A Framework for Designing Ambient Assisted Living Services for Disabled Individuals

by

Michael Kyazze

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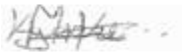
Promoter: Prof J. L. Wesson
Co-Promoter: Dr Kevin Naudé

Declaration

I, Michael Kyazze of student number 212226738, hereby declare that the thesis for the degree of Philosophiae Doctor is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.



Michael Kyazze

Summary

Physically disabled individuals face a number of challenges when carrying out their everyday activities such as moving around, communicating with others, and their personal care. One way of overcoming these challenges is by using personal assistants. An alternative is to enable independence through assistive technology. This research aimed to investigate how physically disabled individuals experience these challenges, and how assistive technology can enable them to be more independent.

In order to achieve the goal of this research, existing literature was reviewed on disability, assisted living, and interaction techniques. The literature study on disability identified some of the challenges faced by disabled individuals in their daily lives. In order to contextualize these challenges, interview studies with eighteen disabled individuals, and twelve personal assistants were carried out in Kampala, Uganda and Port Elizabeth, South Africa. The participants from both Uganda and South Africa were limited to those living in urban areas. The Ugandan participants noted that, whereas technology may assist their daily lives, their most essential needs are basic disability support aids such as wheelchairs and better long canes. This was in contrast with the South African participants, who have access to basic disability support aids. The South African participants identified their key needs as controlling an electronic environment without assistance, e.g. house lights, using a mobile phone, and using a computer without assistance. The interviews narrowed down the scope to focus on individuals with quadriplegia, specifically individuals who have limited hand use, but can comfortably speak and move their heads, and make gestures such as head shake and nod. Literature on assisted living technologies and frameworks, provided the technical foundation for the research.

The literature review of interaction techniques identified a number of possible ways in which individuals with quadriplegia can interact with technology. An appropriate set of interaction techniques, namely head shake and nod, voice, and facial feature tracking were identified. Evaluations of the interaction techniques excluded head shake and nod, because of an inconsistency in detecting an individual's head pose in different lighting conditions, when using a Microsoft Kinect. Voice and facial feature tracking using a standard computer camera were identified as the most suitable interaction techniques for this study.

A framework for designing assisted living software services was developed. The framework allows disability researchers and solution developers to understand the needs of a given disability group, and design relevant solutions. To demonstrate that the proposed framework addresses the main aim of this research, a prototype was developed that enables users to control smart lights (Phillips hue), a Smart TV (Samsung), and carry out basic navigation and web-browsing on a computer. Users could interact with the software using voice and facial feature commands.

A usability study was carried out with fifteen physically disabled individuals in Port Elizabeth, South Africa. The results of the evaluation study were highly positive. The successful evaluation of the prototype provided empirical evidence that the proposed framework does assist in the design of relevant and useful software services, to meet the unique needs of physically disabled individuals.

Keywords: Disability, quadriplegia, interaction techniques, assistive technology, ambient assisted living, design framework.

Acknowledgement

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List of Abbreviations

ASQ	After Scenario Questionnaire
DU	Disability Unit
AAL	Ambient Assisted Living
DSR	Design Science Research
ICT	Information Communication Technology
DSRM	Design Science Research Methodology
DSR	Design Research
ICF	International Classification of Functioning, Disability, and Health
HCI	Human Computer Interaction

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Chapter 1: Introduction

1.1 Background

It is estimated that there are over 650 million people with disabilities worldwide (WHO & World Bank, 2011). South Africa has an estimated disability prevalence rate of 7.5%, excluding psychosocial and neurological disabilities. This implies that over 3 million South Africans face the following difficulties: hearing, seeing, communication, walking/climbing stairs, remembering/concentrating and self-care (Statistics South Africa, 2011). The large number of individuals facing difficulties, highlights the need for this research.

One way of overcoming the challenges faced by disabled people is by employing personal assistants. The cost of employing a personal assistant on a 24 hour basis, however, is beyond the financial reach of most people. South Africa provides a care dependency grant to primary caregivers (personal assistants) of children with disabilities who require permanent care, but do not reside in state run institutions. In 2011, nearly 111,000 children received the grant, which was R1,200 per month (DWCPD and UNICEF, 2012; Western Cape Government, 2012). This amount is not enough to cater for all the needs of disabled children, such as the provision of educational assistive devices.

Assisted living may be defined as a system of housing and care that is designed for elderly, or disabled individuals, and offers various levels and combinations of services, care and privacy (Carpenter, Sheridan, Haenlein, & Dean, 2006). Assisted living may be enhanced by various technologies. One such technology is Ambient Intelligence (AmI), which is defined as the presence of a digital environment that is sensitive, adaptive, and responsive to the presence of people (Cook, Augusto, & Jakkula, 2009). Ambient Assisted Living (AAL) is the use of Ambient Intelligence to extend the time in which elderly and disabled people can live independently in their preferred environment (AAL-Europe, 2013b; Memon, Wagner, Pedersen, Beevi, & Hansen, 2014). One of the application areas of AAL is a Smart Home Environment. A Smart Home Environment is one that integrates diverse context-aware, automated technologies and services, with the aim of unobtrusively enhancing the lives of its inhabitants (Alam, Reaz, & Ali, 2012). AAL may enable disabled people to be less dependent on personal assistants. AAL innovations can be made up of hardware, and software components. The term *AAL Services* as used in this report, specifically refers to AAL software.

A literature review was carried out in order to identify the key challenges faced by physically disabled individuals. Interview studies with disabled individuals and their assistants, were conducted in order to understand how individuals experience the challenges identified from literature in their daily lives, and how they cope with them. Eighteen disabled individuals, and twelve personal assistants from Kampala, Uganda, and Port Elizabeth, South Africa, were interviewed. The interview studies identified individuals with quadriplegia as a suitable group for the focus of this research. Quadriplegia is defined as paralysis caused by illness, or injury to a human, that results in the partial, or total loss, of use of all their limbs and torso (Langtree, 2010). The interview studies also identified their difficulty in using technology by disabled people, as one of the challenges that can be addressed by using ICT. Some of the activities categorised under using technology, and which this research will address, are those of using a mobile phone, using a computing device, and controlling an electronic environment.

1.2 Research Contribution

This research proposes a framework for designing AAL services for disabled individuals. There are various aspects, such as requirements identification, that are involved in the design of AAL services for disabled people. Existing AAL frameworks such as UniversAAL, however, mainly focus on the technology aspect. Using the proposed framework, three AAL services were designed, implemented, and evaluated. The AAL services were determined from literature and interview studies conducted with physically disabled individuals and their assistants. Chapter 9 discusses the research contributions in detail.

1.3 Problem statement

Physically disabled individuals experience difficulties in carrying out everyday activities. Caregivers may be able to provide assistance, but this is costly, and the caregivers may not always be available on a 24-hour basis. AAL systems may be of help to these disabled individuals, but most homes do not incorporate AAL. There is a need to understand how AAL can be used to assist physically disabled individuals. A framework is proposed as a means of understanding how to design AAL Services for the physically disabled.

1.4 Aim of Research

The aim of this research is to propose a framework for designing AAL services for physically disabled individuals in a home environment. The framework was validated by using it to design three AAL services to assist physically disabled individuals with some of their challenges. The challenges were identified through interview studies with a representative sample of physically disabled individuals. Evaluation studies were carried out in order to evaluate the efficacy of the developed AAL services.

1.5 Research Questions

The primary research question for this project is:

RQ0: *How can AAL services be designed to assist physically disabled individuals in a home environment?*

In order to address the primary research question, the following sub-questions are also formulated.

RQ1: What are the challenges faced by disabled individuals?

RQ2: How can ICT be used to address some of the challenges faced by disabled individuals in a home environment?

RQ3: What are the requirements for enabling independence of disabled individuals in a home environment?

RQ4: What interaction techniques can be used to implement the identified requirements?

RQ5: How can ICT solutions be designed that support the identified challenges?

RQ6: How effective are the designed solutions in addressing the identified challenges?

RQ7: What are the design recommendations resulting from this research?

1.6 Research Objectives

The main objective of this research is:

RO0*: To develop a framework for designing AAL services to assist disabled individuals in a home environment.*

The following sub-objectives will support achieving the main research objective:

RO1: To understand disability, and how disabled individuals experience disability (Chapter 2).

RO2: To understand the concept of Assisted Living, and explore assisted living technologies that can benefit disabled individuals (Chapter 3).

RO3: To identify the challenges faced by disabled individuals in a home environment that can be addressed using ICT (Chapter 4).

RO4: To review different interaction techniques that may be used by physically disabled individuals to interact with the environment (Chapter 5).

RO6: To design and implement a prototype that addresses the identified challenges (Chapter 6).

RO7: To evaluate the effectiveness and usefulness of the prototype (Chapter 7).

1.7 Research Methodology

A research methodology is defined as a systematic way to solve a problem. It is the science of studying how research is to be carried out (Rajasekar, Philominathan, & Chinnathambi, 2006). A suitable research methodology was required to address the aim of the research, and the associated research questions. It is important to choose a research methodology that is appropriate for the nature of the research being undertaken. Saunders, Lewis, & Thornhill (2009) introduced a concept of viewing research as an onion with many layers. A researcher goes from outside, through each of the layers, and justifies their position within each layer. The layers are Philosophies, Approaches, Strategies, Choices, Time Horizons, and Techniques and Procedures.

