products that can be developed. Chapter 5 and 6 presents the specification and realization. Section 7 the results and evaluation. Finally, section 8 presents the conclusion and discussion.

Chapter 2 – Background

2.1 Assistive Technology

An interplay between assistive technology and its fields of use is important to ensure that the technology will indeed fulfill the users' needs, meaning that not only requirements of engineering, manufacturing, and ergonomics are considered, but attention is also paid to user experience, the aesthetics of the technology, and the quality of its interaction with the user [5][6]. The state-of-the-art technology allows us to dive deeper into the user experience aspect of the technology. The following points, based on research on AT users in Australia of what they expect from AT [1], indicate what needs to be accomplished to have a fully working reliable system and reasons why creating assistive technologies is complicated.

- Determination of the best combination of devices, personal care, and environmental design.
- Access to sufficient funding for good quality and long-lasting devices.
- Holistic assessment of needs so that each device works well and does not interfere with other supports.
- Consideration of AT needs across the lifespan and as needs change.
- Support throughout the process of getting AT, including device trial, training, and maintenance.
- Consideration of personal preferences and identity so that AT is chosen to suit lifestyle and participation.

The AT user perspective shows the designer how much time and emphasis must be given. A future-proof support system needs to be developed. This means having experts in the AT that are created that can adapt the product for the users' needs as their context changes. These contexts can be a case where something breaks or a new device needs to be added to the system. It's also important to have such support accessible in case of emergencies. DFI (Disability Federation of Ireland) recommends in their discussion paper to prioritize user-centered research in technology design, underpinned by the principles of Universal Design. All innovation and research funding targeting the development of technologies across the industry must also provide for accessibility [6].Following this recommendation will result in faster innovation, more expertized people, and better service for AT users.

Research on the evaluation methodologies of AT interaction devices suggests that empirical or trial and error are the most common evaluations [8]. The research stumbles on problems of economic and knowledge barriers during the designing of AT devices. It only makes sense that these evaluation methods are the most common since a personalized device needs experimentation to be perfected. Users can give input of what they need in their AT devices to a certain degree until the experience of using the device comes in. This opens more doors for the user to explore and better understand the product that's been built. One of the main concerns of AT users stated in research done on AT users with mild dementia is simplified user interfaces with large fonts, simple functions, and language options [9]. Many users of AT devices have a low eHealth literacy level. Therefore, the user interface design should apply to the correct level of eHealth literacy. Another approach to taking the right route of the design process for an AT is through the assistance of a psychotechnologist [10]. The psychotechnologist is an expert in the person and the technology which can assist in identifying a solution that takes into consideration of the social context the user might be in. Most of the experts in the AT field are not psychological experts which can result in a product that doesn't consider the social contexts the AT user will be in.

Creating functionality from limited physical movement used to be a challenge. A research paper about remapping residual coordination to control assistive devices and recovering motor functions shows that even the slightest of movements can be turned into an operational function. They showed that it is possible to define and implement transformations from body motions to cursor control space with low-cost technologies [11]. The possibility of a highly customizable interface for the users and to have low-cost technologies to fulfill this need shows that specialized AT has great potential.

2.2 Telepresence Devices

A category of AT systems are telepresence systems which refers to technologies that allow a person to feel as if they were present. The telepresence is a combination of “tele” meaning distance, and presence. Telepresence systems provide thus the appearance or effect of being present via telerobotics, at a place other than their true location. Using telepresence systems users interact with the corresponding telerobots or systems to to provide the feeling of being in that other location.

In addition, besides of monitoring the remote environment users may also have the ability to control and affect the remote location. Typically, this is done by submitting the the user's position, movements, actions, voice to the remote location to initiate some action and thus have an impact on the remote environment. A two-way connection with the telerobot and the use will thus take place.

Different telepresence systems can be distinguished among which telepresence videoconferencing is a popular one. Hereby the participants to a conference can be at different locations and still meet like they are in the same place. Advancements in technology have allowed to extend the capabilities of videoconferencing and enable realistic conferencing.

Telepresence has also been applied in health care and for elderyly assistance guidance. Hereby, using telepresence the caretakers can be present at the location of the patient and provide remote assistance. Another application is the guidance of a telerobot to perform medical treatments. In [12] a literature review has been performed that analyzes and categorizes different telepresence systems in healthcare. The review aimed to define social presence, identify autonomous “user-adaptive systems” for social robots, and propose a taxonomy for “co-presence” mechanisms. Various important topics have been explored including robot sensing, perception, action, reasoning, appearance, automation, and cognitive approaches. Furthermore, an overview of social robotics systems and application areas have been given, which provides future directions for telepresence and co-presence robot design. The key concepts related to telepresence are defined as follows:

2.2.1 Co-Presence Design

Co-presence design focuses on the realization of co-presence in teleprecence robots. This requires the design of both the robot-side and the remote user (robot’s operator) side solutions. The robotside interface focuses on interactions between the robot and the local user (bystander) and between the robot and the remote user (operator). Different types of human-robot interfaces are described that focus on different aspects including sight, hearing, touch, and body-sensing technologies.

2.2.2 Sensing

For observing the environment the telerobots need to be equipped with the appropriate sensors. Different types of sensors cameras can be used for this purpose including 3D or 2D cameras, pressure sensors, touch sensors, directional sound sensors (arrays), high-precision proximity sensors (e.g., range laser finder (lidar)), and robot pose and position sensors (e.g., gyroscopes, accelerometers, and GPS) [12]. One of the important challenges of using multiple sensors is the fusion of the sensor data. With advanced techniques valuable information can be extract and synthesized such as sound locations, speech segregation and recognition, attention, gesture recognition, human action analysis.

2.2.3 Action Capabilities

Besides of sensing the environment the telerobots are often also equipped with actuators or effectors that have the capability to define some action such as movement, and provide sound. This requires that the telerobots have sufficient mobility and navigation capabilities. With the technological advancements in both robot software and hardware, lighter and stronger materials, component miniaturization, and lighter and more powerful batteries have broadened robots' capabilities [12]. Robots have now a more robust navigation even in unstructured environments and in rough terrain, and they can climb stairs, walk fast, and run, such as the Boston Dynamics ATLAS robot [13] or Honda ASIMO Robot [14]. In addition to these developments we can also observe advances in humanoid mobility and equilibrium, including compliant interactions and variable speed [15]. Robots start to resemble more and more human beings and have arms, hands, and fingers with advanced degrees of freedom enabling types of interactions such as high-fidelity gestures, grasping objects smoothly, or even open doors and pass though them. Further, the advancements of facial features help to support expression synthesis [16], and speech synthesis technologies which in its turn enable better human robot interaction.

2.2.4 Reasoning

The sensing capabilities provides a view on the environment, the acting capability can help to take action and control the environment. Actions are taken based on reasoning. The reasoning of robots have been made smarter with advanced software reasoning algorithms that help to support localization and mapping. In [17], for example, various different approaches and algorithms have been explored for a telepresence robot to detect and position itself with a group of people for social interactions. The integration and application of these smart algorithms can help support intelligent interactions with the robot, hereby simplifying the control, reducing the effort, and improving the intuitiveness.

2.2.5 Appearance

The appearance of robots can be in different forms. To support the acceptability of the robots enrolled in a social context it has been noted that appearance is an important concern. For this purpose designers have developed robots with human-like appearances. For example, The Geminoid robot has an incredibly realistic head and facial features [18], which enables more effective communication through facial expressions and natural gestures. Several studies show that realistic appearance of telerobots contribute consistently and positively to social presence [19][20], In [21][22], the effect of visual and behavioral realism on the perceived quality of communication using avatars was explored. They concluded that realistic components/robots have a positive effect on social presence. In parallel to the search for a realistic robot that resembles the human being, some warnings have been provided regarding the so-called Mori's "uncanny valley" [23][24]. Hereby, it is stated that if a robot is an imperfect replica of a human being, people may feel defrauded in their expectations regarding the affinity as a pair, triggering strange, familiar feelings of unease and revulsion.

2.2.6 Time Delay Mitigation

In telepresence systems it is important that the interaction with the telerobot is synchronized and performed in real-time.This is not trivial and has a substantial impact on the complexity of telepresence systems. Important metrics hereby are defined as time delay, jitter, distance, bandwidth constraints, packet loss, or blackout in internet-based solutions can delay or distort interactions [12]. Several approaches have been proposed for this purpose. Traditional methods to mitigate time delay in telerobotics focused on user interface design and control theory-based models and evolved into predictive displays and control [12]. More recent solutions adopt time series prediction methods to predict the time delay, robot movements, and user intentions (e.g., user's gaze prediction [25]). These methods typically make use of nonlinear statistical models and neural network (NN) or machine learning (ML) techniques.

2.2.7 Video and Audio Quality

The quality of telepresence is also determined by the video and audio quality. Video quality defines the medium to present the remote environment, including the visualization of persons (face expressions, gestures, postural behaviors, etc.). Audion quality refers to the quality of the audio channel and the bidirectional communication between the remote and local users to exchange audio messages. Hereby, human voice recognition plays an important role in person identification, contributing to the sense of co-presence [26]. In addition, voice transmission needs to be fluid without cuts or delays. To identify the direction of the sound source, provide a spatial sound or detect the movements of the user, telepresence robots can also make use of an array of microphones.

2.2.8 Telepresence robots

Telepresence robots are classified into the following two different categories:

- **Mobile robotic telepresence robot system**

These are defined as remotely controllable telerobots with video sensing equipment that allows remote users to navigate within a local environment and socially interact with other persons. These systems have locomotion capabilities and can incorporate semi-autonomous functionalities to mitigate operation loads such as navigation aids, points to follow, and obstacle avoidance.

- **Robotic telepresence system without locomotion**

These are defined as remotely controllable or semi-autonomous robots with sensing capabilities that enable social interaction with people in the local environment. However, these telepresence robots do not have locomotion capability. Users can remotely control parts of the robot (e.g., the head movements and facial expressions, and arm or hand gestures) or enable some semi-autonomous behaviors (e.g., blinking, face tracking, eye saccade, and breathing).

Figure 1 shows a list of robots with locomotion in the current market that have been discussed in [12]. Figure 2 shows the robots that do not have locomotion capability.

Robotic Telepresence Systems	Application Area	Expression or Manipulation	Navigation Features	Cost
Giraff	Eldery	Head tilt (screen display/camera)	No	USD 11,900.00
Double 2, 3	Office, education, hospital	Motorized height	Accelerometer and gyroscope for balance, kickstands when static	USD 2749.00
PadBot 2	Office, education, hospital	Tilt head (screen)	Obstacle detection, collision avoidance, anti-falling system	USD 1297.00
PadBot U1—v2	Office, education, hospital	Tilt head (screen)	Collision-prevention sensors. Edge detection and anti-falling sensors.	USD 797.00
PadBot T1	Office, home	No	Collision prevention, cliff sensor	USD 185.00
Beam Pro	Corporate, manufacturing, medical	No	Crash avoidance, assisted driving	USD 14,945.00
Ava 500	Healthcare, office	No	2D or 3D imaging, sonars and lasers for autonomous navigation, omnidirectional navigation, scheduling capabilities, cliff sensor	USD 32,000.00
Ohmni SuperCam	Office, home	No	Includes downward-facing camera for full visibility	USD 2195.00
VGo	Office, education	Tiltable head	Crash avoidance, notification of obstacles locations, cliff sensor	USD 3995.00
TeleMe 2	Office, education	Laser pointer option	Crash avoidance: infrared sensors detect obstacles and will automatically reduce robot's speed	USD 3995.00
RP-Vita	Healthcare, FDA clearance	Active patient monitoring	Obstacle avoidance, omnidirectional and autonomous navigation	USD 80,000.00
Teleporter	Office, factory, hospitals	Laser pointer, secondary webcam	Crash avoidance: infrared, 3D, or sonar sensors	USD 14,995.00

Figure 1. Mobile Robotic Telepresence Systems in the current market (adopted from [12])

Robotic Telepresence System	Application Area	Expression or Manipulation	Cost
Kubi	Office, education	Pan 300°, tilt 900°(screen)	USD 675.00
TableTop TeleMe	Office, education	Pan 360°, tilt head (screen)	USD 3995.00
SelfieBot	Office, education	Pan 180°, tilt 180° head (screen)	USD 195.00
Meeting Owl Pro	Office	Static 360° camera (1080p)	USD 999
Robovie mR2	Research	Expression, arms, gestures, eye blinking (cameras), 18 joints (3 in each eye), 18 servo motors	-

Figure 2. Robotic Telepresence Systems in the current market without locomotion capabilities (adopted from [12])

2.3 Platform Development

In system development one can decide to develop one system or develop a so-called platform that includes the components to develop a variety set of components to developed multiple different systems. Here the focus will thus be on developing reusable components that will be composed to develop systems faster. Thus instead of a single system focus a family of systems is considered. Obviously the development of such platforms is not easy and requires a broad insight in the overall domain.

Related to the notion of reusable platform is the notion of a software ecosystem that is defined as a collection of systems, which are developed and co-evolve in the same environment [27]. A software ecosystem includes a common platform that can be used by developers to develop reusable components, and users who can reuse these components to develop new systems. A software ecosystem defines in essence a community of internal and external actors that compose software systems to satisfy their needs. The term is inspired from natural ecosystems in which organisms are characterized by symbiotic relationships and their survival relies heavily on the survival of the ecosystem [28].

Platform development differs from the traditional software and system development approaches in which a single independent system vendor develops a single system. In platform development and ecosystems, an inter-organizational approach is adopted in which various companies and stakeholders collaborate and are integrated.

An example of platform and ecosystem are the smartphone software ecosystems such as that of Samsung and Apple. Thereby a platform is provided for external developers who can build applications, which are then made available for a broader community.

The answers to the first two research questions (stakeholder requirements, and design of robots) can be used to guide the design of a reusable platform for developing assistive technology products.

We can already identify several existing platforms in practice. For example, "remap.org.uk" makes a good effort to unite disabled people with experts who can solve their problems. However, from the engineering/designing point of view, the platform is lacking in many ways. The interface is not welcoming for collaborative design and does not promote the rewards for participation. This pattern is visible in most of the platforms for disabled people. In building such a platform building up trust and value for different users is necessary [29].

The world's largest citizen science platform "Zooniverse.org" does promote its projects with a good interface that attracts the user to explore. The projects on the website are thoroughly explained and what needs to be done to improve them. The platform for disabled people should follow a similar approach to have a better citizen science experience. The information should be shared with minimal clicks and provide all the information that different types of users (disabled, developer, engineer etc.) can need. The Zooniverse team has worked with many science teams to furtherly develop a system that has appropriate levels of generalization to abstract complexity away from individual project development [28]. Therefore, it's necessary to present the users with an interface that can generalize and rid complexities before showcasing it to them.

2.4 Stakeholder analysis

A number of stakeholder categories can be identified regarding assistive technology products. These include stakeholders responsible for the development and testing of the products, stakeholders and their relatives or personnel that use the products, research institutes, and government institutes that define the lawmaking and the funding of these systems. In the following we describe each of these categories in more detail.

2.4.1 Providers

This category includes the stakeholders that are responsible for the design, implementation and testing of the AT products. Typically, these include the stakeholders in the system development life cycle. We identify the following stakeholders in this category:

- *Fabrication Lab* – includes a team of persons that work together in a lab in which the AT systems are developed.
- *Designers* – are engineers who are responsible for the design of the overall product.
- *Developers* – are the persons who build the system based on the provided designs
- *Hardware Companies* – can provide the hardware components to the platform for developing products

2.4.1 Maintainers

- *Platform hardware maintainers* – Are the persons who will be responsible for the maintenance of the hardware components that are provided by the platform. This includes both coping with failures and updating the componnents for new requirements. For speedy maintenance these will be typically persons located on site, such as, university students, local engineers, component providers, and local experts.
- *Platform software maintainers* – Are the persons who will be responsible for the maintenance of the software modules that are provided by the platform. This includes both coping with failures and updating the software for new requirements. This category of maintainers do not need to be close but can be remote. This could could include the software vendors of the produced modules.
- *Product hardware maintainers* – Are the persons who will be responsible for the maintenance of the developed hardware components. This includes both coping with failures and updating the product for new requirements.
- *Product software maintainers* – Are the persons who will be responsible for the maintenance of the developed software modules. This includes both coping with failures and updating the product for new requirements.

2.4.2 Users

- *Disable People* – the end-users that will use the AT products.
- *Caretakers* – Relatives or assistive personnel that assist the end-users in using and operating the AT products

2.4.3 Researchers

- *Researchers at academic institutes* – These include researchers at, for example, universities who are interested in assistive technology and the related products.
- *Researchers within companies* – Similar to researchers at academic institutes these researchers are interested in investigating ATs. These researchers, however, will focus more on the state-of-the-practice and aim at enhancing the company products.

2.4.4 Governance

Besides of the development, usage and research of ATs there is also a need to provide the regulation and the governance of these products. We identify the following stakeholders in this category.

- *National government* – Nation wide lawmakers that define the rules regarding the funding of ATs
- *Local government* – Similar to national government these regional local governments might have their own local rules and procedures for funding opportunities
- *Standardization institutes* – These instititutes will define the standard quality rules and criteria for the safe and secure usage of AT products.
- *Insurance Companies* – These companies provide the insurance for both the hardware and software modules.

The requirements and concerns of all these stakeholders must be analyzed to design the required assistive technology products. On the other hand, each of the above stakeholders have a different interest and impact on an AT project. To depict these differences we have used the so-called Power-Interest Matrix, as it is shown in Figure 3. As we can see from the matrix four different segments are identified for the interaction of the stakeholders.

The segment *Keep Satisfied* shows the stakeholders with low interest and high power. For our project these include the national and local governments who define the governance and funding rules. Although these stakeholders do not have a direct interest in the AT products they need to be satisfied.

The segment *Engage* defines the stakeholders with high power and high interest. These are directly related to the development of the AT products and aim at successful AT products. These stakeholders must be engaged in the project.

The *Monitor* segment defines the stakeholders with low interest and low power. In our case these include Fab Lab and Standardization Institutes. The Fab Lab provides the resources for the development of AT products but does not have a direct impact on the final outcome of the products. In a similar sense, standardization institutes have lower interest in specific products but have a slightly higher since they set the rule for the development of the products.

The final segment, *Keep Informed* include the stakeholders with high interest but low power. These include caretakers, academic researchers and industrial researchers. The caretakers have a lower power than the researchers; the industrial researchers have a higher impact than academic researchers.

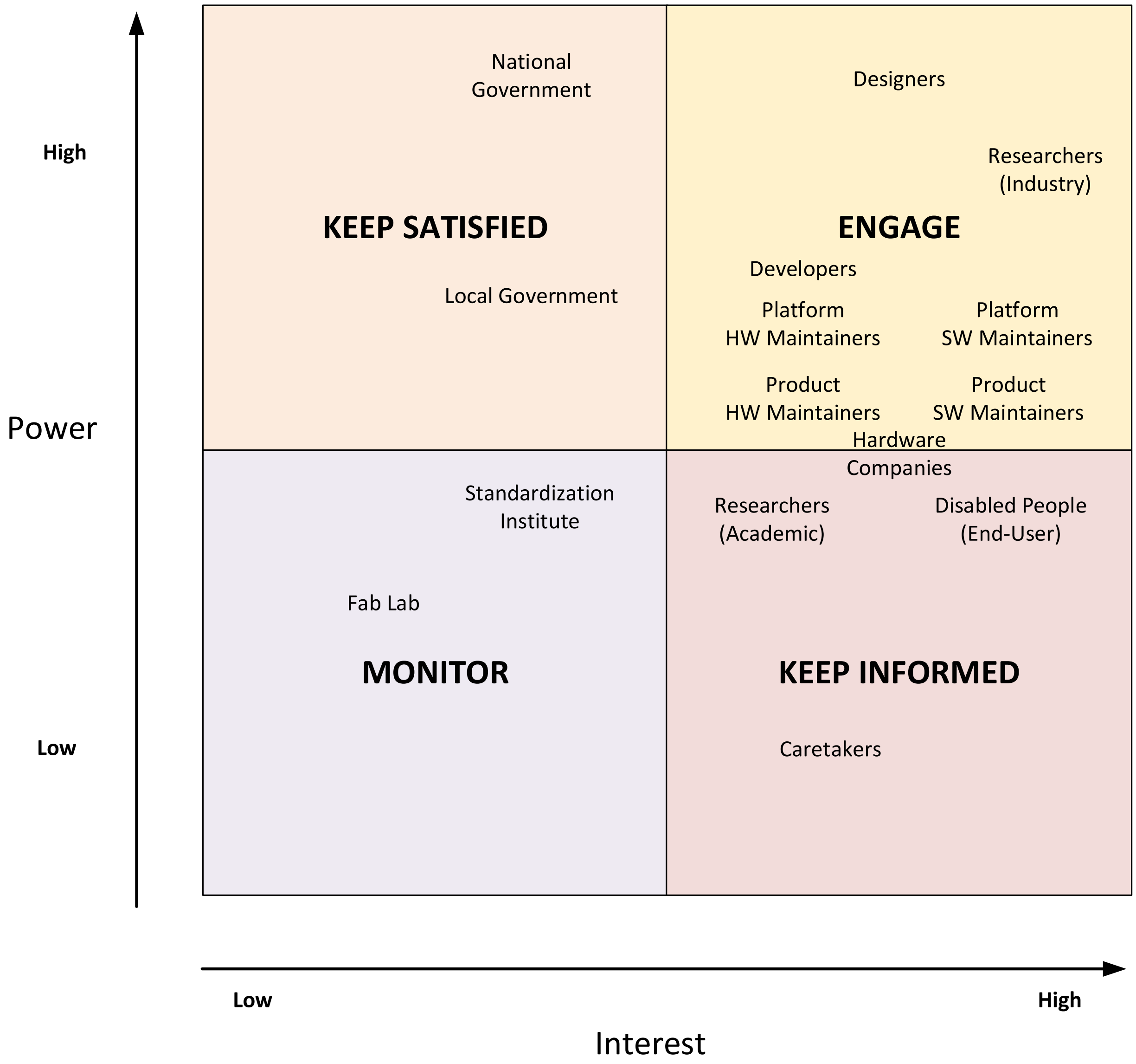

Figure 3. Power Interest Matrix for supporting the Stakeholder Analysis

Based on the stakeholder identification and the analysis the requirements need to be identified, which will be further used to devevlop the AT products. We can distinguish between two categories of requirements. On the one hand we need to describe the requirements for the collaborative platform that will be used to develop the specific AT products. On the other hand, we need to describe the requirements for the specific AT product. The details of the requirements for the platform and the specific AT products are described in chapter 4.

2.5 Requirements

Two different types of requirements can be distinguished including platform requirements and product requirements. We discuss the platform requirements in section 4.1. Different products can be derived from the platform each of which can have different requirements. For the requirements of the specific robots we refer to section 4.2 and 4.3.

We can identify a number of common requirements for the AT products that can be developed from the platform:

1. *Safe development*

The provided components and products should adhere to the safety requirements for AT products. The validation of the product is the responsibility of the developers.

2. *Security and Privacy Issues*

The developed AT components will typically include sensor components that can sense the environment and the end-user behavior. All the developed products must be secure regarding the adversarial attacks. Further, the specific data regarding the end-user must be kept private and consent must be provided if the data is shared or made public.

3. *Liability*

The developed products must be robust and not fail. Sufficient liability needs to be provided based on realistic scenarios.

Chapter 3 –
Research Method & Techniques

To answer our research questions, we have adopted a systematic research method. Figure 4 shows the activities of the adopted research method which is modeled using the Business Process Modeling Notation (BPMN). BPMN is a de facto standard for workflow and process modeling. The notation helps us to explicitly provide the steps that are followed in our research method. The activity starts with two parallel activities including a literature review and three expert interviews. In the literature review we identify and describe the key concepts related to assistive technology and platform creation. The first expert interview is carried out with a tutor working on the assistive technology project Bluebot. The goal of this interview is to understand the previous workflow and the future plans for Bluebot. The other two interviews is done with the client who is in the process of kickstarting an assistive technology platform and is the father of our end-user. The interview with ArF-Father consisders two topics: platform creation and an assistive technology tool for his son. These two steps are followed by stakeholder analysis in which we aim at identifying the key stakeholders and their concerns for the required system. In the concept development step, we develop the conceptual design for the required platform, the eye tracking module for Bluebot and the telecommunication robot. The telecommunication robot concept will be taken on as a case study.

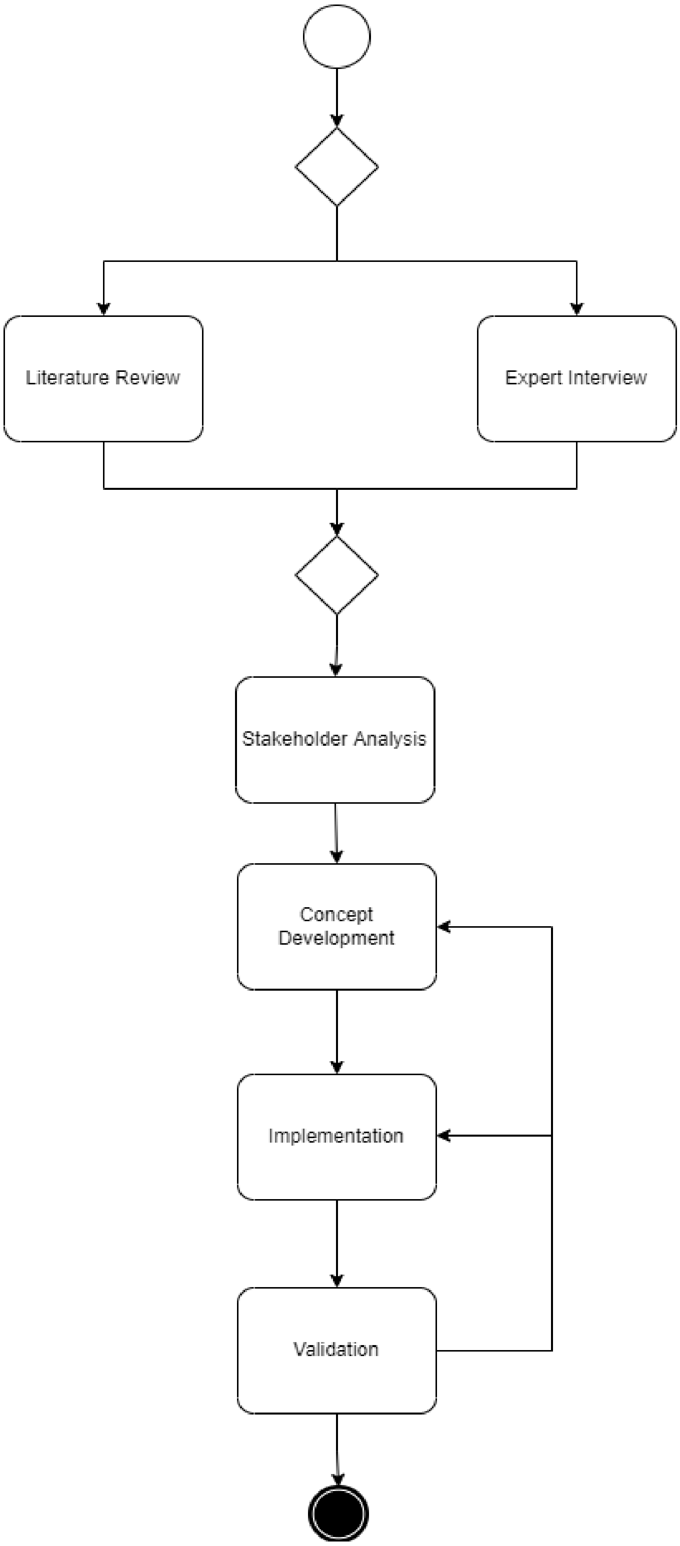

Figure 4. Workflow for the adopted research activities

Chapter 4 – Ideation

In this chapter we will provide the ideation and specification process and derive the conceptual design and requirements of two different AT products and the platform. The steps for the ideation process is shown in Figure 5. The process starts with retrieving and analysis of the interview results which provide key requirements and interesting ideas. Subsequently, the goals of the Bluebot project is identified. This is followed by a brainstorm and idea creation process in which ideas are created for a more practical solutions.

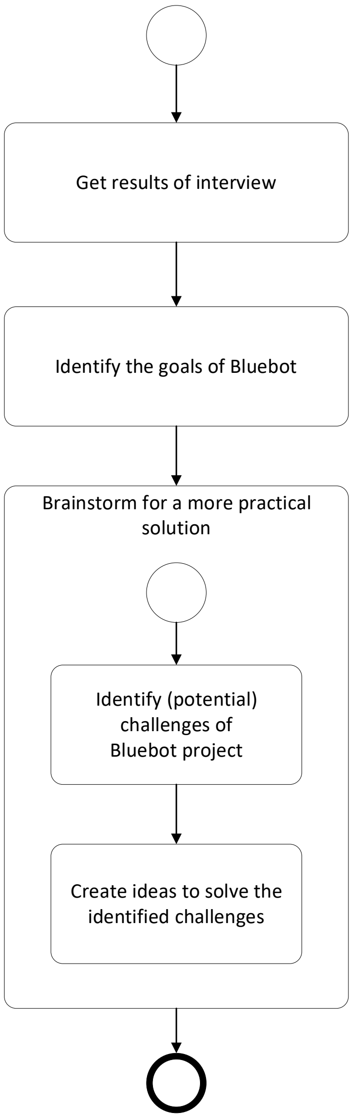

Figure 5. Steps for Ideation Process

In section 4.1 the interface of the remotely controlled AT product BlueBot will be described that was developed before. BlueBot is a robot that can autonomously move using wheels. This will be used as an illustration of the platform. In section 4.2 we discuss the conceptual design of the so-called Parrot Robot that we have used in this project. This robot is carried by another person to support the social communication and virtual mobility of the end user. In section 4.3 we describe the conceptual design of the platform. In this project we focus on AT products for disabled persons who can only use their eyes. Hence, eye controlled technology assistance products will be needed.

4.1 Eye Controlling Interface for Bluebot

Figure 6 shows a robot that looks similar to Bluebot. Bluebot is a robot that can be remotely controlled using the eyes of a disabled user. Using eye movements the robot can move and be used to communicate with other persons using visual and sound medium. The goal of this was to have a remotely controlled substitute (digital twin) for the disabled person. For the further development of Bluebot it was required that the robot could navigate to a place that was given and autonomously drive to that position. With this the disable person could indicate the place that he/she wishes to visit and the isolation would somehow decreased, and mobility would increase. This on its turn would lead to an increased participation of the end user in social life. Besides the social perspective, the goal of Bluebot was also to increase the experience and feeling of independence of people with a disability. With the remotely eye controlled robot, the disabled person could to a large extent independently move the robot, and also start conversations.

The required functionality was not implemented and we have thus decided to elaborate on this and provide the ideation perspective. This implied that the conceptual design of BlueBot with the newly required would be required. Thus this was primarily considered as a design project in which the necessary design concepts and diagrams were developed.

We did not extend the implementation of the Bluebot robot but using the conceptual design we provided the initial design and approach for the implementation phase. The robot itself included nice functionality but also had some limitations that would require more in-depth analysis and more time to develop. For example, the wheels of the Bluebot was not optimal to move around. Although Bluebot would be remotely eye controlled, it still needs to be very advanced to sense the environment, avoid possible obstacles, and move without complications. Obviously, to develop a highly autonomous robot would require more time and effort. Besides of the technical problems we could also identify some legal and safety concerns. For now, autonomous robots cannot move by themselves in the traffic with the current regulations. Also, these robots could lead to unsafe situations for other people. Altogether the development and completion of the Bluebot was not ready yet, and would require more research and effort for the developers.

Figure 6. Photo of robot that looks like Bluebot

Figure 7 shows the possible eye tracking features that can be used in the implementation of the interface of robots. The eye movements are typically the movements that can be easily performed by the user. A possible map interface is shown in Figure 7.