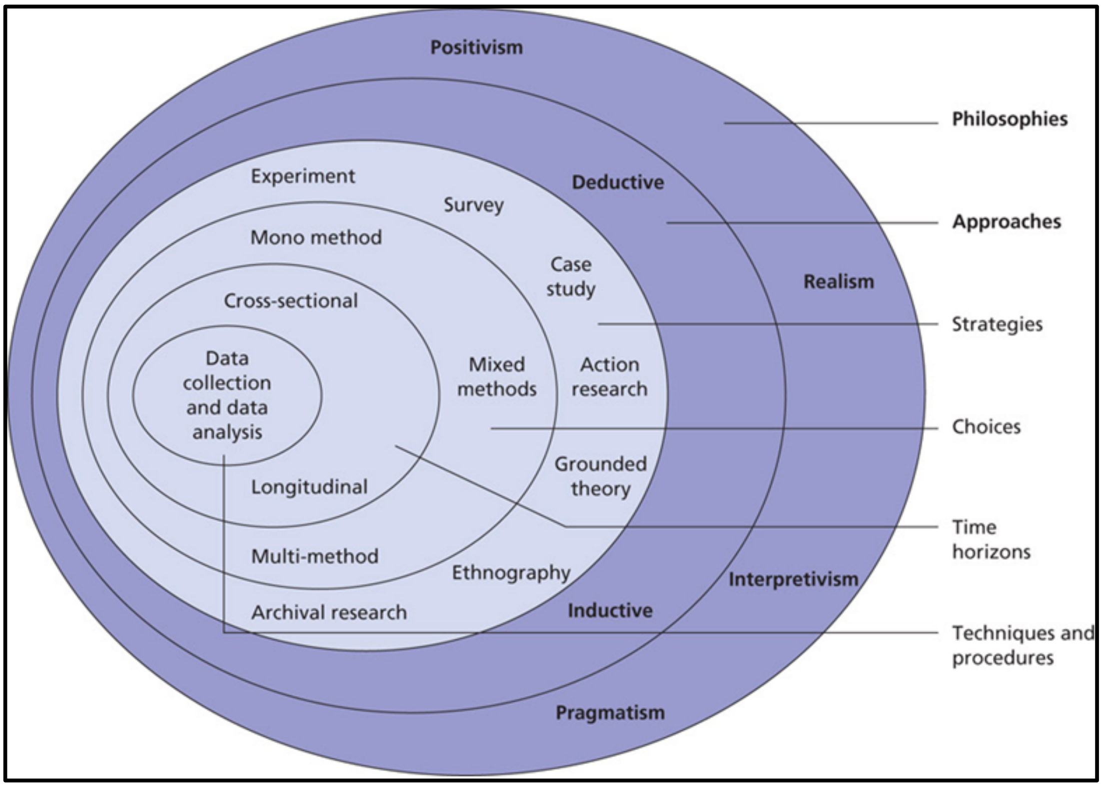

Figure 1-1: The Research Onion (Saunders et al., 2009).

The research onion helps researchers to critically think about their research methodology. It has six layers which are traversed from outside to inside. Figure 1-1 illustrates the research onion. Below is a discussion of its various layers.

1.7.1. Research Philosophy

Research philosophy is based on ontology and epistemology. Ontology is concerned with what constitutes reality, while epistemology is concerned with what constitutes valid knowledge, and how we can obtain it (Saunders et al., 2009). For example, given a computer, what is it, is the question that is studied under ontology, while the question of how we know what it is, is studied under epistemology. Research philosophy is how a researcher views the world, whether we believe there is an objective reality, or not. Believers of an objective reality most likely adopt positivism, realism, interpretivism, or in objectivism epistemology. Believers of a non-objective reality are likely to adopt subjectivism, pragmatism, functionalism, radical humanism, or radical structuralism epistemology (Gray, 2012).

1.7.2. Research Approach/Choices

Research usually involves two related entities, namely theory and data. A research approach may be defined as a framework that describes how the two entities are related, and guides a researcher on how to solve a given research problem (Burney, 2008). There are two main research approaches namely:

1. **Deductive**: Typically starts off with theory before moving on to data collection. Theory about a phenomenon of interest is reviewed, data is then collected to support, or disprove, a given research problem.
2. **Inductive**: Starts off with data and theories are then formulated around the data. No existing theories are used as a foundation for the study. The initial data set is sufficient to formulate a theory without input from existing theories.

A research approach may be chosen based on the nature of the problem. Qualitative research is usually inductive, while scientific research is usually deductive.

The other layers of the research onion are:

- **Research Strategies**: Help researchers to answer research questions by outlining repeatable guidelines that may be used by other researchers
- **Research Approaches:** Mixed methods is a combination of quantitative and qualitative approaches. A mixed methods approach was required to address the various research questions, which are discussed in the Research Strategies sub-section. Limitations of the research are also identified in this section.
- **Time Horizons:** This is concerned with the duration of the research study, and is categorized into two, namely: Cross-sectional: Observe changes one point in time, and Longitudinal: Conduct research over a long period of time to observe changes.
- **Data Collection techniques and analysis:** This is concerned with how researchers collect and analyse their data. A deductive approach will mostly rely on statistical analysis in order to demonstrate the significance of the intervention, while an inductive approach will rely mostly on thematic, or content analysis.

Computer Science related research is mostly multi-disciplinary (Vaishnavi & William, 2008). This incorporates research fields such as business management, education and human behavioural patterns into the development of technology-oriented artefacts. In many cases, the focus of Computer Science research, especially within organisations, is to increase efficiency and improve productivity (Hevner & Chatterjee, 2010). Therefore, the guiding philosophies, methodology and strategy of Computing Science related research, should be carefully chosen to be multi-disciplinary in nature. This research study is an example of multi-disciplinary research, since it involves two domains, namely disability and computing science.

1.7.3. Design Science Research

Design Science Research (DSR) is an alternative research methodology that uses a combination of positivist and interpretivist research philosophies. The DSR methodology is widely applied in information technology and information systems-based research, as artefacts commonly need to be designed, and evaluated, to address a need, or to provide a solution to an existing problem identified within these fields. Johannesson and Perjons (2012, p.8) define the DSR methodology as:

> *"Design science is the scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest."*

An artefact is an item that is created to address a practical problem (Johannesson & Perjons, 2012). Examples of artefacts include physical objects, drawings, methods and guidelines. This research resulted in the design of an artefact as identified in RQ4. An artefact is made up of three parts (Johannesson & Perjons, 2012), namely:

- *Construction:* Describes the components of the artefact, the relationship between these components and the interaction between the components.
- *Environment:* Describes the conditions under which the artefact will function, its intended use, and the target users of the artefact.
- *Function:* Describes the expected functionality to be supported by the artefact, and the resulting benefits of using the artefact.

Table 1-1: The Activities of the DSR Methodology (Johannesson & Perjons, 2012).

	Activity	Description
1.	Explicate Problem	• Involves examining and analysing a problem. • The problem needs to be clearly identified. • Reasons for the problem can also be investigated.
2.	Outline Artefact and Define Requirements	• Involves explaining the solution to the explicated problem. • Also involves identifying requirements for the proposed artefact. • Proposed requirements are identified for the primary purpose of deriving functionality for the artefact, but construction and environment can also be included.
3.	Design and Develop Artefact	• Involves producing an artefact supporting the identified requirements, and addressing the explicated problem. • Primary purpose of this activity involves identifying functionality and construction.
4.	Demonstrate Artefact	• Involves presenting the artefact to determine its feasibility, e.g. using a proof-of-concept.
5.	Evaluate Artefact	• Involves showing to what extent the artefact supports the identified requirements, and addresses the explicated problem.

The process of the DSR methodology comprises a number of activities (Johannesson & Perjons, 2012). Table 1-1 lists these activities and their respective descriptions. Figure 1-2 illustrates the various activities of the DSR methodology and their corresponding outcomes.

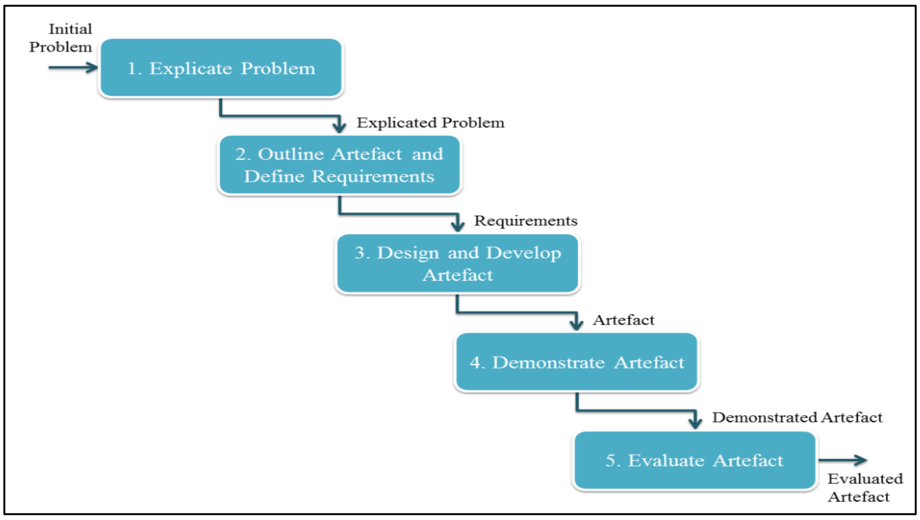

Figure 1-2 An Overview of the DSR Methodology (Johannesson & Perjons, 2012).

The DSR methodology has three cycles. Design science is concerned with the creation of an artefact for a defined problem. It involves an iteration of activities within a defined context, including (Hevner, 2007):

(i) A clearly defined environment that is achieved by going through a relevance cycle;
(ii) The building process and evaluation of an artefact produced with a design cycle; and
(iii) The establishment of a proper theoretical framework within a rigour cycle of studying and contributing to the supporting theories.