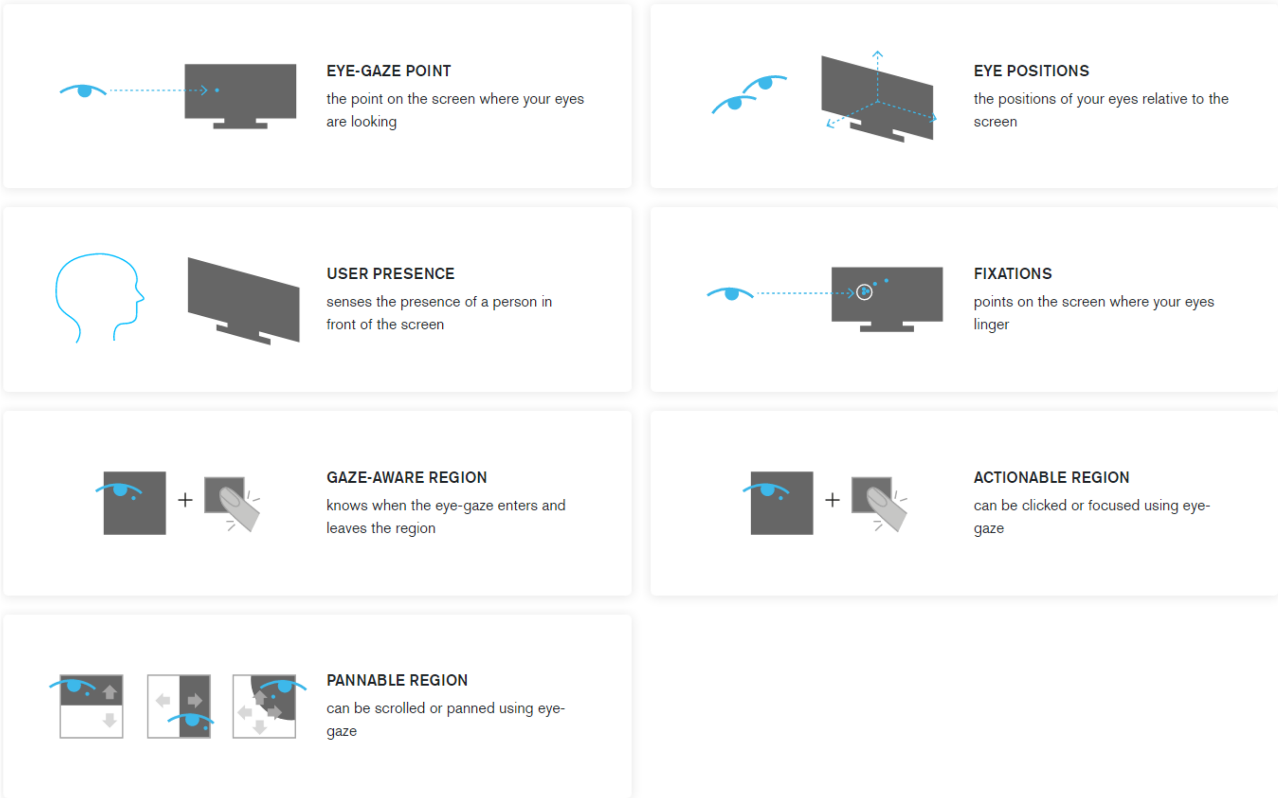

Figure 7. Possible eye tracking features to be used in the integration

4.2 Parrot Robot - an Assistive Telecommunication Robot

In this section, we will illustrate the development of a novel product, a telecommunications robot. The idea of the robot is to support the social networking and traveling of the disabled person. Usually disabled persons are less mobile and can miss opportunities to go to some places or meet some people. The Parrot Robot can be carried by another person on his/her shoulder, similar to a parrot. What the robot sees and hears, the disabled person will also see and hear. This is similar to the concept of surrogates in the corresponding Surrogates movies. The 'surrogate' here is the person that carries the Parrot Robot to help the disabled person.

As stated before, Bluebot had a number of limitations. It is not yet fully autonomous, has some system limitations (e.g. wheels), cannot yet be introduced in the traffic given the current regulations, and could lead to safety problems. Hence, a more practical assistive technology tool was needed. For this we aimed to develop the Parrot Robot that was considered as a more practical alternative.

The goal of the Parrot Robot is similar to the Bluebot robot. It also aims to enhance the social mobility and independence of people with disabilities. However, it aims to be easier used without too many concerns. The idea here is not to depend solely on an autonomous robot, but instead keep the human in the loop by letting them carry the Parrot Robot. For this solution, a caretaker or a relative is thus required to help the end user for interacting with the Parrot Robot. This does not mean that the caretaker has to be present at the location of the end user and the robot. The robot can be carried by many different persons, which thus provides additional flexibility in a social manner. The end user will not be dependent on an expensive and hard to maintain robot and caretaker. Furthermore, the Parrot Robot is realizable with less effort and could be put in practice much earlier than the Bluebot. Overall, the Parrot Robot will be also cheaper, and thus more affordable to a broader number of people. From a market and government perspective this alternative with Parrot Robot is thus quite a nice solution. The summary of the comparison of Bluebot with Parrot Robot is shown in Table 1

Table 1. Comparison of Bluebot and Parrot Robot

Comparison Criteria	**Bluebot**	**Parrot Robot**
Mobility of end user	Yes, through robot itself	Yes, through telecommunication robot carried by a person
Independence	Fully independent	Dependent on a third person to carry the robot
Convenience	Hardware fails would cause bigger issues, accessibility issues	Easy to use, most likely can access any place, hardware/software fails would cause minor issues
Compatibility with eye tracking usage	Fully integrated	Minor flaws
Price	Expensive autonomous robot	Cheaper camera robot
Possible Scenarios	Any context a human can be in with the condition of being accesible	Dinners, walks, small meetings
User Experience	Personal, fully in control	Somewhat personal, mandatory company

4.3 Conceptual Design of AT Platform

Figure 8 shows the conceptual architecture of the AT platform for disabled people. As it is shown in the figure the platform can be used by developers to develop and store smart modules. On the other hand end-users, disabled people and teachers can use the modules for assisting daily activities. Platform coordinators are the third category of stakeholders who have the responsibility to manage the overall platform.

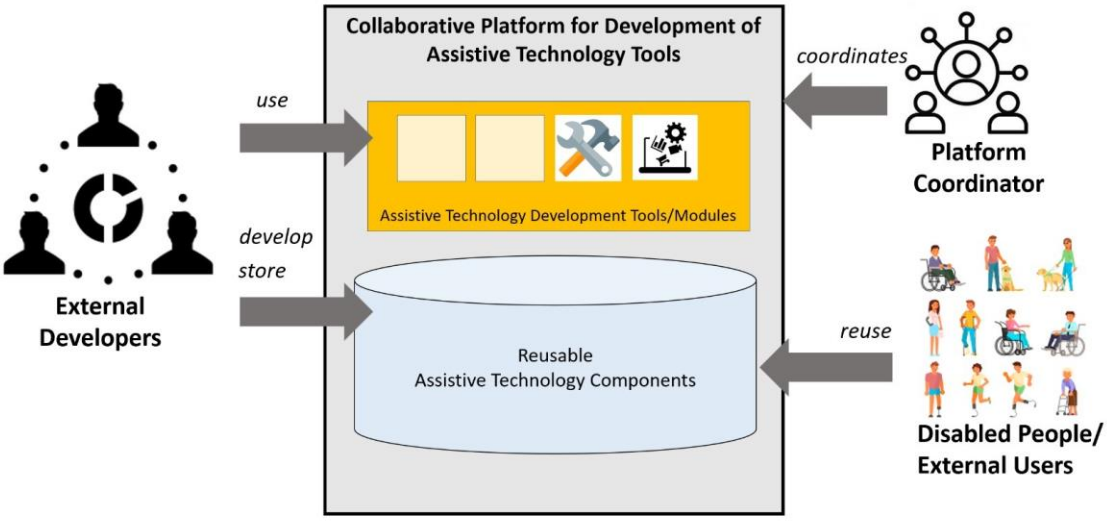

Figure 8. Envisioned Online Platform for Disabled People

Based on the interview, the final goal will be to develop such a platform that can be used by a broad number of disabled people who require different AT products. Developing such a platform is not easy and this will take a longer time. In this project, we provide the conceptualization and the requirements of the platform, but the realization of the platform is out of the scope of this project. We will present though the realization steps for the individual robot that can be derived from such a platform.

Chapter 5 – Specification

In this chapter we will provide the specification of the identified products and the platform. Section 5.1 describes the specification for Bluebot, section 5.2 for Parrot Robot, and finally section 5.3 provides the specification for the platform.

5.1 Specification of the Eye Controlling Interface for Bluebot

For the Bluebot interface the following requirements can be identified. These requirements are based on literature review and open free interview with a software and hardware developer of Bluebot (See Appendix A for the questionnaire). These two developers have also tutored future students that would work on this AT project. The requirements have unique identifiers for easy tracing during the development process. Here B refers to Bluebot, and R to requirement.

B-R1. Looking at buttons and the directional arrows for half a second should trigger event of the button

The system should be controlled by the eye focus and movements of the user given a map. In case more than half a second is looked at the particular place of the provided map then the corresponding button should be triggered. For example, if the user looks for more than half a second at the arrow in the left corner of the map, then that button will be triggered. This means that the screen should move to the left as indicated by the arrow.

B-R2. Copy-Paste-Search button

Sometimes looking at the particular place in the map can take too long (half a second or longer). For a quicker movement functionality needs to be provided to cope a given address, which can then be pasted, using eye movements, upon which the address is then automatically searched.

B-R3. Button to switch between map interface and Bluebot interface

Besides of the map interface the Bluebot interface. The system needs to provide functionality to switch between these interfaces easily (e.g. close/open/switch) interface button

B-R4. Select/open options menu

Looking at a point in the map for a second will select it and open an options menu. Looking away for a second will close it.

B-R5. *Accesibility information*

The robot cannot access any space and as such the system should provide information about the accessibility. In addition, this counts also for the accessibility of the disabled user. For example, in case of steep stairs this should be shown. Accessibility space can be clearly shown using for example colors (green is accessible) or number system (1 is least accessible, 5 is very accessible).

B-R6. *Customizable Buttons*

Besides existing buttons, it should be possible to customize these buttons or add totally new buttons. The functionality of these newly defined buttons should be based on the user needs relating to a variety of functionalities, such as, movement, searching for hotels/persons, alerting services, etc.

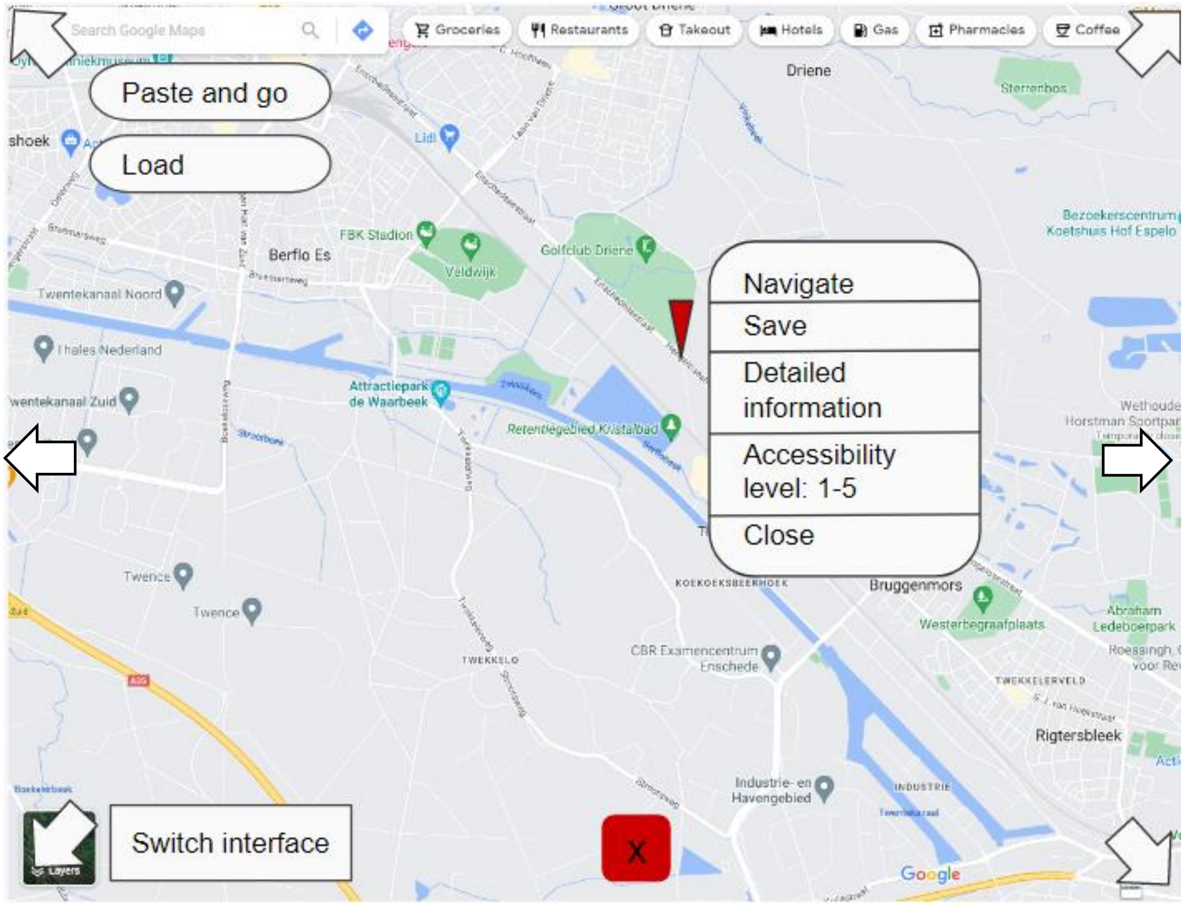

Figure 9. Envisioned interface for Bluebot map integration

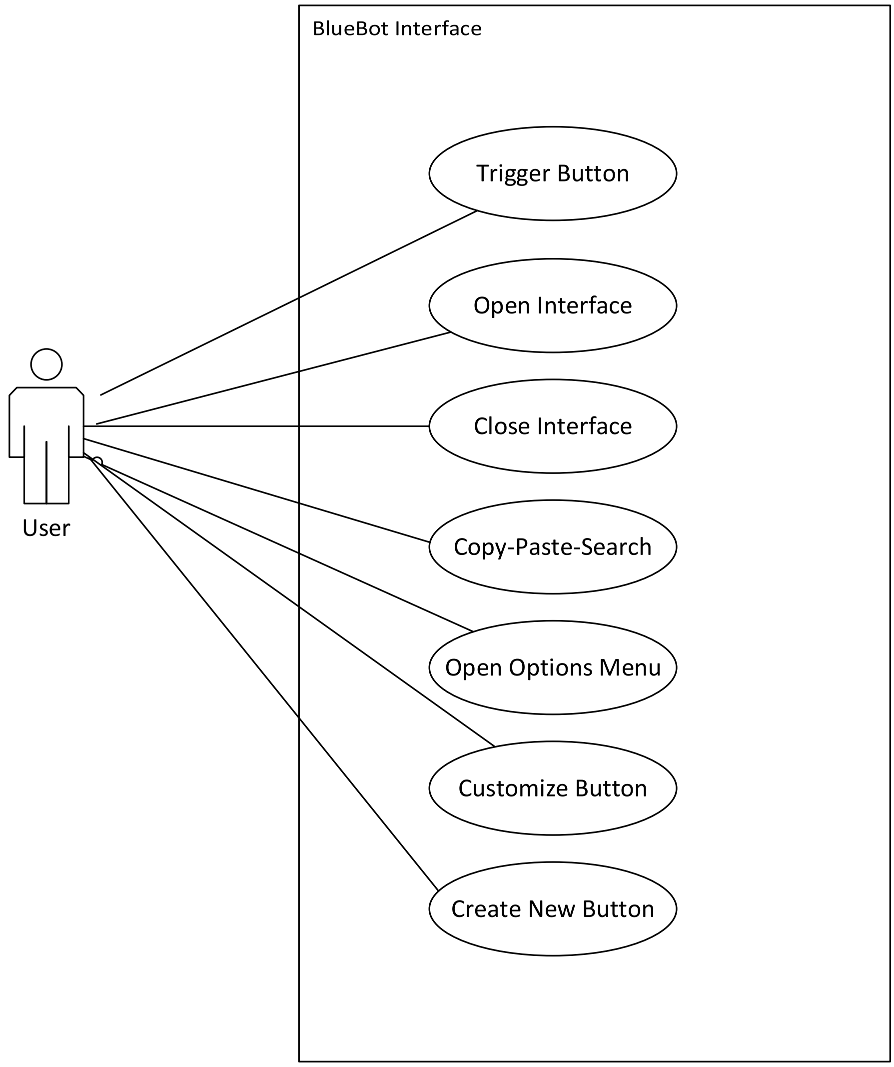

Figure 10. Use case diagram for the use of BlueBot Interface

5.2 Specification of Parrot Robot - an Assistive Telecommunication Robot

Based on the interview results and the literature review we can identify the following requirements for the Parrot Robot. The requirements have again unique identifies, whereby PR stands for Parrot Robot, and R for requirement.

The validation of the requirements related to the answers of the interview is shown in

R1. The Robot should have the necessary sensors and actuators

This robot should include visual and audio sensors that can observe and listen to the environment. The robot should be able to rotate its head to look around.

R2. Real-time visualization and audio

The visual images together with the audio needs to be transferred in real time to provide the lively experience and follow the developments in real time.

R3. Remote Control

The Parrot Robot will be carried by another person, but it should be also remotely controlled by the disabled person. This could be typically using a provided interface that can be easily operated by the user.

R4. Long Battery Life

Since the goal is to carry and use the Parrot Robot for longer distances, the battery life should be sufficiently long.

R5. Play prerecorded sounds for faster communication

The disabled persons needs to be supported in the communication with persons during the remote controlled trip. To speed up and ease the communication prerecorded sentences (e.g. hello my name is Tom) needs to be possible. In practice, the communication between persons follows use recurring sentences. The user should be able to add/update sentences easily.

R6. Easy to carry

The Parrot Robot needs to be carried by another person. It should be designed in such a way that it is easy to carry (stable, not too heavy).

R7. Interface controllable with an eye tracker device

The robot should be controllable using an eye tracker device.

R8. Customizable Robot

The current Parrot Robot can have some limitations. In case of advanced technology (which is expected given the platform) the Robot needs to be easily enhanced to accommodate new features or support new personal experiences. This is an advanced feature that can be implemented based on the evolution of the components and the products.

R9. The Robot should be mounted at the back of the wheel chair since AnF-Son cannot look back

Table 2. Tracing Parrot Robot requirements to questions and answers of the interview (See Appendix A for the questionnaire)

Requirement	**Question/Answer in Interview**
PR-R1	Q24 “I am not into that, so skip them” Based on literature review, and own background and experience on creative technology.
PR-R2	Q24 “I am not into that, so skip them” Based on literature review, and own background and experience on creative technology.
PR-R3	Q31 “Okay, I think you you found some sighs Look around. Look around with eyetracking. Okay, I like to pop up with idea with me with some sentences Andre Woods could speak. And the photo the film maybe that's the that's also very interesting. And to share what he sees without us, I think the nice, nice features” Based on this statement we concluded that remote control should be possible through easy eye-tracking
PR-R4	Q26 “battery life should be as long as possible”
PR-R5	Same as Q31 (see above)
PR-R6	Q35, Q25 “The robot should be mounted on the back of the wheel chair” This implies that the robot should be easy to carry.
PR-R7	Since AnF-Son has the lockedin syndrome this was considered as an obvious requirement
PR-R8	Q31 – key scenarios “And I'm curious about your thoughts. I can't I am curious. I think they can be something but I don't know yet the value, how often we will use it. And this is new.” It appeared that the robot had to provide different features, and hence from this we concluded that the robot should be easily customizable
PR-R9	Q-37 Additional question “I mentioned the robot on top of the head support…” This requirement was raised during using testing because AnF-Son could not look back.

The use case diagram for the use of Parrot Robot is shown in Figure 11.

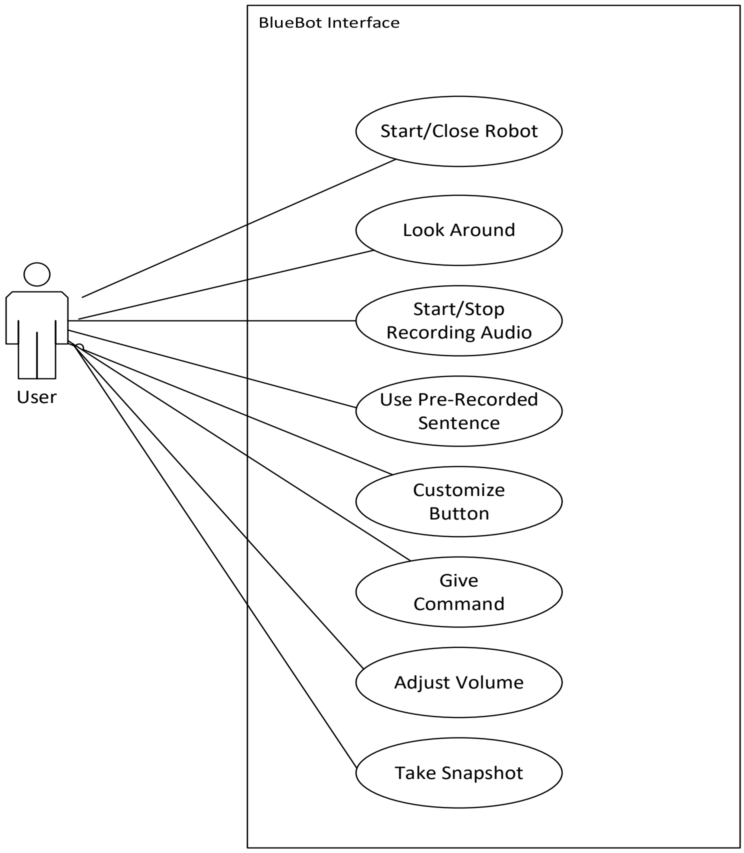

Figure 11. Use case diagram for the use of Parrot Robot Interface

5.3 Specification of the Platform

For the platform, we can identify the following key requirements:

P-R1. Provide a functional interface for developers to store and offer reusable components or products

The platform needs to have sufficient reusable components that can be used to develop specific AT products. These components can be for example hardware components such as sensors, cameras, actuators etc. Or these can be also software modules for analyzing images, speech, and text. These components can be provided by multiple different developers, and offered by the platform. For example, sensor components might be developed by third-party companies who can offer their products on the platform, which can then be bought by developers or users.

P-R2. Detailed timeline interface

During the development of the project the platform software should provide functionality to track and visualize the progress of the developed components and products. This will be in particular important for the development teams that consist of multiple members and who need to plan and synchronize their activities for a successful and timely development of the product. Besides of the development team, also the relevant external stakeholders for the corresponding project can use the provided functionality to get an insight in the progress of the project. This interface can consists of any type of document (video, pdf, audio etc.) and preview them in a manner suitable to the system.

P-R3. Provide a functional interface for users to select and/or order AT components and/or products

Similar to the functional interface for developers, also a functional interface for developers is needed to support the selection of the needed components or full AT products.

P-R4. Information on available hardware/software of the product

In addition to the accessibility of the reusable/downloadable components, the system should also provide the corresponding information regarding each component and product that is available. This will be helpful in deciding whether the found component/product is indeed the one that is needed.

P-R5. Provide guidelines on developing products using the components in the platform

The users can select the components from the platform but the composition of these components into full AT products might not be trivial. Hence, guidelines on the composition and the development of various AT products need to be provided by the platform.

P-R6. Provided automated document generation

For some products it might be necessary to automatically generate the document that will be used when developing or operating products. The system should provide sufficient functionality to develop such generators and/or use existing generators to automatically generate the documentation for the required product. This is an advanced feature that might not be possible or available for all components. However, the platform should provide the means for automated generation.

P-R7. Project environments and map functionality

Certain assistive technology project will need space and professional tools. Therefore, the platform should include a map that showcases where projects can be developed or are being developed. These places could consist of university design labs and fabrication labs.

P-R8. Provide a forum for discussing ideas and sharing knowledge

Typically, the platform provides an opportunity to develop products but also to experiment with new ideas. Developers must have a forum in which they can share their ideas and experiences. This will help create new ideas and support the resolution of existing problems regarding AT products.

P-R9. Provide transparent information regarding cost and funding options

Each product needs to be accessible for the users that need these products. In addition, full transparency needs to be provided by the platform regarding the overall costs and the possible governmental subsidiary support.

P-R10. Provide tutoring on how to develop assistive technology to developers

Developing assistive technology is a sensitive task. Understanding the needs and desires of a disabled individual is essential in the development process. Hence, the need for tutoring on how to this the right way.

P-R11. User engagement

In the development of AT products it is highly recommended that the users for which the AT product is used are engaged. The platform should provide the functionality to support the engagement process. This could be for example by linking the developer and the user, together with a common medium/window for communication of the ideas.

P-R12. Search engine, filters, and categories

The system should provide a sophisticated search engine that can be used to find the required components/products efficiently. For this the search engine needs to adopt a feasible categorization mechanism that is understandable for developers and users. This will be in particular required in case the platform will grow and listing the components will not be feasible anymore.

P-R13. Community/forum

The system should provide a discussion and forum board in which developers and users can participate to share their experiences, discuss the common problems, and help each other in finding feasible solutions. For this the system should provide integration possibilities with third party communication platforms such as Slack, Discord, and MS Teams.

Table 3. Tracing platform requirements to questions and answers of the interview (See Appendix A for the questions in the questionnaire)

Requirement	**Question/Answer in Interview**
P-R1	Q6 “we intend to make it broad for many different kinds of users. And as I said, they're all all handicapped people. So there's a broad scope and also many things have been the same event it but it's very important to adjust them to the situation which is needed.”
P-R2	Q12 Presented idea by me “a timeline interface that people can just look into and see in detail, what and which decisions were made . Answer by ArF-Father. “Now, that kind of project documentation is quite important.“
P-R3	Q6

	"we intend to make it broad for many different kinds of users. And as I said, they're all all handicapped people. So there's a broad scope and also many things have been the same event it but it's very important to adjust them to the situation which is needed."
P-R4	Q11, Q14, Q15 The platform will have hardware and software products therefore detailed information on them is necessary.
P-R5	Q15 The platform will host a vast amount of components therefore guidelines on how to use them is necessary.
P-R6	Q7 "You said the research question. So that's important, when you don't put a question. Right, you don't get a good answer. So that's where it starts. And also in the development work choices are made, okay, we can do this, or we can do this or we can do that. Then add the decision moments."
P-R7	Q10 "So we have to see how it can be done online, or whether you want to come or whatever, it's online, you can do many things, and it would really help to work internationally. Because the remap, which inspires us is in their existing practice for 50 years." The requirement will allow easier organization of international coworking.
P-R8	Q16, Q17 "We have mattermost channels. That's what we intend to use." Mattermost is a communication platform that can be used locally.
P-R9	Q42 "So at the moment view, we have some funds in order to but yeah, of course you need you need some money, at least for parts for, for the hardware for software for all kinds of things and how Better Work is voluntarily and how more funding how more. Yeah, we can also put people to work or whatever." "as cheap as possible, or it's cheap as possible? So we discussed it at the end. Okay, so many things. So he says the robot symmetry. So there are many robots not us anymore, but with terrible parts. So it's always costly and handicapped people quite often don't have jobs or don't have well paid jobs. So they cannot afford they cannot afford expensive"
P-R10	Q15 ArF-Father says that AT development is a sensitive task and requires intensive care. Therefore we require tutoring on AT development.
P-R11	Q1, Q16, Q17

	"And we will see people who will come over attracts other people. So there are really many people who like to make things and don't have tools and would like to make things for for people who really need it"
P-R12	Q6 With this requirement we aim to create a better user interface
P-R13	Q11, Q12 Asked question and statement. "What about a communication protocol for everyone that you can openly contribute to? So they don't have to be invited? Thus it will be easier for them" ArF-Father's answer. "I don't know, I haven't thought of that. In detail."

The use case diagram for the envisioned system with the actors Developer and User is shown in Figure 12. Here we can which use cases both actors can trigger. Some use cases are common for both (e.g. login) while other can only be accessed by the specific actor (e.g. only developer can remove components).

The use case diagram from the platform coordinator perspective is shown in Figure 13. The platform coordinator can trigger all the use cases that the developer and user can do. In addition additional specific use cases as shown in Figure 13 are reserved for the platform coordinator.

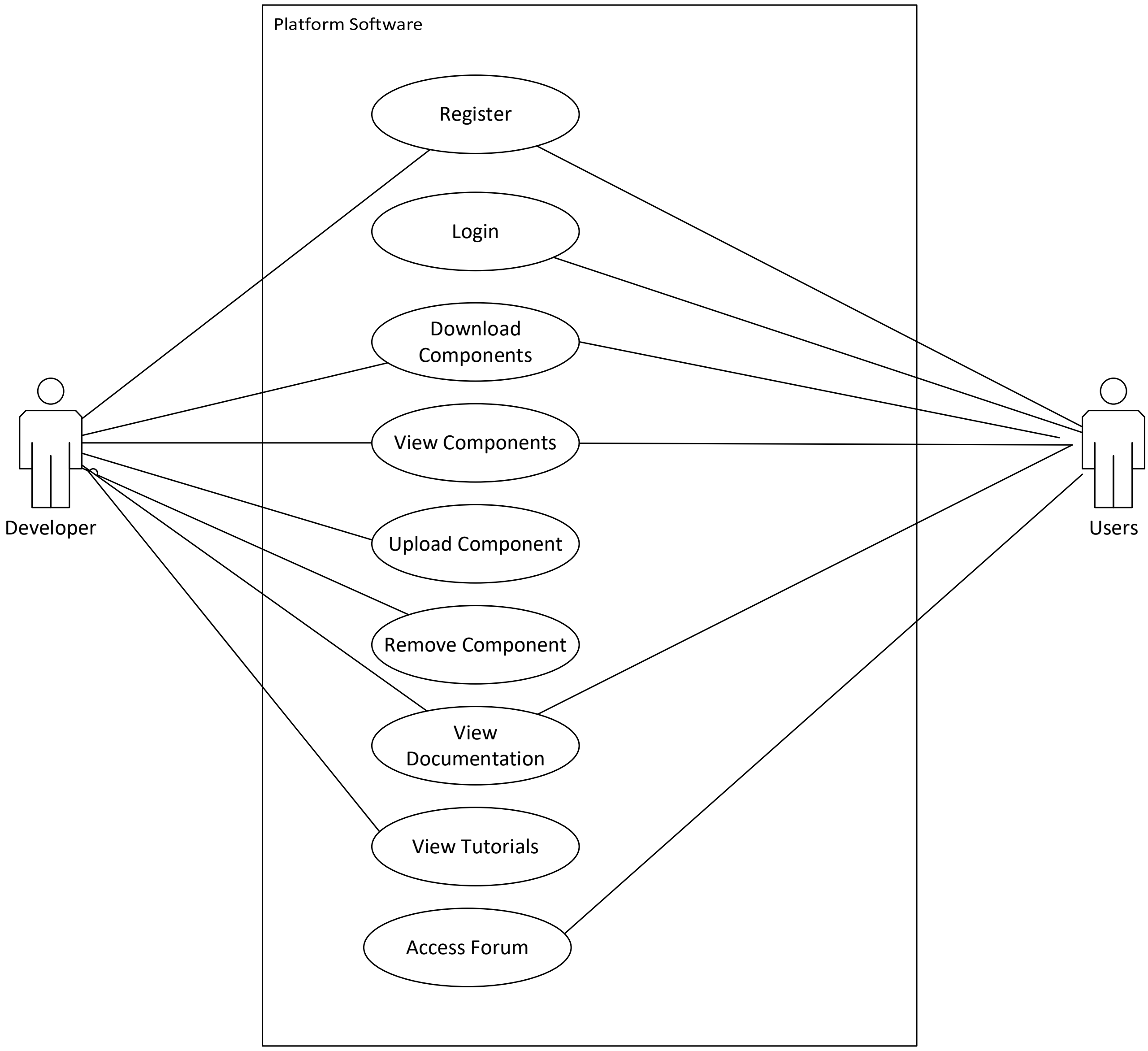

Figure 12. Use case diagram for the AT System – Developer and User Perspective

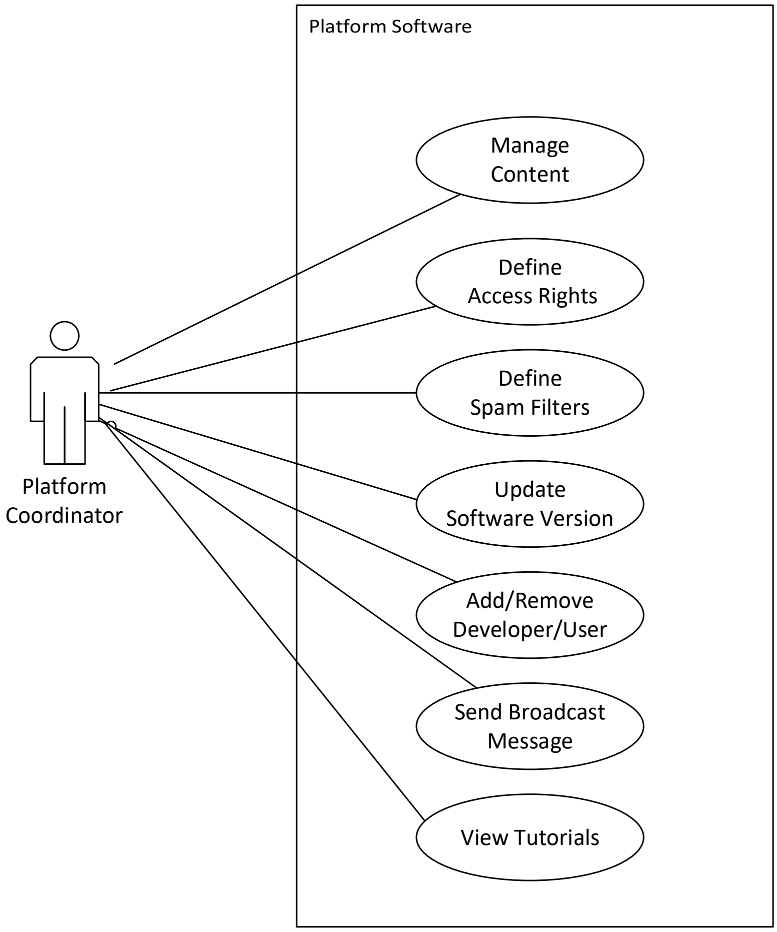

Figure 13. Use case diagram for the AT System – Platform Coordinator Perspective

Chapter 6 – Realization

The requirements considered the perspectives of the different stakeholders, the use case diagram showed the expected key functionalities. So far, no detailed design was given, since the focus was on the conceptualization of the system. Here we will elaborate on the system design including the used hardware and software. For the system design we will use deployment diagrams. In addition we will describe the user testing.