The three DSR cycles illustrated in Figure 1-3 are discussed in detail below:

Relevance Cycle

The relevance cycle initiates DSR with an application context that not only provides the requirements as inputs, but also defines acceptance criteria for the evaluation of the research results (Hevner, 2007).

This research seeks to help physically disabled individuals to be less dependent on personal assistants while in their home environments by using ICT. Disabled individuals at the Nelson Mandela University Disability Services Unit, Cheshire Home, Kampala, Uganda and their assistants were involved in identfiying the requirements for this research. The requirements were obtained through a literature review, and interview studies with disabled individuals and their assistants.

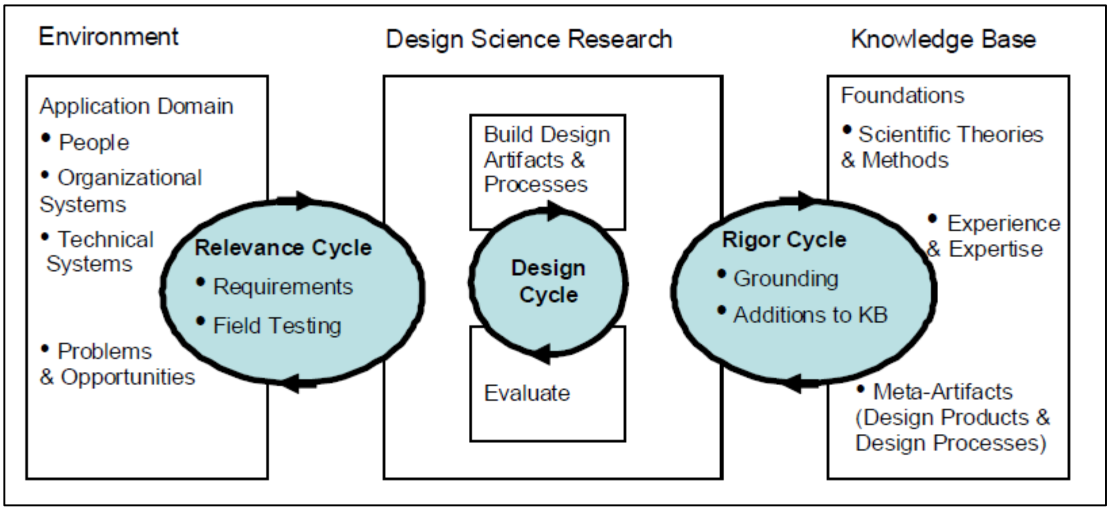

Figure 1-3: Design Science Research Cycles (Hevner, 2007).

Design Cycle

The design cycle iterates between the construction of an artefact, its evaluation, and subsequent feedback to refine the design further. Design alternatives are generated during this cycle; the alternatives are evaluated against requirements until a satisfactory design is achieved.

The requirements obtained through the relevance cycle are used as a basis for designing an AAL framework for providing AAL services to disabled people. Each design was evaluated by domain experts. The designs were also evaluated against the acceptance criteria indentified in the relevance cycle, and where necessary, the criteria in the relevance cycle were updated.

When a satisfactory design was achieved, a prototype AAL system was developed. The prototype was demonstrated to two expert users. The feedback from the expert users was incorporated into the prototype before a user study with disabled individuals was conducted. For each developed prototype, three design cycles were implemented.

Rigor Cycle

The rigor cycle provides past knowledge to the research project to ensure it contributes to the body of knowledge. It is important for researchers to thoroughly research and reference the knowledge base to guarantee that the designs produced are research contributions, and not routine designs based upon the application of well known processes (Hevner, 2007).

Literature was reviewed (Chapters 2 and 3) in order to gain a better understanding of disability and AAL. Existing gaps were also identified through literature reviews and the interview studies. The knowledge obtained was used to improve the design. The knowledge was also presented at the South African Telecommunications Networks and Applications Conference (SATNAC) 2015 conference as work in progress, a journal article discussing the research findings will also be published on completion of the research programme.

Drechsler, and Hevner (2016) propose an extension to the three cycle DSR model discussed earlier in this section. The proposed extention is a fourth cycle (Change and Impact) that captures the dynamic nature of Information Systems (IS) artefact design and how it impacts the wider society. Figure 1-4 illustrates the extended version of the DSR model with the addition of a fourth cycle. The change and impact cycle covers the design artifacts' second-order impacts to a wider organizational and societal contexts. For instance, assistive tecthnology that is designed to address specific challenges that are faced by a particular group of disabled persons, these challenges would be the immediate application context. The wider context are the challenges that are faced by disabled people in general.

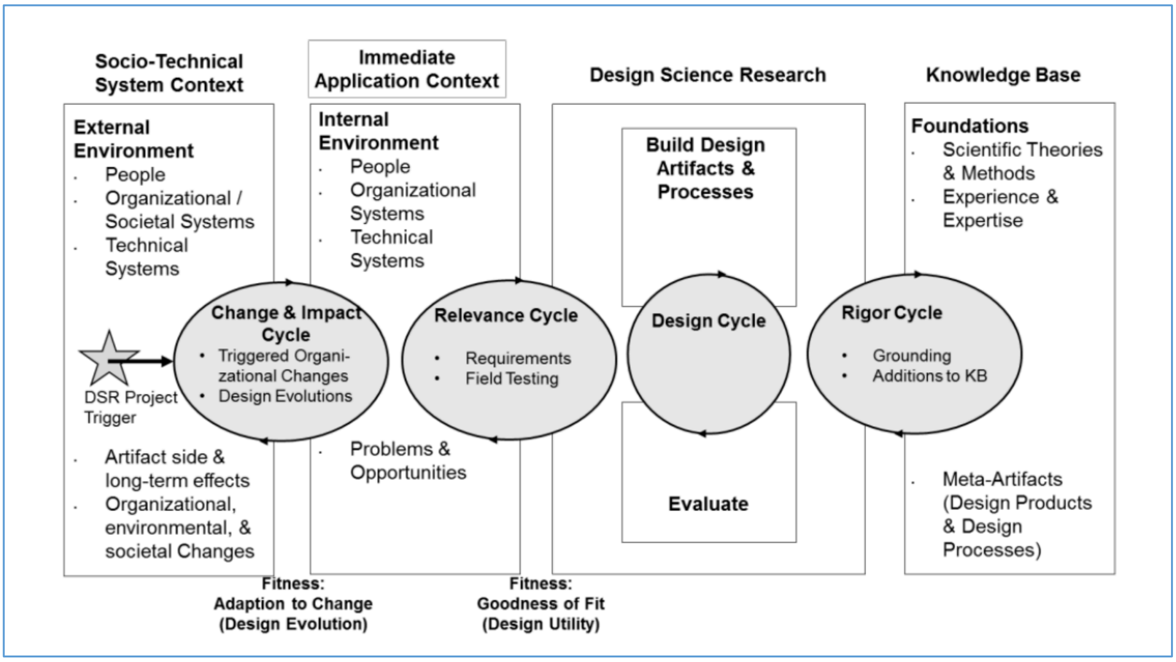

Figure 1-4: Design Science Research Change and Impact Cycle (Drechsler & Hevner, 2016).

A discussion of the Change and impact cycle as related to this research programme is presented in Chapter 9, Section 9.4.

1.7.4. Research Methods

A research method refers to the various specific tools or ways that data can be collected for research purposes (Neville, 2007). The research methods for this research study are: literature review, survey, design, prototyping, experiment and critical thinking. These strategies are used within the confines of the DSR methodology.

a) Literature Study

Literature studies are used to gain an understanding of a topic in a research area of interest. A literature study was used to introduce the Disability and Assisted Living topics, and to identify some of the challenges faced by disabled individuals. A literature study was also used to investigate the shortcomings of current interaction techniques that disabled individuals use to interact with technology. The literature study addresses the *Explicate Problem* and *Outline Artefact and Define Requirements* DSR activities. The literature study helped to fulfil this by identifying some of the requirements for Assisted Living for disabled individuals.

b) Interviews

Interviews are useful for getting a story behind a participant's experiences. The interview research strategy addresses the *Explicate Problem* and *Outline Artefact and Define*

Requirements DSR activities. A semi-structured interview study was used to identify what challenges disabled individuals experience. The interview study was also used to contextualise the challenges identified from the literature study, and to define the requirements for Assisted Living in a home environment.

c) Artefact Design

Design may be used to create novel artefacts that address a specified need, or needs (Johannesson & Perjons, 2012). Design, as a research strategy, was used to conduct the *Design and Develop Artefact,* and the *Demonstrate Artefact* DSR activities. The artefact design was based on the requirements identified from the literature and survey strategies. Existing interaction techniques were not sufficient to address the research needs, and hence new interaction techniques were proposed. Assisted Living tasks were identified that need to be supported by the selected interaction techniques.

d) Prototyping

Prototyping can be used to build artefacts which convey research knowledge in a constructive way (Olivier, 2009). Prototyping was used in combination with the Design Research Strategy to conduct the *Design and Develop Artefact* and the *Demonstrate Artefact* DSR activities. A prototype was used to implement the Assisted Living requirements. Initially, a sample application was developed to evaluate various interaction techniques. The most suitable interaction techniques, as chosen by disabled individuals, were used to implement the prototype artefact that was used for the usability evaluation.

e) Experiment

An experiment is conducted to assess a theory, or to observe the result of a particular intervention (Johannesson & Perjons, 2012). The theory to be assessed in this research is how the proposed artefact will enable disabled individuals to be more independent in a home environment. The experimental research strategy addresses the *Evaluate Artefact* DSR activity. Disabled individuals participated in an experimental evaluation that was aimed at choosing the most suitable interaction techniques.

f) Critical Thinking

Critical thinking involves various skills such as: analysing arguments, making inferences using inductive, or deductive reasoning, judging or evaluating, and making decisions or solving problems (Lai, 2011). Critical thinking can thus be used to analyse results, or outcomes, of specific research to confirm the contributions of a given body of work. Chapter 4 identifies requirements for enabling independence of disabled individuals in their home environments. The critical thinking research strategy, enabled the addition of valuable knowledge to the body of knowledge of the assistive technology design process. The evaluation study also provided results that may be useful to inform similar future research. The resultant requirements, together with the results of the evaluation study, were critiqued to identify design recommendations, and to inform the design of future assistive technologies for physically disabled individuals.