6.1 Deployment Diagram

Figure 14 represents the deployment diagram that shows the used machines and the allocated software to the machines. The notation is based on the Unified Modeling Language (UML). The cube symbols represent the nodes, while the rectangles in the nodes represent the allocated or deployed software applications.

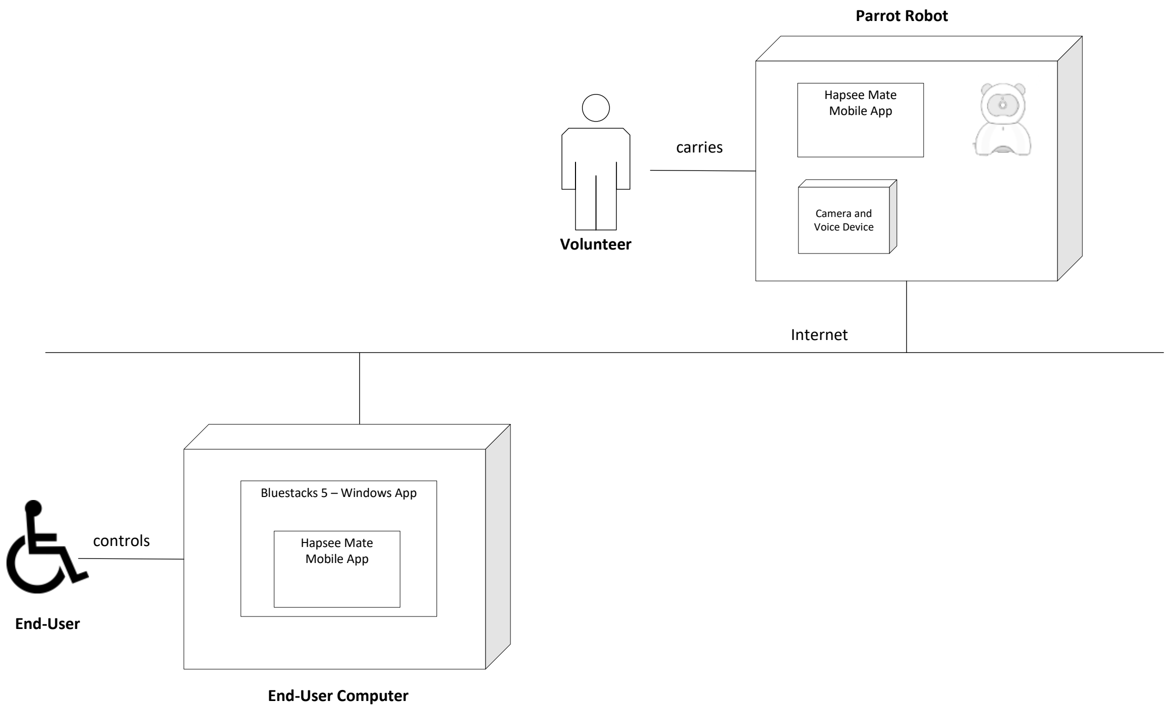

Figure 14. Deployment diagram showing the used hardware and the allocated software – without cloud

From the figure we can see that there are three different type of nodes. First of all, the user works on PC in which the Bluestacks 5 Windows application is installed, which allows the user to run mobile applications on Windows. Within the Bluestacks 5 the mobile application HapSee Mate is installed which the user can control with his eyes.

The second node represents the Parrot Robot which includes itself a video and audio device. Further Hapsee Mobile application is installed on Parrot Robot. The Parrot Robot is carried by a volunteer which could be a caretaker, relative or friend.

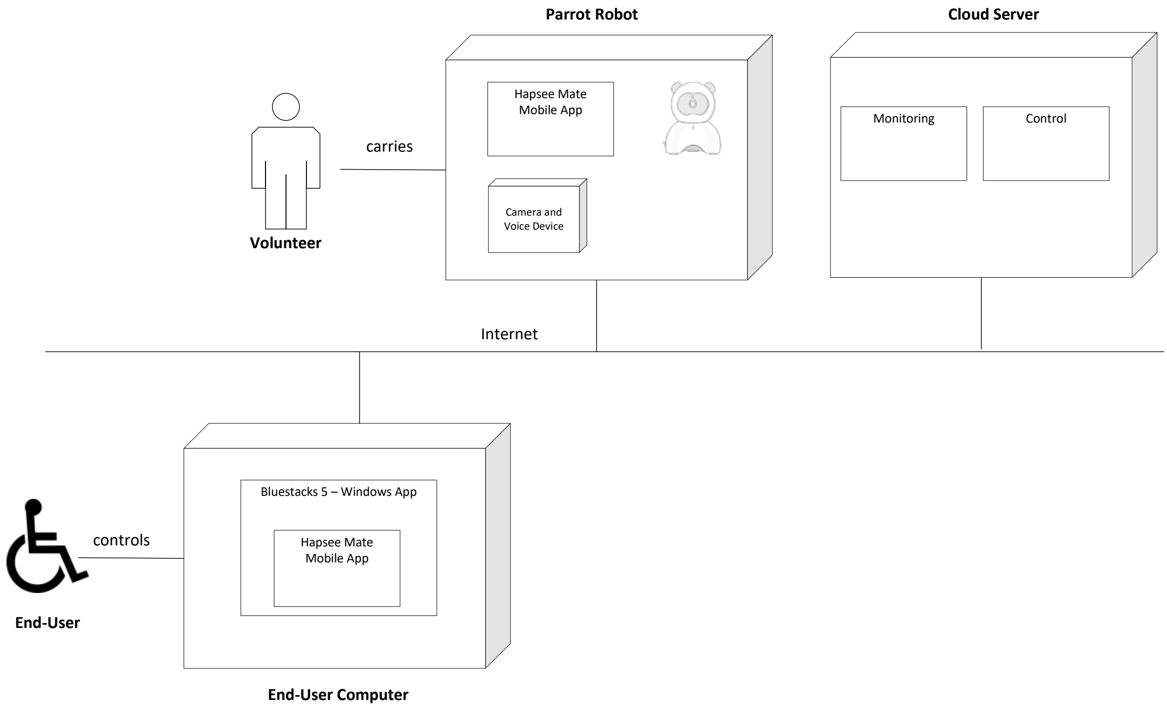

Figure 15. Deployment diagram showing the used hardware and the allocated software – with cloud

Alternatively, the system can also make use of cloud applications which is deployed on the cloud node. In this case the deployment diagram will be as shown in Figure 15. The cloud now includes advanced modules for monitoring and control functionality.

6.2 End User Interface

As stated before, the user works on a PC in which the Bluestacks 5 Windows application is installed, in which the mobile application HapSee Mate is installed. The which the user can control with his eyes.Figure 16 shows the Bluestacks 5 Windows interface that the end-user can use.

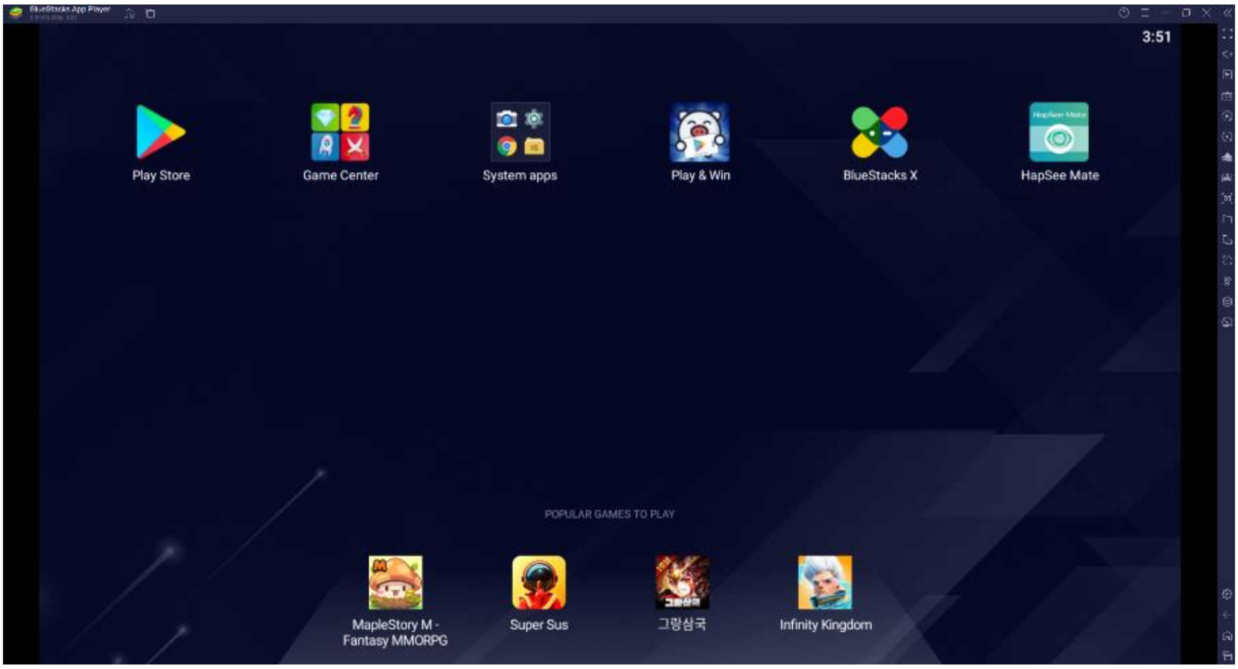

Figure 16. Inteface of Bluestack 5 that is used to run mobile applications on Windows

Figure 17 and Figure 18 show the HapSee Mate interface that is used by the end-user to control the Parrot Robot. Figure 17 includes arrows that the user can look and navigate the camera. Further, the interface also provides voice control and pre-recorded audio files to support the communication and interaction. Finally, the interface allows recording and snapshotting of footage.

Figure 18 shows a full screen view which provides a larger screen of the screen. Similar to the previous interface again recording and snapshotting of footage is provided. Besides of these advantages this interface does not have point and click arrows and needs to be controlled swipe actions only. We use a program called AltController to imitate these actions with custom created buttons, that can be triggered with eye control. The big rectangles imitate the swipe actions, the small buttons can be clicked.

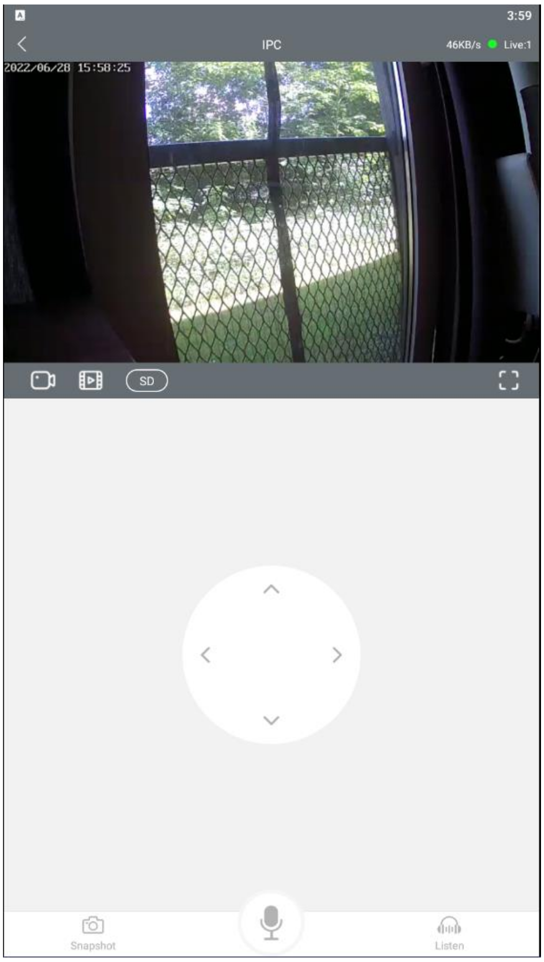

Figure 17. HapSee Mate Interface of Control and Monitoring

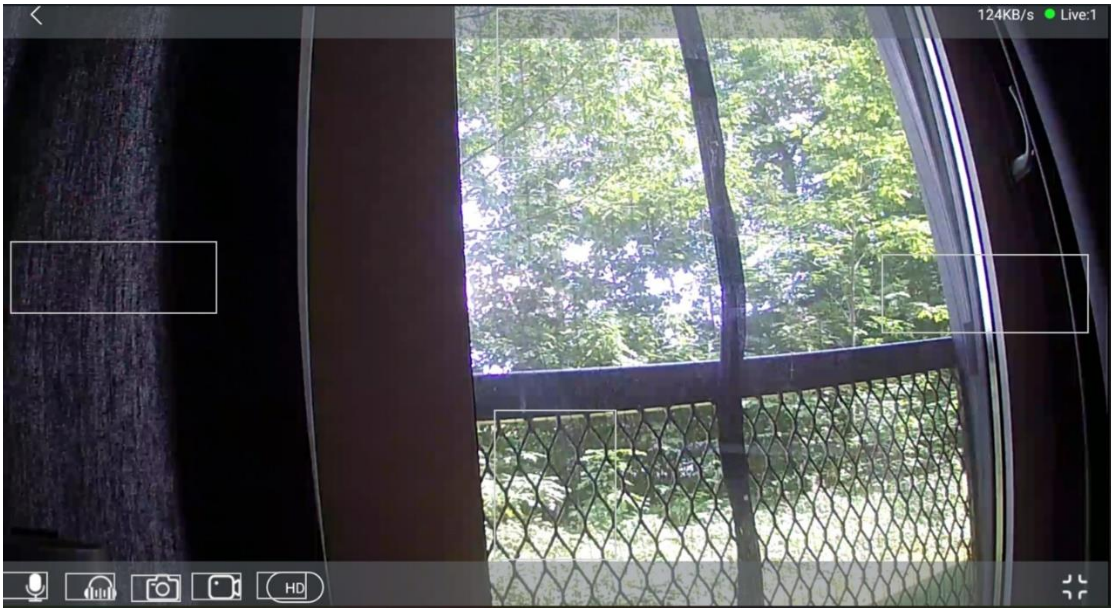

Figure 18. HapSee Mate Interface enhanced with Eye Control Interaction

Figure 19 shows the interface of AltController where you can remap your keyboard and mouse inputs into shapes on the screen which can be triggered with the eyes.

Figure 20 shows the interface for drawing shapes that we used.

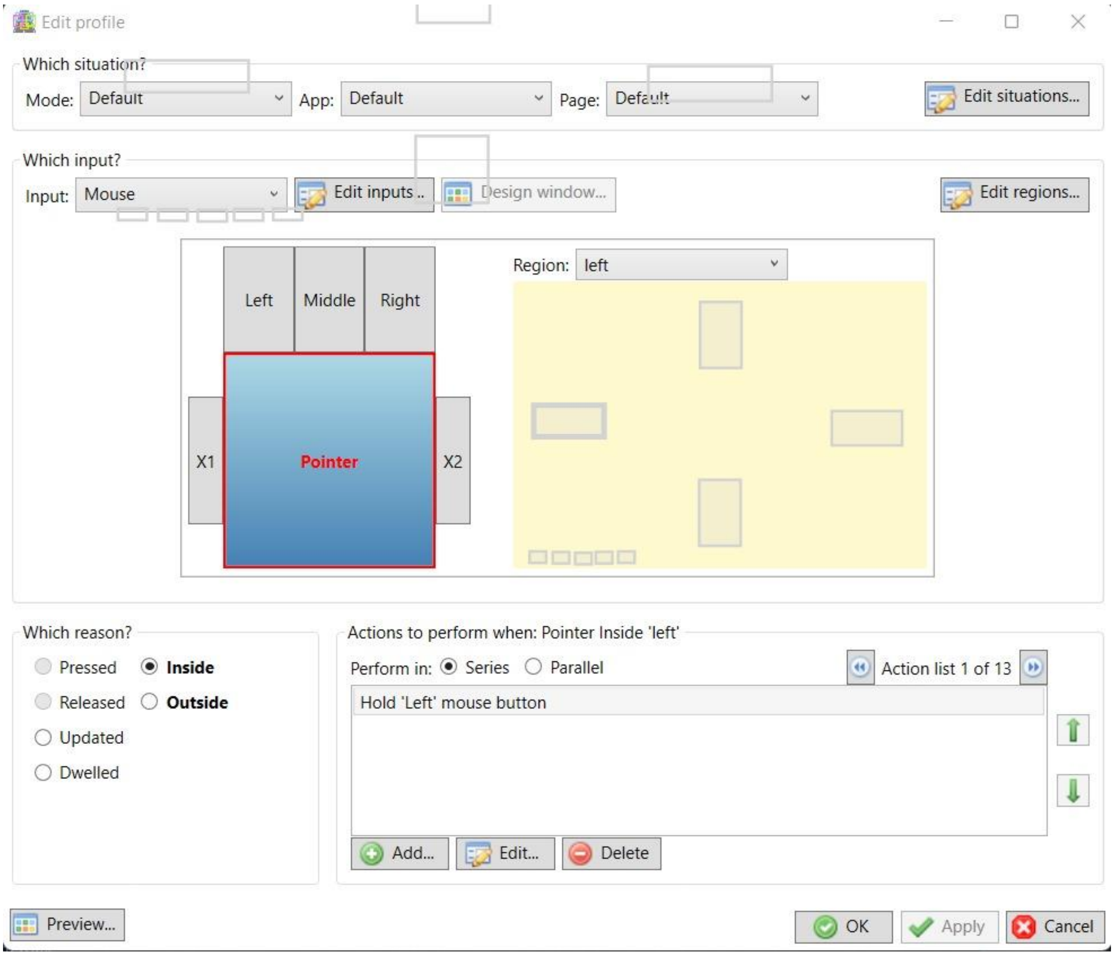

Figure 19. AltController input creation interface

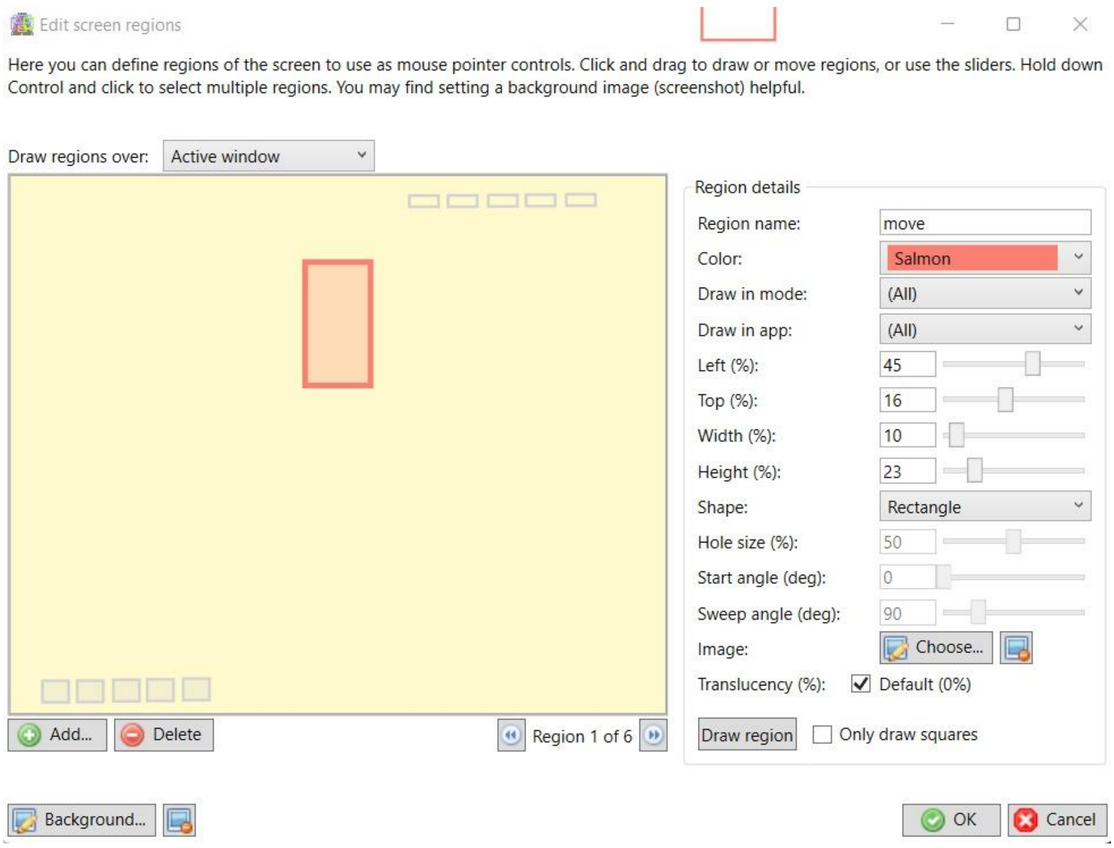

Figure 20. Interface of drawing of the buttons

Figure 21 shows how the swipe action is remapped to the rectangle buttons. When entering the rectangle, the script holds the left mouse clicked and releases it when the box is exited. With this this the swipe action is implemented. Based on the entered and exiting directions, the camera is moved to those directions.

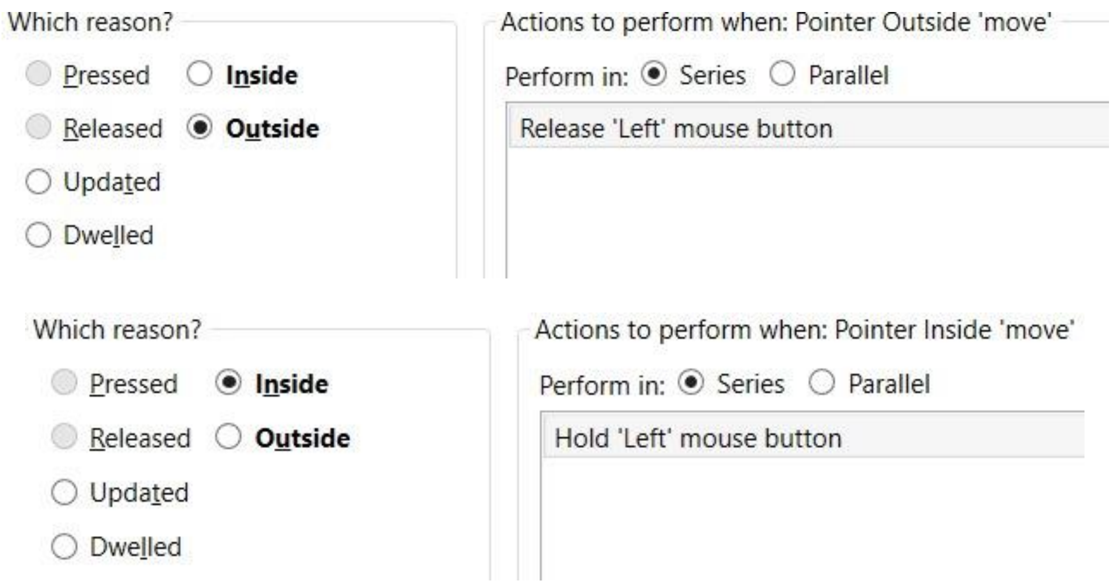

Figure 21. Interface showing how the camera rotation button are scripted

Figure 22 shows how the little rectangles imitate click actions when the user looks into the rectangle for 0.5 seconds (Dwelled), left mouse button is triggered imitating the left mouse button click action.

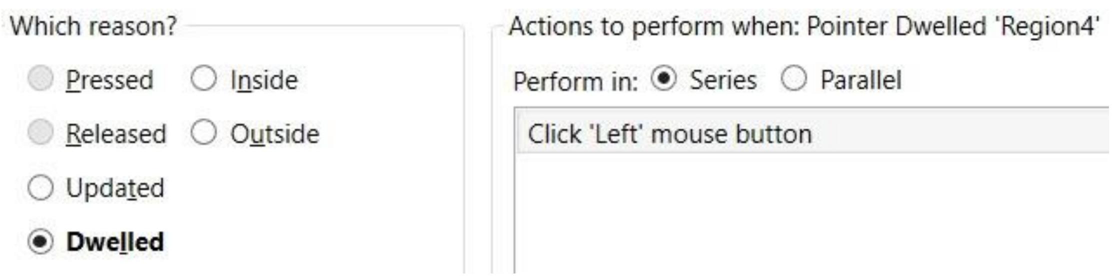

Figure 22. Interface showing how the clickable rectangles are scripted

In the HapSee Mate application we can select the camera device and define the configuration settings. Figure 23 shows additional options for the Parrot Robot in the settings page of the camera device. As it can be seen from the figure several setting options are provided. Besides account properties, the audio and video properties can be configure to support the accessibility to the user. The sharing device setting allows monitoring for multiple users at once.

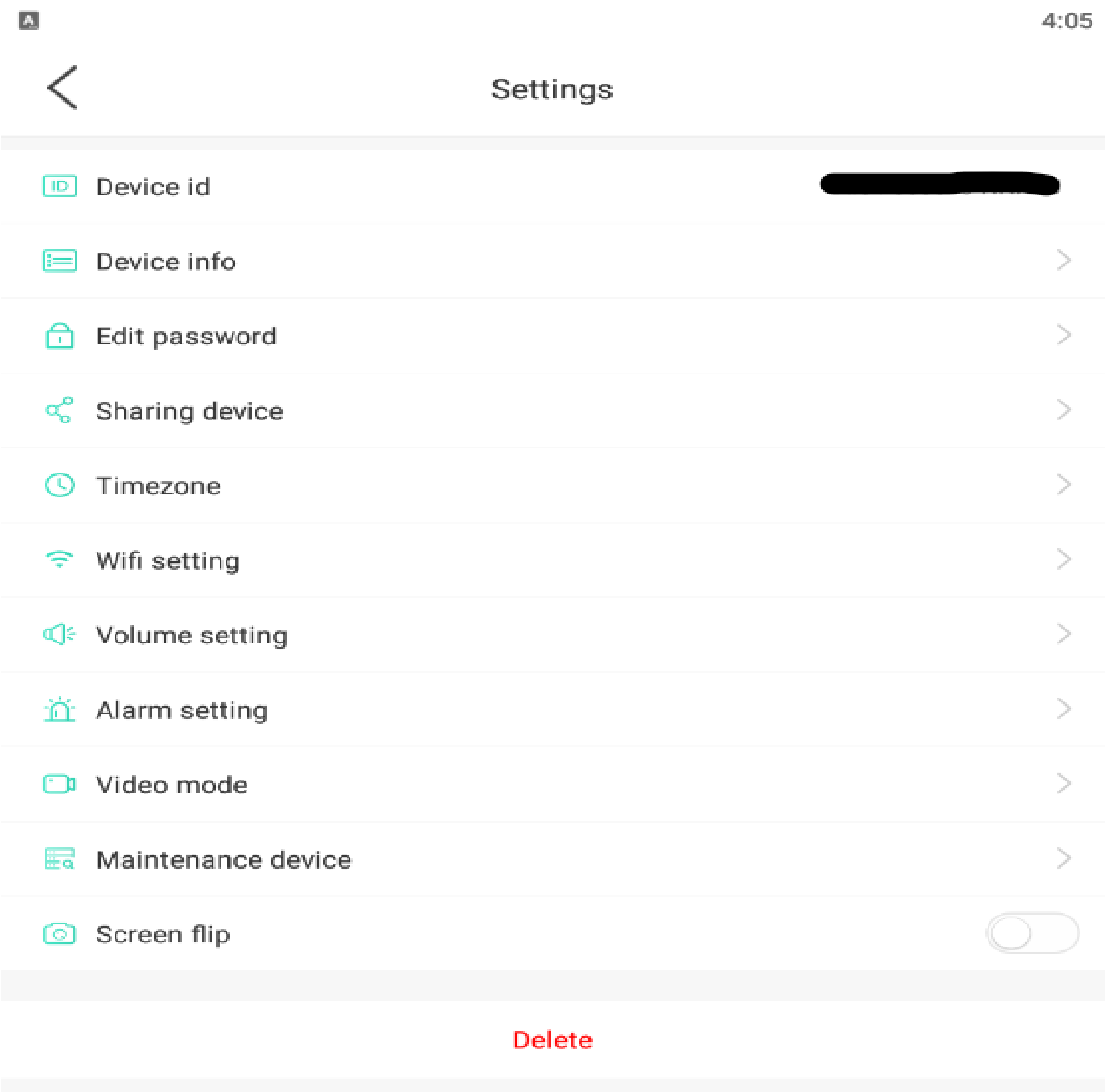

Figure 23. HapSee Mate interface of additional settings for the Parrot Robot

6.3 Camera Device Configuration and Parrot Robot Setup

Figure 24, Figure 25, and Figure 26 show the three steps needed to setup the monitoring and control functionalities of the camera device. Again these are configured using the HapSee Mate application. The robot is connected to the hotspot of the users mobile device by using the “SETUP CAMERA BY AP HOTSPOT” option. The user can decide to use a data package or wifi depending on their use cases.