1.7.5. Possible limitations

The developed AAL system was evaluated in South Africa through a user study. The Ugandan interview participants did not have a chance to evaluate the system.

1.8 Ethical considerations

The study was granted ethics clearence (H15-SCI-CSS-031) and (H15-SCI-CSS-031/Extension). The ethics clearence letters are attached in Appendix A. All interactions with disabled persons were carried out in the presence of an individual with experience in social work. This made the disabled persons comfortable and also eased communication.

1.9 Scope and Constraints

This research focuses on individuals who have motor-related physical disabilities, and the user evaluation study was limited to participants from two disability centres, the Nelson Mandela University Disability Services Unit, and Summerstrand Cheshire Home. A usability study was carried out in a lab environment, and also at Cheshire Home.

1.10 Conclusion and Dissertation Structure

Table 1-2 provides a summary of the research questions and the research methods that were used to address them.

Table 1-2: Summary of Research Questions, Methods and Chapters.

Research Question	Research Method	Chapter
RQ 1. What are the challenges faced by disabled individuals?	Literature Study	Chapter 2
RQ 2. How can ICT be used to address some of the challenges faced by disabled individuals in a home environment?	Literature Study	Chapter 3
RQ 3. What are the requirements for enabling the independence of disabled individuals in a home environment?	Survey	Chapter 4
RQ 4. What interaction techniques can be used to implement the identified requirements?	Iterative Design, Prototyping	Chapter 5
RQ 5. How can ICT solutions be designed that support the identified challenges?	Iterative Design, Prototyping	Chapter 6
RQ 6. How effective are the designed solutions in addressing the identified challenges?	Usability Study	Chapter 7
RQ 7. What are the design recommendations resulting from this research?	Critical thinking	Chapter 8

Chapter One (Introduction): This chapter provides a general overview of the research. It outlines the importance and significance of the research for disabled individuals. This chapter also discusses and motivates the research methodology (DSR).

Chapter Two (Understanding Disability): This chapter explores disability in general. It reviews existing models of disability and related theory, types of disabilities, and the challenges experienced by disabled individuals.

Chapter Three (Assisted Living): This chapter explores theory related to Assisted Living. A review of various technologies that may assist disabled individuals was also carried out, with a focus on a home environment.

Chapter Four (Interview Study to Identify Challenges Experienced by Physically Disabled Individuals): Using the knowledge obtained from Chapters Two and Three, interview studies were carried out in order to contextualize the challenges identified from literature, and also to narrow down the scope of this research study. This chapter concludes by identifying the software requirements for this research.

Chapter Five (Interaction Techniques): This chapter reviews literature on interaction techniques that can address the identified challenges, experimental tasks are developed, and a pilot evaluation carried out to identify the most suitable interaction techniques.

Chapter Six (Design & Implementation): This chapter discusses the design and implementation of the artefacts.

Chapter Seven (Evaluation Design and Results): This chapter discusses the design and results of an evaluation study with 15 disabled individuals.

Chapter Eight (Proposed Framework): The AAL services were evaluated by disabled individuals. Modifications to the proposed AAL framework were made in accordance with the feedback from the evaluation.

Chapter Seven (Conclusions): Concludes the research and emphasises the contributions made, challenges encountered, and opportunities for future research.

Figure 1-5 illustrates the structure of this dissertation.

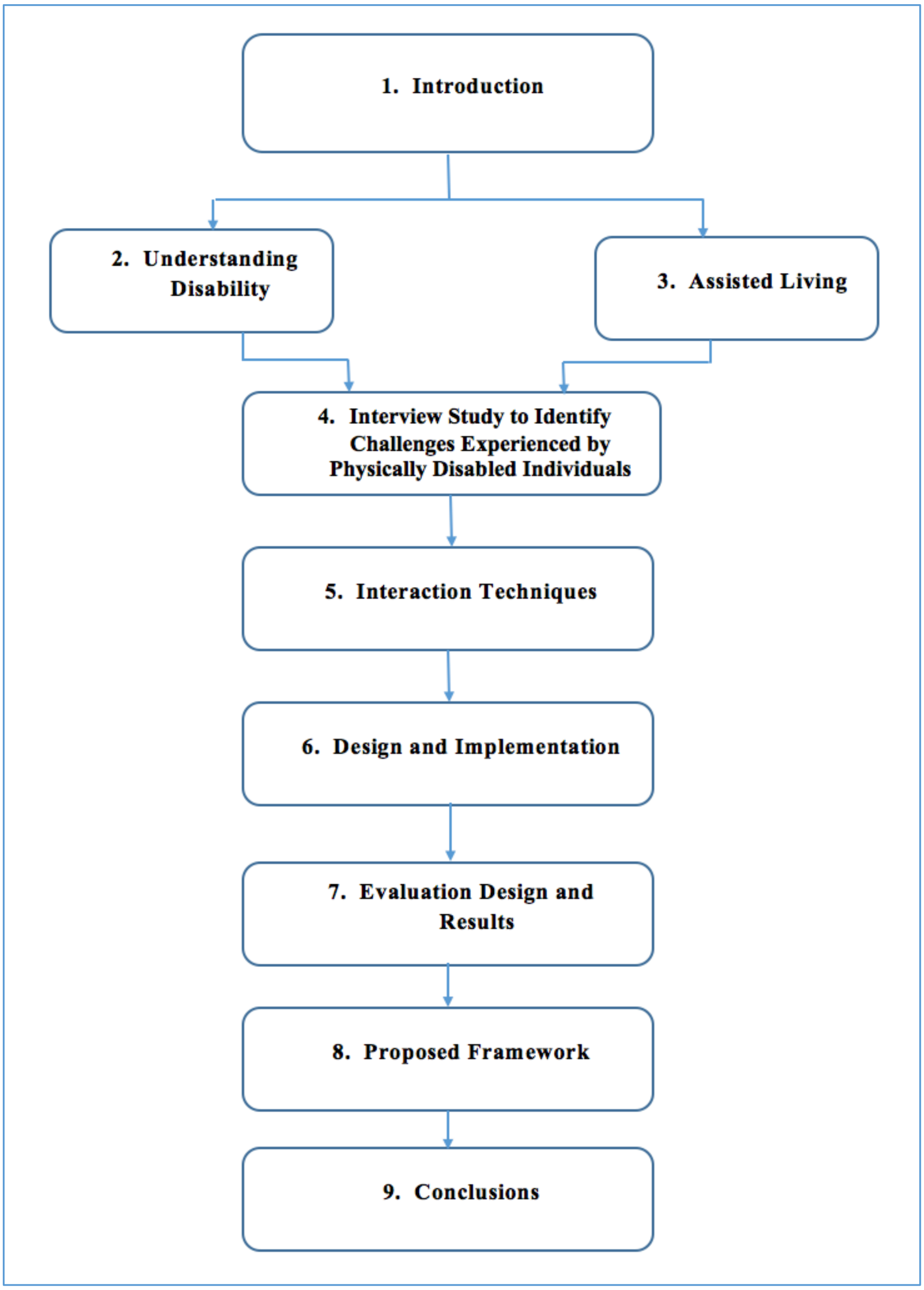

Figure 1-5: Dissertation structure.

Chapter 2: Understanding Disability

2.1. Introduction

The purpose of this chapter is to meet research objective one (RO1), which is: To understand disability, and how disabled individuals experience disability. Figure 2-1 illustrates the structure of this chapter.

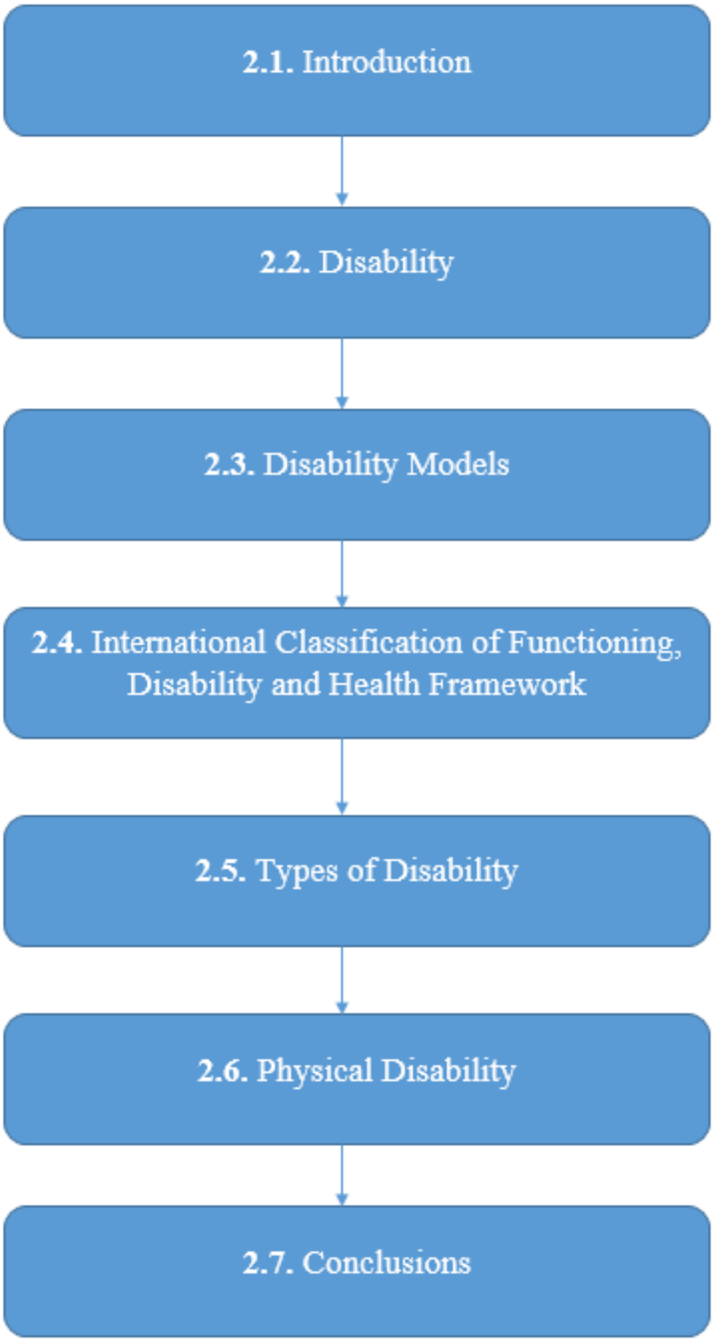

Figure 2-1: Structure of Disability Chapter.