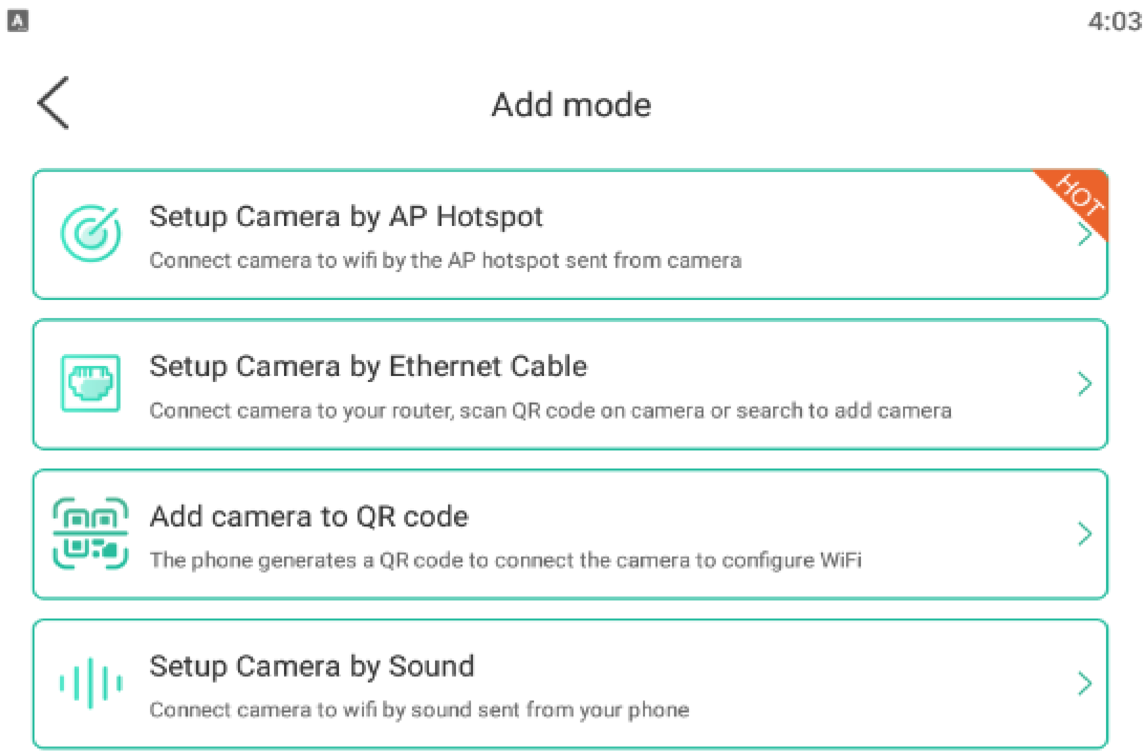

Figure 24. Camera configuration interface step 1

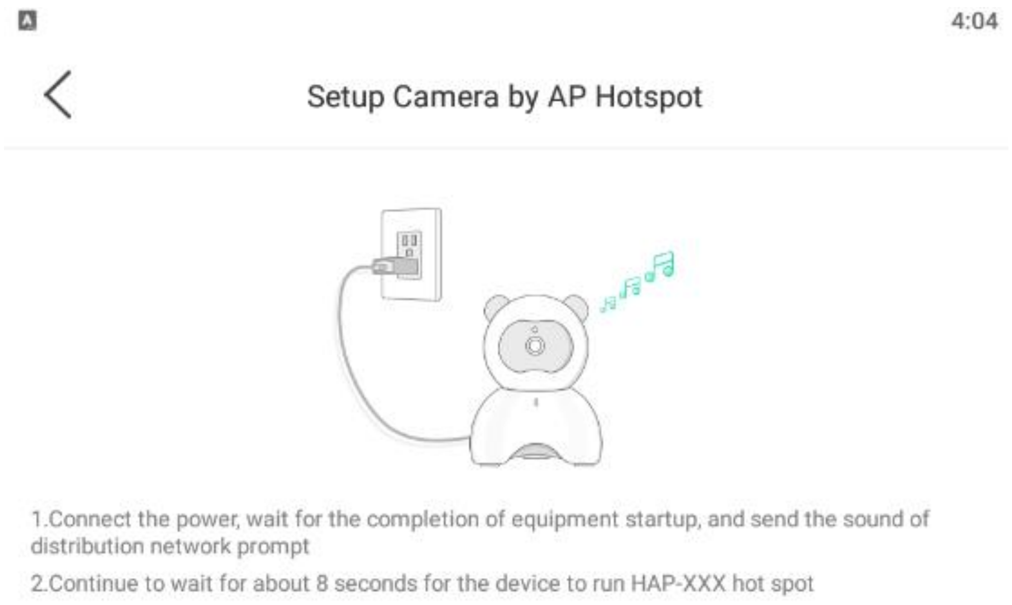

Figure 25. Camera configuration interface step 2

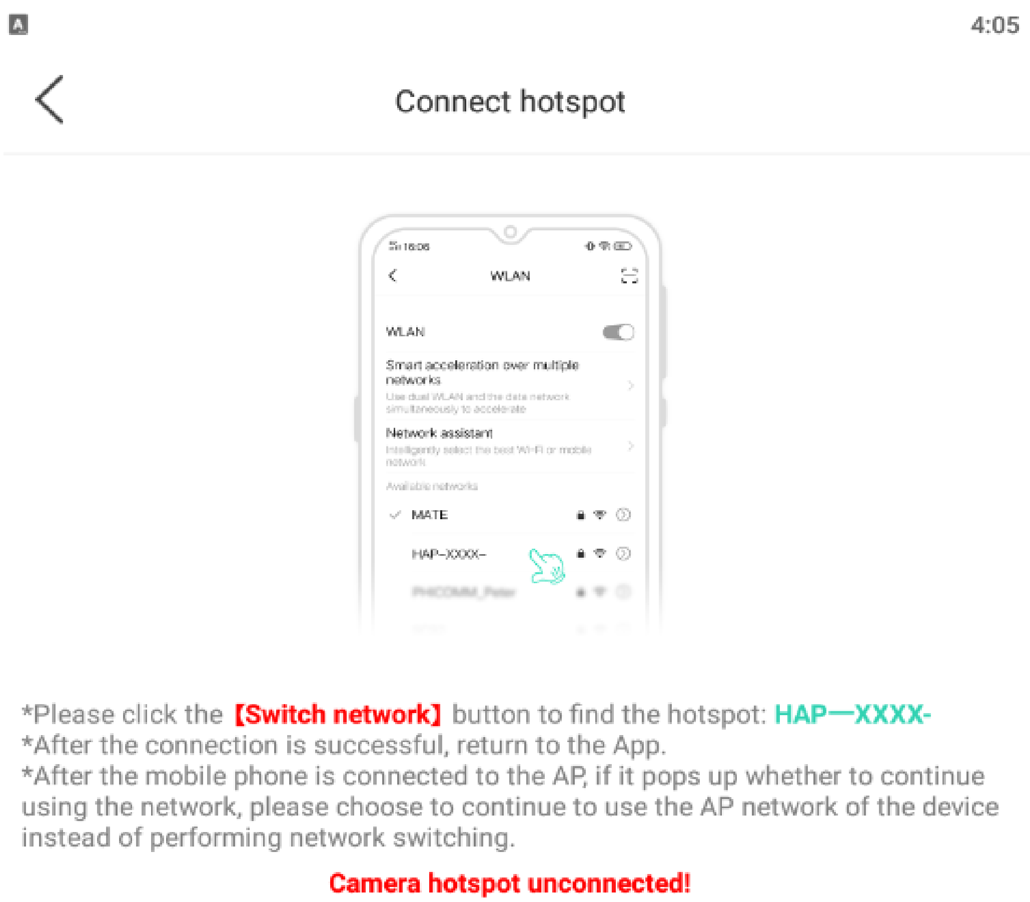

Figure 26. Camera configuration interface step 3

The Parrot Robot can be used in three different scenarios including indoor, outdoor and dinner. With the indoor scenario the Parrot Robot uses the indoor wifi and can be put on a stationary location using indoor power outlet. For the outdoor and dinner scenario, the Parrot Robot needs to use data packet internet connection, needs to be carried by a person, and will need a powerbank. The dinner scenario is similar to the outdoor scenario but assumes that multiple persons are around which can complicate and disturb the connection. These scenarios will also be considered in section 5.2.4 when testing the system.

Figure 27 shows the components used in the creation of Parrot Robot. A 5000mah powerbank, camera strap-on, and a remotely controllable camera. The powerbank and the camera are taped together, the camera strap-on goes through the hole inbetween to form the Parrot Robot which is shown in Figure 28 and Figure 29.

Figure 27. Parrot Robot Components

Figure 28. Parrot Robot front view

Figure 29. Parrot Robot back view

Figure 30. Parrot Robot main use case

As seen in Figure 30 the strapon is used to carry around the product as a parrot. Hence, the name Parrot Robot.

Chapter 7 – Results and Evaluation

In this chapter we show the results and evaluation process. First the adopted test process of user evaluation is described. This is followed by an explanation of test configurations. Subsequently, the end-user test results are presented.

7.1 Adopted Test Process of User Evaluation

After the camera device configuration and the setup of the Parrot Robot we have performed user tests. The process that we have used for these end-user tests is shown in the process flow in Figure 31. As an input the following quality metrics have been provided:

- *video streaming quality*
  the quality of the video streaming of the connected camera device.
- *audio quality*

  the audio quality of the connected audio device
- *response time*

  time between the triggered action and the returned result
- *additional functionalities*

  Besides video and audio, also other functions need to be executed such as recorded audio playing. All these functions must be checked.
- *mobility*

  ease of carrying and moving the Parrot Robot
- *user experience*
  the perceived experience of the end-user with the provided user interface. This is more difficult to measure and is based on the feedback of the end-user

If a test has passed the subsequent test is performed, if not we have checked how to improve the system. A number of iterations was necessary to pass the test. A test was considered to pass if the measure for each metric was 4 or higher.

After testing the indoor test, subsequently outdoor test and dinner test were performed. Each of these tests use the same quality metrics but have different conditions.

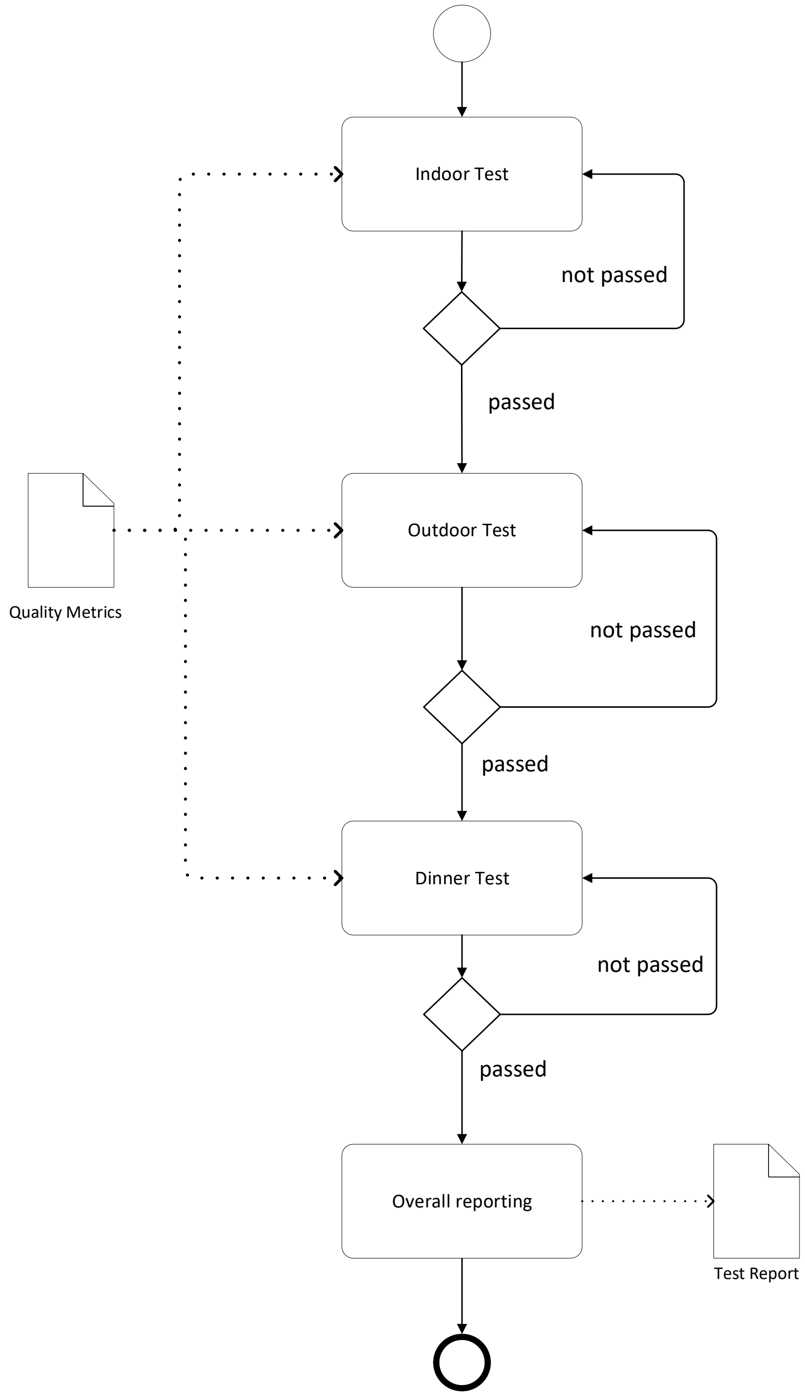

Figure 31. End-User Test Process for Parrot Robot

7.2 Test Configurations

As stated before, three different test configuration scenarios were defined including indoor test, outdoor test, and dinner test. All these test scenarios were carried out in the design lab of the University of Twente. For each scenario we have changed the conditions to meet the three different scenarios. For the test the key person, AnF-Son his father ArF-Father and I were present. AnF-Son was in his wheelchair with his computer Tobii. I had my own laptop in which the software for Parrot Robot was installed. We used AnF-Son’s computer Tobii to connect to my laptop via TeamViewer, which is software to control another person computer remotely. Thus AnF-Son could use the software of my laptop via his own computer Tobii. For each of the three scenarios AnF-Son had to perform the following tasks using eye control interface that was designed by me (Figure 18):

- Turn the camera of Parrot Robot to the right, left, up and down.
- Take a snapshot
- Record a video
- Listen audio conversations
- Talk

AnF-Son had already an eye control interface on his Tobii computer, but this was paused to avoid interference with the improved interface that I had designed. The above test scenario steps are shown in Figure 32.

When had to talk (the last scenario step), he had to use his own interface of Tobii, that included a specially designed user interface that covered a large part of the screen. Because of this it appeared to be too difficult to use both programs at the same time. To still test this functionality his father ArF-Father has talked to the computer.

The different test configuration settings were as follows:

- *Indoor test configuration:*
  One stationary person interacts with Parrot Robot that is on a stationary position on the table in the design lab
- *Outdoor test configuration:*
  One mobile person which carries the Parrot Robot (mounted on the shoulder). The user interacts with this mobile person and observes the environment using Parrot Robot.

- *Dinner test configuration:*
  One mobile person carrying the Parrot Robot (mounted on the shoulder) has a conversation with another person. The user listens to and observes the conversation.

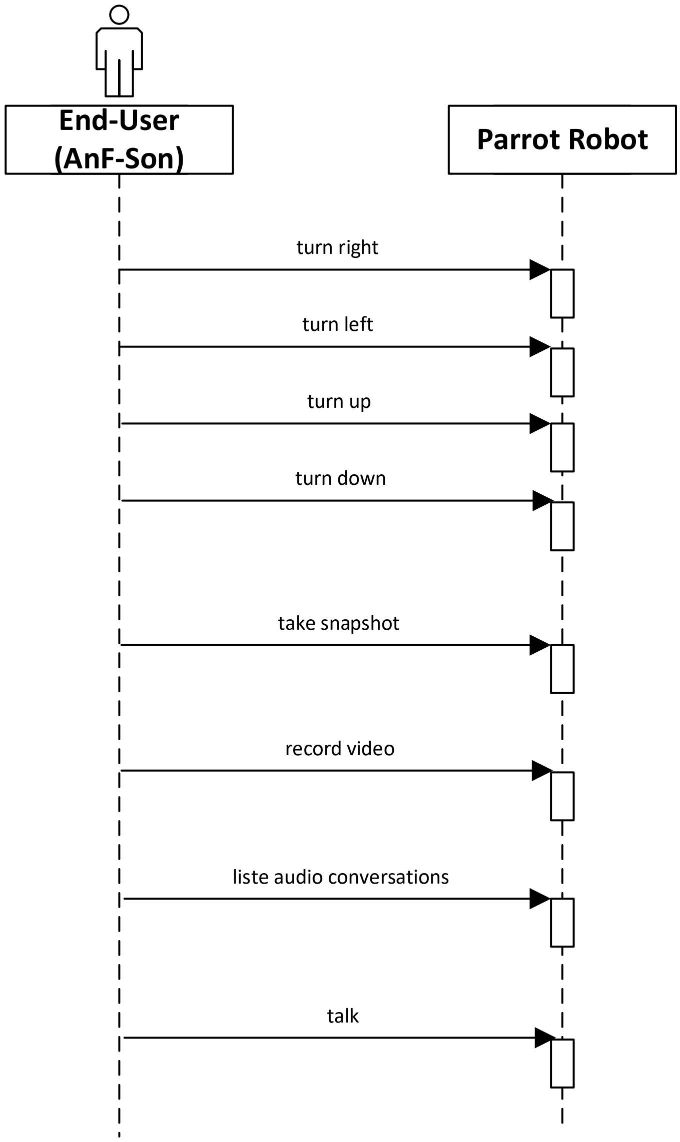

Figure 32. The adopted scenario steps for the three test configurations

7.3 Parrot Robot End-User Test Results

So far we have described the configuration of the camera device and the setup of the Parrot Robot. Subsequently, we have described the end-user tests of the Parrot Robot. We have considered three different scenarios including indoor usage, outdoor usage, and usage with more people around (dinner). A number of quality metrics have been defined to evaluate the Parrot Robot. For this we have developed a systematic process that performs each test separately.

The results of the test scenarios with respect to the defined metrics is shown in Figure 33. The measurement of the metrics were provided on a scale from 1 to 5 (low to high), for which I have created a Google Form to enter and store the answers. These answers were summarized in Figure 33. The user evaluation was done by ArF-Father, father of AnF-Son.

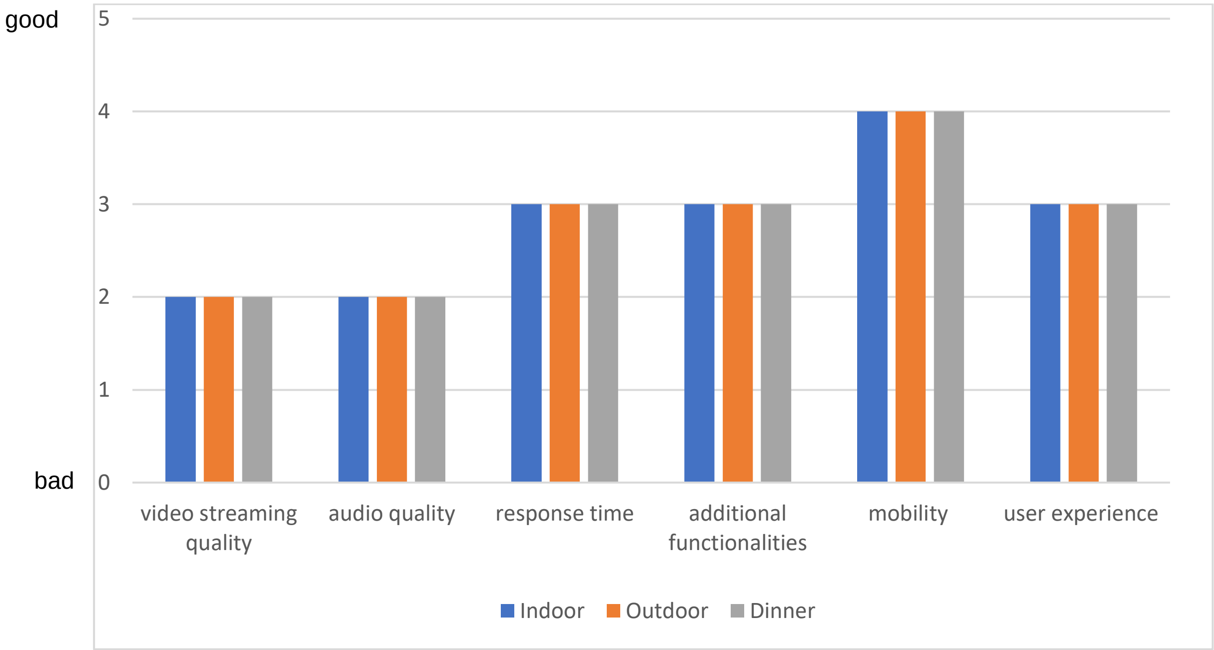

Figure 33. Results of the test scenarios with respect to the defined metrics (0 is bad, 5 is good)

As it can be observed from the figure, all the test scenario steps were evaluated with 2 or higher. Video streaming and audio streaming were evaluated lower (2) which shows the need for further improvement for these features. This can be explained from the fact that we used a Robot that was relatively cheap, and thus had lower video, audio, and response time quality. More expensive versions of the robot can be used to increase these metric evaluations.

The mobility was evaluated high (4) and Parrot Robot was considered to be useful from this perspective. In fact, this was also one of the key features. Hence the idea of such a Parrot Robot seems thus to be very practical and open for many open uses cases. We have only considered a few use cases. During testing process we have identified even more use cases.

The response time, user experience and additional functionality metrics were evaluated average (3). As stated above, the response time is related to the performance of the robot. The user experience proved difficult at the beginning because of the learning experience. AnF-Son was used to his own interface on Tobii and had now to use another interface during the testing process. The lower user experience can also be explained because the interface was covering more space than necessary for ease of testing.

Based on this observation we have adjusted the interface as shown in Figure 34. To save screen space we transformed the four separate rectangles into one rectangle colored red to increase visibility. Additional functionality including taking snapshots and recording video was appreciated because it could save AnF-Son's memories with ease. However, because of the low video and audio performance of the robot, the evaluation was again lower.

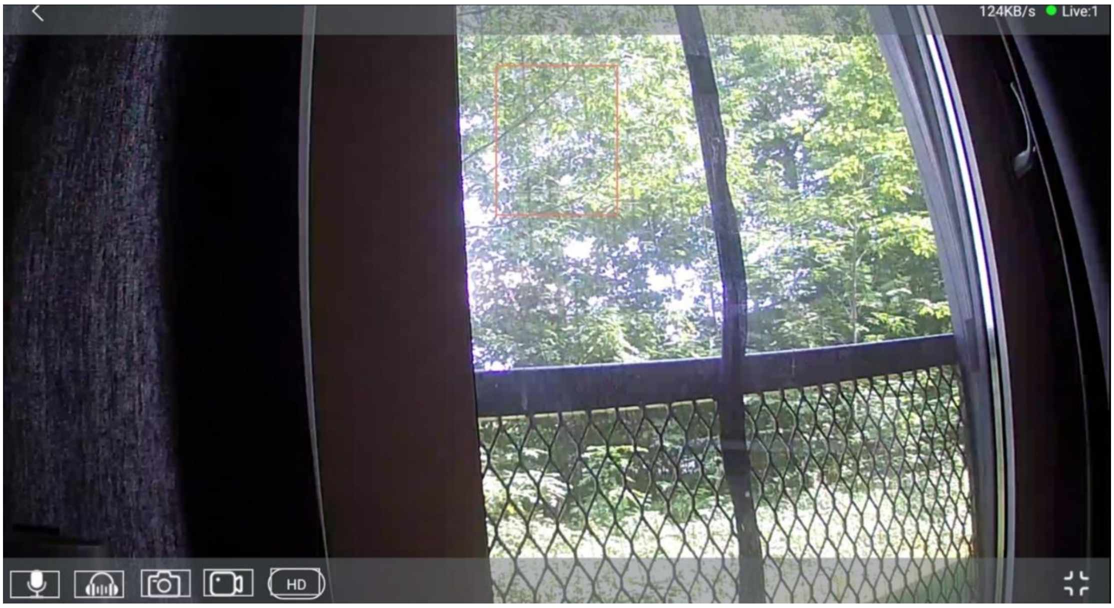

Figure 34. Adjusted interface to enhance the user experience

The observed results of the test scenario steps for the different test configurations is shown in Table 4.

Table 4. Observations of the test scenarios

Test Configuration **Test Scenario Step**	**Indoor**	**Outdoor**	**Dinner**
Turn the camera of Parrot Robot to the right, left, up and down.	Not so much need for turning. When turned it was easier since it was on a stationary position.	Diffucult to operate since the camera is shaking from the movement.	Turning quickly to follow the conversation was difficult because of the response time and inexperience with the user interface.
Take a snapshot	Not so many moments to capture. Simple to use.	Many moments to capture. However, camera shake causes blurry images.	A more stationary scene with other people was fun to capture.
Record a video	Simple to use and user liked the idea of recording and rewatching. Easy to record in stationary position.	Recordings were blurry.	Easy to record.
Listen audio conversations	Audible but low quality. Since conversation is with one person the content of the conversation is easily understanble.	low quality audio combined with surrounding sound makes the conversations unclear.	Conversations are audible yet not so clear at times.
Talk	Easy to talk. Audio not so clear.	Easy to talk. Audio not so clear.	Audio was too loud at times and volume adjusting is not part of the eye control interface.

Chapter 8 – Conclusion

Assistive technology is important for disabled people and can help them be active in society and improve their wellbeing. However, designing assistive technology products is difficult and needs to consider different requirements and constraints. The context of this research is related to the 25 year person, AnF-Son, who is coping with a locked-in syndrome (LiS) and using a wheel chair. To define the scope of the research we have provided an interview with AnF-Son's father, who plans to develop a platform on assistive technology. The interview was carefully planned and based on the interview results three different research questions where defined. To answer these research questions we have first performed a literature review to gain more insight into the stakeholders, the design approaches, and the available platforms. The outcome of the literature review showed that assistive technology is a promising and has huge potential to support disable people. On the other hand, the required technology is also still evolving and not all applications have been explored yet. The study in this project is complementary to the existing studies in the literature.

Like every literature review, this study also has some limitations due to the selected scope and the available time. The literature review has used a selected set of papers and reports that were found useful to answer the research questions, and which could be analyzed within the available timeframe. For a larger timeframe, the literature review could be extended with a more thorough analysis and include a larger set of reports which could probably result in additional insight. Besides the identified studies the overall analysis of the identified literature is based on the subjective interpretation of the author. The results could be further sharpened by a larger team of reviewers and a collaborative decision in case of different interpretations.

The findings for the specific research questions are discussed in the following.

RQ1. What are the key stakeholder requirements of an assistive technology platform for disabled people?

The identification and analysis of stakeholders was very useful for both the development of AT products and the platform. Different stakeholders were identified and these were located in a power-interest, which helped to gain insight in how to engage these stakeholders in the development process. Identifying the stakeholders is not easy and this required insight from both the interview and the literature. The identified stakeholders were similar as discussed in the literature of assistive technology [1]. Several common stakeholders could be identified such as the end-user, developer, platform owner etc. In our case we also had specific stakeholders such as the caretaker who had to carry the robot. The second problem was the prioritization of the stakeholder requirements. For the Parrot Robot we believe that we have identified all the stakeholders and also mapped these properly to understand the different impacts.

Different assistive technology projects might require different stakeholders. In our particular project besides of the end-user and the developer an interesting stakeholder was also the caretaker or friend who had to carry the Parrot Robot. The stakeholders have different requirements and these might be conflicting. The prioritization of the stakeholders and their requirements can also be different for each project. For future projects the identified stakeholders and the prioritization of the stakeholder requirements might thus be reconsidered.

RQ2. How to develop an eye controlled telecommunication robot?

After an understanding of the stakeholder requirements and the overview of the literature we could start the focus on the development of the eye controlled telecommunication robot. As discussed in the background telepresence robots have gained increased interest with the advancements in technology. Several different kind of telecommunication robots have been proposed which differ with respect to the functionalities they provide [12]. Our study is complimentary to this literature of telepresence robots and proposes the design eye controlled telecommunication robot. The robot that we have proposed can be categorized as a telepresence robot without locomotion ability since it has to be carried by someone. This was done for obvious and practical reasons.

To develop the robot a systematic method was used for this in which we have applied an ideation, specification, realization and validation process.

In the ideation process we have focused on the eye controlling interface for Bluebot, the Parrot Robot, and the AT platform. BlueBot is a robot that was developed before. We have identified and discussed the limitations of Bluebot and explained the need for a the development of a novel product, a telecommunications robot, Parrot Robot. The idea of the robot is to support the social networking and traveling of the disabled person. Parrot Robot can be carried by another person on his/her shoulder, similar to a parrot. We have compared Bluebot and Parrot Robot based on important quality criteria. It was concluded that Parrot Robot is a convenient and affordable alternative to Bluebot. Based on the insight of the stakeholders and the design approaches we have also provided a first conceptual design of a platform that will enable the development and usage of modules for the development of assistive technology products. The development of such a platform for assistive technology development is highly dependent on the engagement of the users and other stakeholders.

In the specification process we have provided the requirements for Bluebot, Parrot Robot, and the platform. For this, we have listed the requirements, used use case diagrams and user interface diagrams. The specifications helped us to gain insight in the important requirements.

For the realization we have elaborated on Parrot Robot and described the deployment diagram. We distinghuished both a cloud-based and non-cloud based solution. The end-user interface and the camera device configuration together with the Parrot Robot setup have been discussed in detail.

RQ3. What is the conceptual design and requirements for a platform dedicated to assistive technology for people with disabilities?

As discussed before the adaption of a collaboration platform can benefit the development of AT solutions [27]. These platforms help to develop AT systems faster and also support the innovation of new ideas. We have explored the idea of such AT platform and discussed the conceptiual design. For the future work the eventual goal is to elaborate on and develop such a platform that includes the necessary reusable components for developing assistive technology tools. Developing a platform is important so support the development of a broader set of tools for different requirements [28]. Different disabilities exist which require different assistive technology tool. The availability of such a platform will help support the fast development of such tools. Further, it will help to create new ideas that might further support the realization of different assistive technology needs.

In this project the Parrot Robot was considered to be an instance of such a platform. This implies that the components of the Parrot Robot are used from a platform. In essence, each hardware and software component that can be reused for developing products quickly could be put in the platform.

For the overall study we have adopted a systematic approach in which we have used the current knowledge of AT systems. Further strength of this study is the identification of a problem from a real situation and the application of the solution in the real context.

We have identified a real AT problem that was derived based on the needs of a disabled person. Hence, the solution was also directed aligned with respect to the needs of this end user. This provided relevant and important insights in developing and operating such AT systems. Based on the experience of this study we would recommend that for the development of such AT systems the involvement of the end user is crucial. This is also because the needs of the disabled people are also different and might require dedicated solutions. Obviously within the available timeframe the proposed solution is at the prototype level and could be further developed. The main reason for this prototype level was to achieve a practical and cheap solution that could be further developed in the future. In particular for this the existing knowledge on telepresence robots [12] could be applied to provide a more robust and sophisticated robot. As stated before the robot that we have developed does not have a locomotion ability and uses cheaper audio and video components. Nevertheless, this prototype could be enhanced by including other advanced features of telepresence robots.

We believe that a nice overview has been provided for developing AT products and the use of a platform. The three research questions have been sufficiently answered and insight is provided into the stakeholders, the design approaches, and available platforms. Yet, assistive technology research and development can be a long and costly process. Improving these conditions lies in improving several conditions: hardware/software availability, funding, and creative design. Systematic approaches with well-thought frameworks could be applied to the design processes to reach the desired product with absolute efficiency. The idea of an online collaboration platform will trigger and support the research and design of AT products and processes. However, it is important that certain rules and frameworks are followed with an open project in which all the relevant stakeholders are involved, in particular the end-users, that is, the disabled people who are in need of the AT. This could be achieved by involving people around the disabled in the design flow and having project leaders that have at all times an understanding of what is going on with the project.

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APPENDIX A –
Questionnaire for Retrieving Interview Requirements
Interview with ArF-Father

Personal

Q1.Can you say something about yourself and your background?

Q2.What is your experience with AT in general?

Q3.What were the obstacles of the use of AT?

Q4.What were the obstacles of the earlier robot?

Q5.What are your goals for AT in general and for this project?

- For the short term?
- For the mid-term?
- For the long-term?

Platform Requirements

Q6. What should be the scope of the platform?
Which kind of applications should we able to develop?

Q7. What should be the adopted programming language of developers (Java, Python?)

Q8. What should be the adopted operating system?

Q9. What should be the accessibility for developers? Can anyone access the platform?

Q10. What should be the accessibility for users? Can any user access the platform? Also non-disabled people?

Q11. How should these components (for example sensor, software module) be accessible?

Q12. How to track the development of the components?

Q13. What are the quality requirements for the platform?

Q14. Which hardware tools be available on the platform?

Q15. Which software tools be available on the platform?

Q16. What should be the communication protocol with the developers?

Q17. What should be the communication protocol with users developers?

Q18. Can we store data on the platform?

Q19. Should the date be private?

Q20. How to start new projects?

Q21. How to recruit new developers?

Q22. How to recruit new users?

Q23. Do you have any additional issues regarding the platform requirements?

Parrot Robot - Requirements

Q24. What are the system requirements for the robot?

Q25. What should be the overall weight?

Q26. What about battery life?

Q27. What should be the WIFI connectivity?

Q28. Which kind of key scenarios are important?

Q29. What should be the development time?

Q30. What should be the price?

Q31. What should be the key functionalities?

Q32. How smart should the robot? What level of smartness (semi-autonomous, fully autonomous)

Q33. Who should maintain the robot?

Q34. How to prepare the robot for AnF-Son?

Q35. What are the key wishes and requirements of AnF-Son?

Q36. Which kind of failures can happen?

Q37. Do you have any additional issues regarding the Parrot Robot?

Product Requirements - General

Q38. What are the liability issues?

Q39. What are the safety requirements?

Q40. What are the funding requirements?

Appendix B -
Ethics request of experiment and progress

Ethics procedure Reflection

For this study the problem analysis was performed with the end user. For this purpose an interview and an experiment was performed. We have checked the ethical issues for this study by checking the ethical checklist as provided by the ethics committee of the University of Twente. Each concern was checked and discussed with the supervisor. To align with the ethical principles the names of the end users were anonymized and the transcript of the interview was removed. The end user and the caretaker have explicitly provided for the experimentation and the reporting of this study. Besides the reported experimentation results no further data was stored or shared. Due the different circumstances including illness (covid), the ethical request procedure could not be requested officially from the university. However, everything was done to meet the requirements that were imposed the ethical procedure. This was also discussed and communicated with the supervisors. During the experimentation and interview we have used the first version of the consent form. Later on adjustments were made based on feedback provided by the supervisor and ethics pre-check team of the university. These included the formulation of the information letter and the checklist was shortened for understandability. The final and first edition of the consent form is provided below.

Consent form final version

Dear reader,
In this letter, we would like to inform you about the research you have applied to participate in. The experiment will take place on 12-07-2022 from 16:30 to 18:00, in Design Lab of university Twente. The purpose of this research is to understand the key requirements and improvements necessary for a remotely controlled with eye tracking telecommunication device and an assistive technology platform. In the

proposed research, entitled “Parrot Robot”, comfort, usability, quality metrics and design of the product are questioned. You will be given an user interface to control the parrot robot remotely with eye tracking. Then you will be asked to answer several questions, take a survey and partake in an interview about the parrot robot and the platform. The information and data we gain from these will be used and stored within the research documentation. The interview will be audio recorded via a smartphone and transcribed to be used in research. The audio recording will be deleted after it's transcribed to be used in research. Besides the interview your answers to the survey about the user test conducted on "Google Forms" will be collected and stored anonymously. At the end of the entire research, you may, if you so wish, be informed about the results obtained by means of a debriefing. You will be free to stop participating at any time for any reason. There are no risks to the research participants.

Informed Consent for standard research
‘I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure. My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Irfan Tekinerdogan. If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethicscommittee-cis@utwente.nl, i.d.tekinerdogan@student.utwente.nl, e.dertien@utwente.nl'

I have read and understood the study information and the informed consent dated 12-07-2022. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

Yes ☐

No ☐

I consent voluntarily for myself and the other party as a legal guardian for the other party to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

Name of participant   Signature   Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher Name   Signature   Date

Consent form first version

Dear reader,

In this letter, we would like to inform you about the research you have applied to participate in.

The experiment will take place on 12-07-2022, in Design Lab of university Twente. The purpose of this research is to understand the key requirements and improvements necessary for a remotely controlled with eye tracking telecommunication device and an assistive technology platform. In the proposed research, entitled “Parrot Robot”, comfort, usability, quality metrics and design of the product are

questioned. You will be given an user interface to control the parrot robot remotely with eye tracking. Then you will be asked to answer

several questions, take a survey and partake in an interview about the parrot robot and the platform. The information and data we gain from these will be used and stored within the research documentation. The interview will be audio recorded via a smartphone and transcribed to be used in research. The audio recording will be deleted after it's transcribed to be used in research. Besides the interview your answers to the survey about the user test conducted on "Google Forms" will be collected and stored anonymously. At the end of the entire research, you may, if you so wish, be informed about the results obtained by means of a debrie ng. You will be free to stop participating due to discomfort. There are no risks to the research participants.

Informed Consent for standard research

‘I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure. My

questions have been answered to my satisfaction. I agree of my own free will to participate in

this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results

are to be used in scienti c publications or made public in any other manner, then they will be

made completely anonymous. My personal data will not be disclosed to third parties without

my express permission. If I request further information about the research, now or in the future, I may contact Irfan Tekinerdogan.

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email:

ethics-comm-ewi@utwente.nl or i.d.tekinerdogan@student.utwente.nl

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I have read and understood the study information dated 12-07-2022, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

Yes

No

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason. I understand that taking part in the study involves the audio recording and transcribing of the interview.

Yes

No

I understand that information I provide will be used in for research for a thesis.

Yes

No

I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.

Yes

No

I agree to be audio recorded

Yes

No

I give permission for the transcript that I provide to be archived in the research paper as an appendix so it can be used for future research and learning.

Yes

No

Name of participant   Signature   Date

I have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Name of witness   Signature   Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.