2.2. Definition of Disability

The World Health Organisation (WHO), and the World Bank (2011), state that the definition of disability is complex, dynamic, multidimensional, and contested. For the purposes of this research study, disability is defined as an umbrella term for impairments, activity limitations and participation restrictions, especially referring to the negative aspects of the interaction between an individual and that individual's contextual factors (environmental and personal factors) (Leonardi, Bickenbach, Ustun, Kostanjsek, & Chatterji, 2006). This definition of disability was chosen because it is the one used by the WHO in their 2011 world report on disability. The above definition of disability, however, is only one way of viewing it. It is important to understand the differences between the various ways that disability is viewed, as it may lead to a better understanding of disability in general.

2.3. Disability Models

Four models of disability exist, namely: Biomedical, Functional, Environmental, and Social Political Models. The Functional and Environmental Models both define disability as an interaction between an individual and their environment, and hence are discussed as one model. The models are discussed below in detail (Smart & Smart, 2012):

1. **Biomedical Model**

The biomedical model defines disability in the language of medicine, and disabilities are viewed as entirely an individual experience. This model is not considered to be interactional because the definition of "the problem," and the treatment of the disability, are all considered to lie within the individual with the disabilities. There is less multi-disciplinary collaboration when disabilities are medicalized (Smart & Smart, 2012).

2. **Functional and Environmental Models**

These models consider the functions of an individual and their environment. Disability is defined in relation to the skills, abilities, and achievements of the individual in addition to biological factors. These two models are considered to be interactive because the disability of the individual interacts with the environment. If the location of a problem shifts, the onus for the solution of the problem also shifts. By viewing the definition, the cause, and the difficulty associated with disability as interactional, helping professionals can aim interventions at adapting the environment and functional demands to the needs of the individual with a disability (Smart & Smart, 2012).

3. The Socio-Political Model

The socio-political model, also referred to as the minority model of disability, has the capability to explain and describe more of the day-to-day life of people with disabilities. For most disabled individuals, the prejudice and discrimination they experience in the broader society, are more of an obstacle than medical impairments, or functional limitations (Smart & Smart, 2012). The socio-political model can trigger new insights, which we may not otherwise develop.

The models discussed provide various view points on disability. The choice of a view point may be guided by the objectives of an interested party, such as a medical doctor, social worker, researcher, or technology solution developers. For example, a doctor who is attending to a child with autism, will rely on a medical model and administer medication that may aim to boost the body functioning of the child. However, a social worker who cares for the child, may rely on the socio-political model to help the child in their daily life. Governments and politicians, however, may take the functional and environmental models and formulate laws that require accessibility standards such as wheel chair ramps and lifts, to be mandatory for public facilities.

This research programme views disability using the International Classification of Functioning, Disability and Health Framework, which is discussed in Section 2.4. The framework includes aspects of all the models discussed in this section.

2.4. International Classification of Functioning, Disability and Health Framework

The International Classification of Functioning, Disability, and Health Framework (ICF) is a framework for describing and organising information on functioning and disability. The ICF helps describe what a person with a disability can do in a standard environment (their level of capacity), as well as what they actually do in their usual environment (their level of performance) (WHO, 2002). For purposes of this research, the ICF is viewed as a potential template to inform technology solution developers, in developing solutions for disabled individuals. The ICF is based on a universal, culturally sensitive, integrative, and interactive model of health and functioning that provides sensitivity to psychosocial and environment aspects of health and disability (Simeonsson, Leonardi, Lollar, Bjorck-Akesson, Hollenweger, & Martinuzzi, 2003).

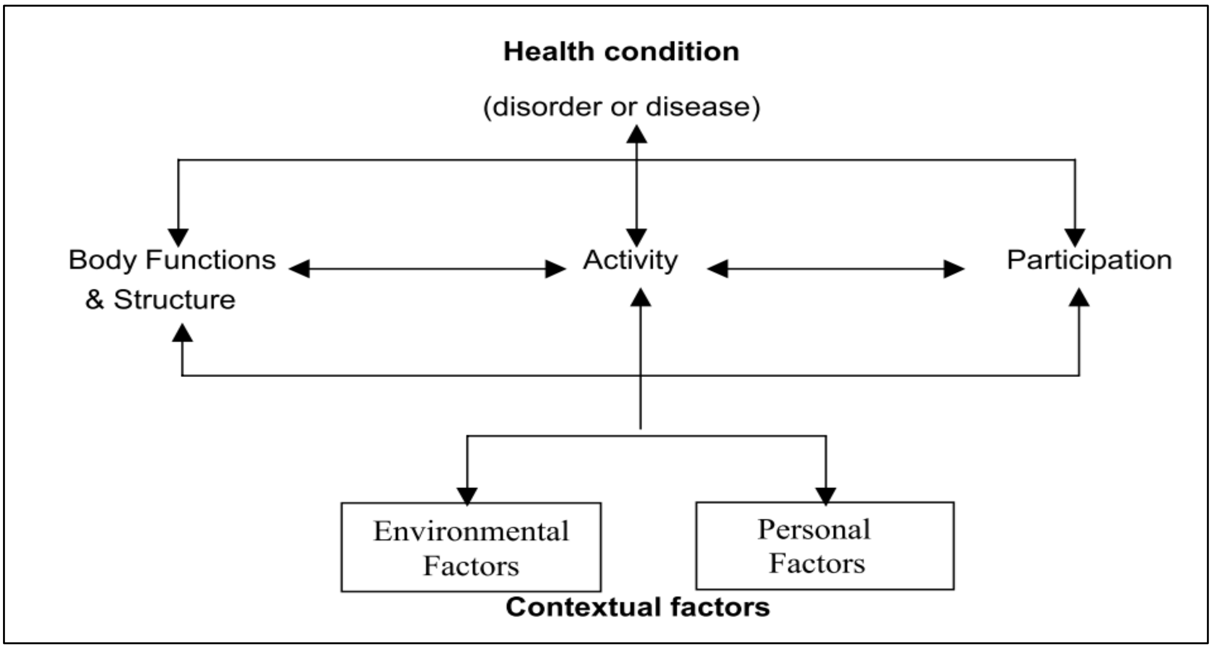

Figure 2-2: ICF conceptual framework (WHO, 2002).

Figure 2-2 illustrates the ICF conceptual framework. The conceptual framework of the ICF provides different domains for a person in a given health condition (e.g. what a person with a disease, or disorder, does do, or can do) in two parts. Part 1 deals with Functioning and Disability, while Part 2 covers Contextual Factors.

2.4.1 Components of Functioning and Disability

The Body component comprises two classifications; one for the functions of the body systems, and one for the body structures. The chapters in both classifications are organized according to the body systems. The Activities and Participation components cover the complete range of domains, denoting aspects of functioning from both an individual, and a societal perspective.

Activities and participation: These components cover the domains of functioning, from an individual, and a societal perspective. For technology solution developers conceptualizing a design, this framework can be used to explore an individual's capability to use different input mechanisms, such as a keyboard, or mouse (body functions and body structures). Once the physical functioning of an individual is clarified at an individual level, then the way that person functions in their environment can be explored with respect to potential (activity), versus actual ability, to participate within a social context (participation). The discrepancy between identified potential (activity), and actual participation, can serve as the focus of a technological attention for intervention targeting.

2.4.2 Components of Contextual Factors

A list of Environmental Factors is the first component of Contextual Factors. Environmental factors have an impact on all components of functioning and disability, and are organized in sequence from the individual's most immediate environment, to the general environment. Personal Factors is also a component of Contextual Factors, but they are not classified in ICF because of the large social and cultural variance associated with them. The components of Functioning and Disability in Part 1 of ICF can be expressed in two ways. On the one hand, they can be used to indicate problems, e.g. impairment, activity limitation, or participation restriction summarized under the umbrella term disability, or, on the other hand, they can indicate non-problematic (i.e. neutral) aspects of health and health-related states, summarized under the umbrella term "functioning".

The ICF framework provides a standard language and a conceptual basis for the definition and measurement of health and disability.

The definitions of the various components in the ICF are:

1. **Health condition**: Components of health that are a focus of health care professionals. For example, disease, disorders and injuries.
2. **Body Functions**: Physiological functions of body systems, e.g. walking.
3. **Body Structures**: Anatomical parts of the body such as limbs and their components.
4. **Impairments**: Problems in body function, or structure.
5. **Activity**: Execution of a task or action by an individual.
6. **Participation**: Involvement in a life situation.
7. **Activity Limitations**: Difficulties an individual may have in executing activities.
8. **Participation Restrictions**: Problems an individual may experience in involvement in life situations.
9. **Environmental Factors**: Physical, social and attitudinal environment in which people live and conduct their lives.

The ICF has been used as a basis for the design of a framework for physiotherapy management (Harvey, 2007). Below is an example of using the ICF to gain a better understanding of how quadriplegia affects individuals.

- **Health condition:** Quadriplegia, which is defined in Chapter 1, section 1.1.
- **Body Functions, Structure, and Impairments:** Spinal Cord Level of Injury (Appendix B).
- **Activity Limitations:** The inability to use hands to carry out activities of daily living such as cooking and personal care.
- **Participation restrictions:** Some of the participation restrictions that an individual with quadriplegia may face are: Using a phone, using a computer, controlling an electronic environment.
- **Environmental factors:** Individuals with quadriplegia may experience many challenges when interacting with their physical environments. Some of these challenges may be overcome by using disability support aids.
- **Personal factors**: Physical disability such as quadriplegia is usually associated with limited opportunities to earn a living, this impacts on an individual's quality of life.

In the above example, the health condition is quadriplegia. An associated impairment is limited hand use. Limited hand use directly impacts on the ability to perform activities such as using a computing device, using a mobile phone, and controlling an electronic environment. This, in turn, has implications for participation such as working, studying, and engaging in family life. Impairments, activity limitations and participation restrictions are all affected by environmental and personal factors, such as availability of support aids, family support, and a source of livelihood for disabled people. The above discussion shows that ICF can help in the identification of challenges faced by individuals with a disability. Disabled individuals may need to be interviewed, however, to gain a better understanding as to how they experience and cope with the identified challenges.

The ICF has two versions with approximately 1,500 categories of classifications (Peterson, 2012). The full version provides four levels of classification detail, and a short detail that provides two levels of classification. In both versions, units of classification are qualified with numeric codes that specify the magnitude, or extent of disability, or function, in a given category, as well as the extent to which an environmental factor impacts individuals with a given disability. The use of the ICF in this research is limited to gaining an understanding of the challenges experienced by disabled individuals, and how technology solutions can benefit from its use. Disability is a complex phenomenon, as identified from literature. Section 2.5 reviews literature to understand the various types of disabilities.

2.5. Types of Disability

Researchers have used varying classifications of disabilities to provide taxonomies of the kinds of impairments that people may have. The classifications are often motivated by the objectives of the researchers. For example, one study investigating employment opportunities for persons with different types of disabilities, classifies disability into six types, namely *communicative-hearing, communicative-speech-reading, communicative-vision, psychological, medical and physical* (Boman, Kjellberg, Danermark, & Boman, 2015). Another study investigating the connection between types of disability, gender and socio economic disadvantage in Australia, classifies types of disability as, *Sensory and speech*, *Intellectual*, *Physical*, *Psychological* and *Acquired Brain Injury* (Kavanagh, Krnjacki, Aitken, LaMontagne, Beer, Baker, & Bentley, 2015). The two studies highlighted above list the same types of disabilities, albeit under different classifications.

The classification used for this research is the one proposed by the Trace Centre (Trace Centre, 2010a), which classifies disability into four types namely: Visual, Hearing, Physical, and Cognitive/Language. This classification was chosen because it is less specific than the classifications discussed earlier. The types of disabilities grouped under this classification are:

2.5.1 Visual disability

Visual disability varies from people with very poor vision, to people who can see light, but no shapes, to people who have no perception of light at all. The following terms are used to describe individuals with visual disabilities:

- *Totally blind*: Individuals who cannot see at all.
- *Legally blind*: Indicates that an individual has less than 20/200 vision in the more functional eye, or a very limited field of vision (20 degrees at its widest point).
- *Low vision*: Refers to a severe vision loss in distance and near vision. Individuals use a combination of vision and other senses to read, and they may require adaptations in lighting, or the print size, and, in some cases, Braille.

According to Stats SA (Statistics South Africa, 2011), 11% of individuals surveyed in the 2011 disability census experience problems with their eyesight. That is, 4,085,898 individuals reported having mild difficulty with seeing, while 738,079 individuals have severe difficulty seeing.

2.5.2 Hearing disability

Hearing disability includes people who are completely deaf, and those who have problems hearing (Hard of hearing).

- *Deaf*: Individuals who are unable to discriminate conversational speech through the ear, that is, they cannot use their ears for communication. This includes individuals who are pre-linguially deaf (born deaf), and deafened (lost their hearing after acquiring spoken language).
- *Hard of hearing*: Individuals who have great difficulty using their ears for communication.

Three point six percent (3.6%) of individuals surveyed in the 2011 South African disability census experience problems with hearing. 1,251,907 individuals experience mild difficulty with hearing, while 288,369 individuals experience severe difficulty.

2.5.3 Physical

Physical disability refers to loss or lack of limbs, damage to muscles, nerves, skin, or bones that leads to difficulties moving about and in performing activities of daily living (such as dressing, eating, cleaning, etc.) (Dpsa, 2001). The nature of physical disabilities includes:

- *Skeletal*: Joint movement limitations, small limbs, missing limbs or abnormal trunk size.
- *Neuromuscular*: Caused by ailments that affect muscular control in part or most of the body.

Two percent (2%) of individuals surveyed in the 2011 South African disability census, experience problems with walking, self-care and verbal communication. 1,100,135 individuals experience mild difficulty with walking/climbing stairs, while 423,179 individuals experience severe difficulty. Furthermore, 837,363 individuals experience mild difficulty with self-care, while 588,869 individuals experience severe difficulty.

Whereas self-care difficulties may not be restricted to individuals with physical disabilities, physically disabled individuals experience more difficulty with self-care.

2.5.4 Cognitive/Language disabilities

Cognitive disabilities can vary widely, from severe retardation to the inability to remember, to the impairment of specific functions such as language.

- *Speech and Language Disabilities*: These may result from hearing loss, learning disabilities, and/or physical conditions. There may be a range of difficulties from problems with articulation, or voice strength, to complete absence of voice. Included are difficulties in projection, fluency problems, such as stuttering and stammering, and in articulating particular words or terms.
- *Attention-Deficit and Hyperactivity Disorders*: These are neurological conditions affecting both learning and behaviour. They result from chronic disturbances in the areas of the brain that regulate attention and impulse control.
- *Learning Disabilities*: These are neurologically based, and may interfere with the acquisition and use of listening, speaking, reading, writing, reasoning, or mathematical skills. They affect the way individuals with average, or above average intellectual abilities, process and/or express information.
- *Psychiatric Disabilities*: These refer to a wide range of behavioural and/or psychological problems characterized by anxiety, mood swings, depression, and/or

a compromised assessment of reality. These behaviours persist over time, and are not in response to a particular event (CDC, 2010; John Hopkins University, 2015).

Four point two percent (4.2%) of individuals surveyed in the 2011 South African disability census experience cognitive difficulties (remembering/concentrating). 1,405,098 individuals experience mild difficulty, while 456, 179 individuals experience severe difficulty.

2.5.5 Discussion

The four disability categories identified affect individuals in different ways, from the inability to move independently for the blind, to the inability to communicate for the deaf. The four categories may also have several sub categories, hence the list of disabilities discussed is not exhaustive. The scope of this research is limited to physical disability. Limiting the scope is essential to make a contribution to the body of knowledge of disability.

2.6. Physical Disability

Physically disabled people face a number of challenges in their day-to-day lives. Section 2.5.3 defined physical disability, and how it affects individuals. This section discusses physical disability in detail, by first discussing spinal cord injuries, which are one of the leading causes of physical disability and challenges that may be faced by individuals with physical disabilities.

2.6.1. Spinal Cord Injuries

The spinal cord is a cylindrical structure of nervous tissue composed of white and grey matter, which carries signals back and forth between an individual's body and his or her brain. A spinal cord is uniformly organized, and is divided into four regions: *cervical (C), thoracic (T), lumbar (L) and sacral (S)*, which are illustrated in Figure 2-3. Each region of the spinal cord is comprised of several segments. There are 31 segments, defined by 31 pairs of nerves exiting the cord. These nerves are divided into *8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal* (Dafny, 1997).

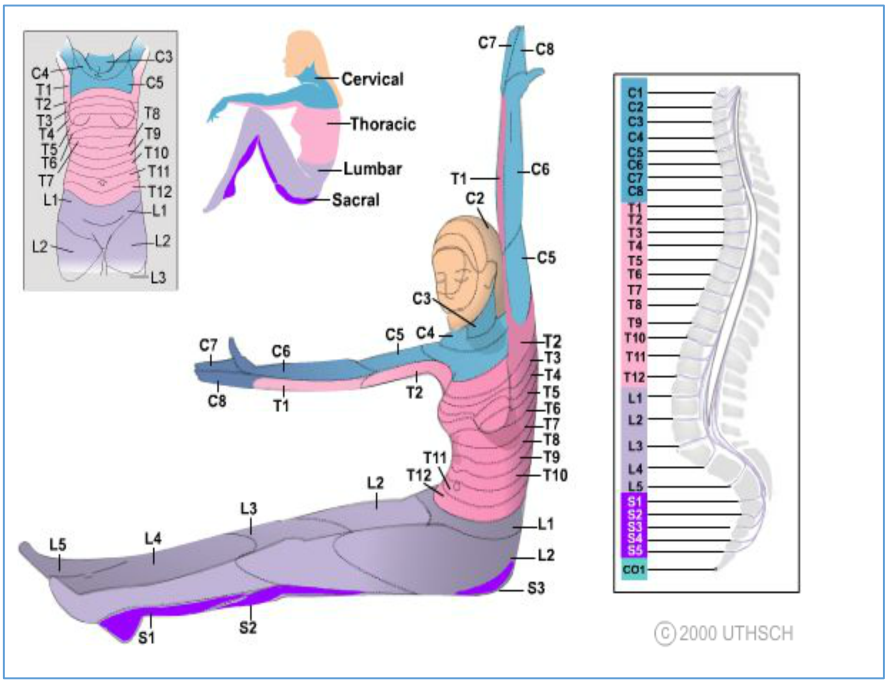

Figure 2-3: Spinal Cord Segments (Dafny, 1997).

An injury to the cervical spinal region is a cause of quadriplegia. The various levels of spinal cord injuries described in Table 2-1 show different levels of dependency, requiring different levels of care and support aids. Individuals who have injuries in C2 - C4 require the most care, while individuals in groups C5 - C8 require varying levels of care, as the individuals retain some autonomy.

Table 2-1: **Spinal cord injuries (John Hopkins Medicine, 2000).**

Level of injury	Possible impairment	Rehabilitation potential
C2 – C3	Usually fatal because of inability to breathe	Totally dependent for all care
C4	Quadriplegia and breathing difficulty	Dependent for all care; usually needs a ventilator
C5	Quadriplegia with some shoulder and elbow function	May be able to feed self-using assistive devices; usually can breathe without a ventilator, but may need other types of respiratory support
C6	Quadriplegia with shoulder, elbow, and some wrist function	May be able to propel a wheelchair inside on smooth surfaces; may be able to help feed, groom, and dress self; dependent on others for transfers
C7	Quadriplegia with shoulder, elbow, wrist, and some hand function	May be able to propel a wheelchair outside, transfer self, and drive a car with special adaptions; may be able to help with bowel and bladder functions.
C8	Quadriplegia with normal arm function; hand weakness	May be able to propel a wheelchair outside, transfer self, and drive a car with special adaptions; may be able to help with bowel and bladder programs
T1 – T6	Paraplegia with loss of function below mid-chest; full control of arms	Independent with self-care and in wheelchair; able to be employed full time
T6 – T12	Paraplegia with loss of function below the waist; good control of torso	Good sitting balance; greater ability for operation of a wheelchair and athletic activities
L1 – L5	Paraplegia with varying degrees of muscle involvement in the legs	May be able to walk short distances with braces and assistive devices

The various levels of spinal cord injuries described in Table 2-1 require various levels of care, dependency and support aids. Individuals who lie between C4 and C2 require the most care, while individuals who have T and L injuries, require the least care.

2.6.2. Support Aids

Disability support aids are objects, which assist disabled people in carrying out Activities of Daily Living (ADLs). Table 2-2 lists some of the challenges, category of disability and existing support aids.

Table 2-2: Support aids for disabled people (BuckinghamHealthCare, 2012; DeafWebsites, 2012).

Challenge	Category	Support aids
Reading	Visual	• Magnifiers: Handheld gadgets that magnify letters on a computers or books for individuals with limited sight (Brady, Morris, Zhong, White, & Bigham, 2013).
Mobility	Visual	• Guide dogs: These dogs are trained to lead blind people around obstacles. • Long cane: Used by the blind to scan their environment for obstacles as they move.
Using technology for access to information and Communication	Visual	• Text to speech software: Individuals with visual disabilities can use such software.
Interpreting visual displays	Visual	• The blind can use screen readers and screen magnification programmes
Communicating with others	Hearing	• Hearing aids: Enhance the hearing of the deaf (DeafWebsites, 2012).

This section has discussed the existence of support aids for the different types of disabilities. Some of the support aids, such as personal assistants, can be used by both blind and deaf people. Other support aids, such as the use of prosthetics, are limited to people with certain physical disabilities. For example, an individual with a bent arm may not be able to benefit from the use of a prosthetic, whereas an individual with no arm may benefit from a prosthetic.

2.6.3. A literature review of challenges experienced by physically disabled people

Disabled people would prefer to accomplish some of these tasks by themselves (De Groot Kim, 2005). Table 2-3 lists some of the challenges faced by individuals who have motor-related physical disabilities. The challenges listed in Table 2-3 were identified from literature.

Table 2-3: Challenges faced by individuals who have motor-related physical disabilities (Trace Centre, 2010b):

Challenges
• *Reading Challenges*: for example, an individual with no hands will have trouble turning pages in a book. • *Mobility*: Individuals with no limbs may require wheelchairs to move around (Disabled World, 2012). • *Using technology*: Individuals with limited hand use have trouble using touch input devices such as smart phones. • *Personal Care*: Individuals with limited hand use experience problems such as inability to bath and cook for themselves.

The challenges faced by the various individuals with motor-related physical disabilities are diverse, and are not limited to the ones listed in Table 2-3. However, a majority of disabled individuals have common challenges such as mobility, communication and interaction with their environments.

The challenges identified in this section do not provide specific details as to how individuals experience them. The interview process and results were reported in Chapter 4. The challenges in Table 2-3 were used in the formulation of interview questions.

2.7. Conclusions

In multi-disciplinary research, it is important to understand the research domain in order to address the issues that exist in this domain. This study resides predominantly in the field of computer science, but is multi-disciplinary in that it touches upon issues of psychology in the experience of disabled persons. This chapter has defined disability as per the needs of this research study, and also explored the different theories (models) of disability.

There are various types of disabilities and individuals with each of the different disability types, experiencing a unique set of challenges. Hence interventions that do not cater for the unique nature of disability types will not have the desired level of impact. This research study will focus on physical disability going forward. The research objective of this chapter, which was, "*To understand disability and how disabled individuals experience it",* has also been addressed.

The first step in the DSR process emphasises the need to explicate a problem to gain a better understanding of a research domain. This chapter has partially achieved this by clearly defining disability, and narrowing down the scope of the research to focus on physical disability. The next chapter explores assisted living, and its associated technologies that may benefit physically disabled individuals.

Chapter 3: Assisted Living Technologies

3.1. Introduction

The purpose of this chapter is to meet research objective two, which is: *To understand the concept of Assisted Living and explore assisted living technologies that can benefit disabled individuals*. Figure 3.1 illustrates the structure of this chapter.

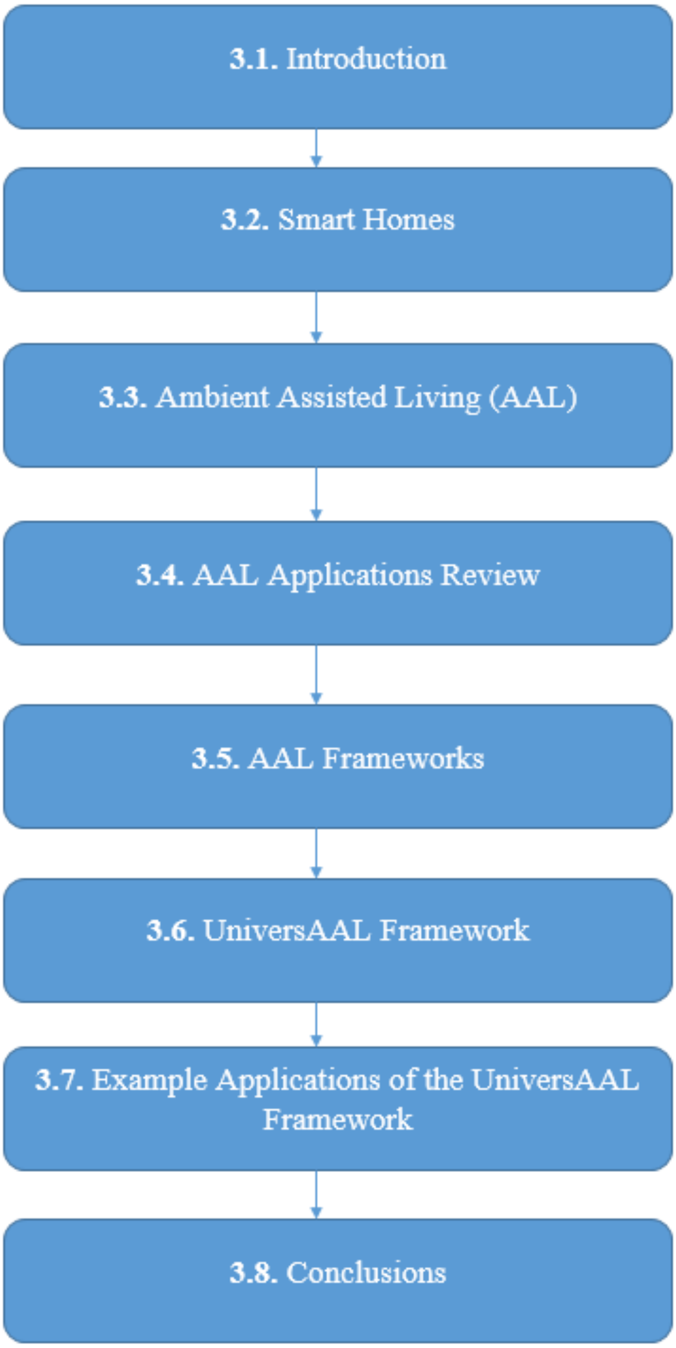

Figure 3-1: Structure of Assisted Living Technologies Chapter.

3.1.1. Defining Assisted Living

Assisted living is defined as a special combination of housing and personalised health care designed to respond to the individual needs of those in need of help with activities of daily living (Regneir & Hamilton, 1995). Care is provided in a way that provides maximum independence and dignity for each resident, and may involve the resident's family, neighbours, and friends. Regneir and Hamilton (1995) note that some of the characteristics of assisted facilities are:

i) **Appear residential in character:** The form and character should look more like a residential home than a hospital.
ii) **Recognize the uniqueness of each resident:** The contribution and needs of each resident should be expressed through a program of activity, and a plan for services that treats each person as a unique individual.
iii) **Foster independence, interdependence, and individuality:** The focus of care should be on self-maintenance with assistance.
iv) **Support family involvement:** A care-giving partnership should be forged that shares responsibility for residents' well-being with family members.

The features of assisted living environments listed above, which were formulated over 20 years ago, are still applicable at present day. Disabled individuals who reside in care homes benefit from the arrangement. However, some disabled individuals reside in their personal homes and are cared for by relatives, or paid caregivers. These personal homes can be adapted to suit the unique needs of a disabled individual.

3.1.2. Discussion

Assistive Technology is defined as any piece of equipment, item, product, or system that is used to increase, maintain, or improve functional capabilities of individuals with disabilities. Chapter 2 reviewed various disability support aids some of which may be categorized as Assistive Technologies (ATs). ATs have a profound impact on the everyday lives and employment opportunities of individuals with disabilities, by providing them with greater independence, and enabling them to perform activities not possible in the past (Brodwin, Siu, & Cardoso, 2012). AT devices and technology may be low-tech (mechanical), or high-tech (electro-mechanical or computerised), and can compensate for sensory and functional losses. AT helps to equalise the capacities of those individuals with disabilities compared to those without disabilities. The next section introduces the concept of a smart home as a possible way of enabling independence for disabled individuals in their home environments, by incorporating various assistive technologies.

3.2. Smart Homes

A Smart Home Environment is one which integrates diverse, context-aware, automated technology and services with the aim of unobtrusively enhancing the lives of its inhabitants (Alam et al., 2012; Sanchez & Tercero, 2010). Wilson, Hargreaves, and Hauxwell-Baldwin (2014) provide three different views of Smart Home Environments:

i) **Functional View:** Smart Home Environments are seen as extending and integrating the functionality already provided in homes, by a range of information and communications technologies (ICTs), with the aim of contributing to better living.

ii) **Instrumental View:** Emphasises the potential of Smart Home Environments in helping to achieve energy demand reduction goals, with associated benefits for households, utilities and policy makers.

iii) **Socio-technical view:** Smart Home Environments are seen as the latest, or next episode, in the co-evolving relationship between technology and society. This view emphasises how the use and meaning of technologies will be socially constructed and iteratively negotiated, rather than being the inevitable outcome of assumed functional benefits.

The three views of smart homes discussed above are not sufficient to help fully understand how disabled individuals may benefit from smart homes. The next section introduces Ambient Assisted Living with the aim of addressing this gap.

3.3. Review of Ambient Assisted Living

A smart home environment that integrates components of assisted living may be termed as Ambient Assisted living (AAL). AAL is the use of Ambient Intelligence to extend the time in which elderly and disabled people can live independently in their preferred environment (AAL-Europe, 2013b; Memon et al., 2014). A key term in the definition is Ambient Intelligence (AmI), which was defined in Chapter 1, Section 1.1. Some of the application areas of AmI include: *Education, Emergency Services, Transportation, Hospitals, Health monitoring and assistance, Work places and Smart Homes* (Cook et al., 2009). This review of application areas is limited to Smart Homes, since the main objective of this research is to assist physically disabled individuals in a home environment.

It is important to note that a Smart Home can exist without AmI. For example, consider a home, which has door locks that can be opened and closed remotely using a mobile phone application. Such a home may be referred to as a smart home, but it is not ambient intelligent. An example of an ambient intelligent smart home is one which can automatically open the door for the home owner without him/her explicitly using a mobile phone application.

3.4. Ambient Assisted Living Applications Review

The importance of AAL research that can lead to practical solutions has been recognised by the European Union's AAL Project (AAL-EU). For example, the AAL-EU, and 23 partner countries, sponsored an AAL 6 year programme (2008-2013) with a budget of 600m Euros (AAL, 2013). Some of the successful projects from the AAL-EU project that can assist the physically disabled, are discussed below (AAL-Europe, 2013a)**:**

i) **CapMouse (LipIt):** Helps the physically disabled interact with technology. The project was initiated in order to develop a prototype of a hands-free computing device, using a head mounted capacitive sensor controlled by the lips that can be used as an input for a human-machine interface. Worn on the head, the device has the capability to help someone with activities such as: controlling a wheelchair, and opening doors. The project has been funded in excess of 2m Euros since 2006, and it is not yet available on the mass market. This shows how expensive AAL projects can be, and how mass market adoption is not guaranteed. The use of lips as an interaction technique is innovative, as some disabled individuals may have limited hand use.

ii) **Domeo:** The project was designed to introduce assistive robotics into the domestic sphere. The project successfully created two pilot devices (RobuWalker and RobuMate), extensively training them in the homes of older adults and generating positive feedback. RobuWalker physically interacts with users to improve their mobility, and can help them stand up, walk and sit, as well as monitoring their vital signs and transmitting this data to the emergency services, if required. RobuMate, links people with the outside world, providing them with entertainment and also cognitive assistance to remind them of appointments, scheduled communications, or the time they need to take their medication. Domeo was launched in 2009, and has been funded in excess of 2m Euros.

iii) **Follow Me:** Enables individuals not to miss a TV programme when they are moving around their home. For example, consider an application that is being displayed on the TV in the living room, where the user is. When the user moves to another room, e.g. the kitchen, the application "follows" the user and is displayed on a screen in the kitchen, while faded out on the TV in the living room.

iv) **Help Me Outdoors:** Enables a caregiver to monitor an elderly person. For example, an elderly person is out walking in the street with a mobile phone that is running the Help Me Outdoors application. The device sends real time information of the location to his PC at home. His caregiver can login remotely to his home PC with a web browser to see whether the person has left home, and if he is in a safe area, or not.

AAL may assist with the challenges faced by the physically disabled, and hence reduce their dependency on personal assistants. The next section reviews various AAL frameworks to gain a better understanding of how to design AAL applications.

3.5. Ambient Assisted Living Frameworks

System modelling and implementation of AAL systems is mostly led by the use of frameworks, architectures, and open source solutions. Memon *et al*., (2014) identify two of the major frameworks and architectures for AAL as: *UniversAAL and OpenAAL.* The subsections below contain reviews of each of these frameworks.

3.5.1. UniversAAL

UniversAAL is a European research project with the goal of building a consensus among the AAL community and consolidating their efforts to produce technically feasible and economically affordable standardized AAL systems. The main components of the domain-specific models in the UniversAAL platform consist of (see Figure 3-2):

i) ***AAL services***: Software artefacts that address a specific need in an AAL Space (e.g. home, car, hospital etc.).

ii) ***Network artefacts:*** Gadgets that implement or contribute to the implementation of AAL services, e.g. sensors.

iii) ***AAL spaces***: Provides AAL services with the help of embedded networked artefacts, e.g. Home, car or hospital.

iv) ***AAL Reference Architecture***: Identifies the basic building blocks necessary for constructing an AAL space.

v) ***AAL platforms****:* Implements the AAL Reference Architecture in order to provide for resource sharing and let users experience an integrated world based on natural communication, and facilitates the cooperation between Networked Artefacts distributed in an AAL Space.

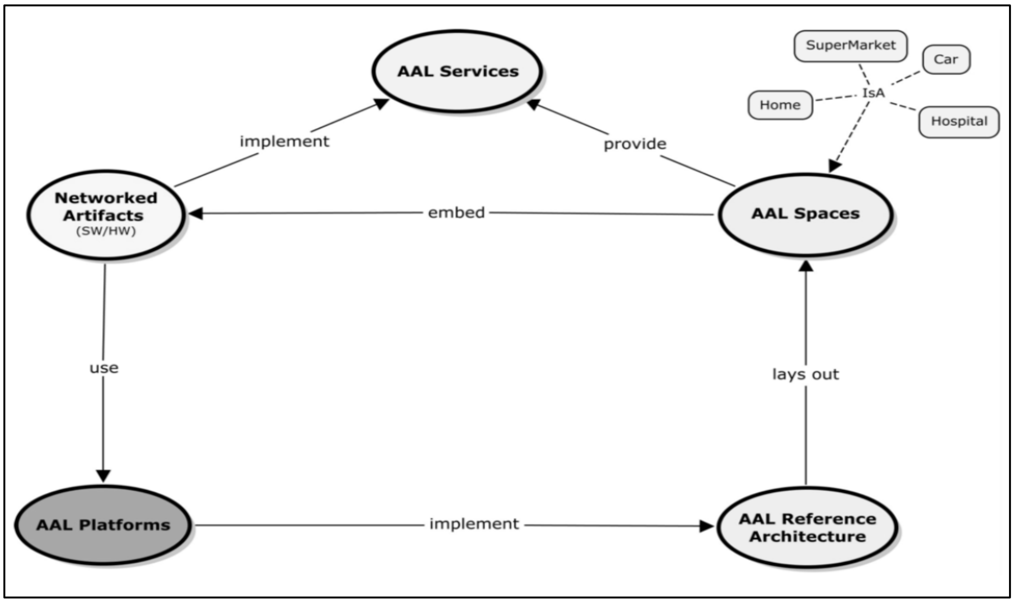

Figure 3-2: UniversAAL concept map (Tazari, Furfari, & Valero, 2012).

Tazari et al. (2012) provide concept maps for each of the details in the root concept. Figure 3-3 illustrates the various components of an AAL service. The AAL service helps in providing assistance to an individual who needs it (physically disabled in our case).

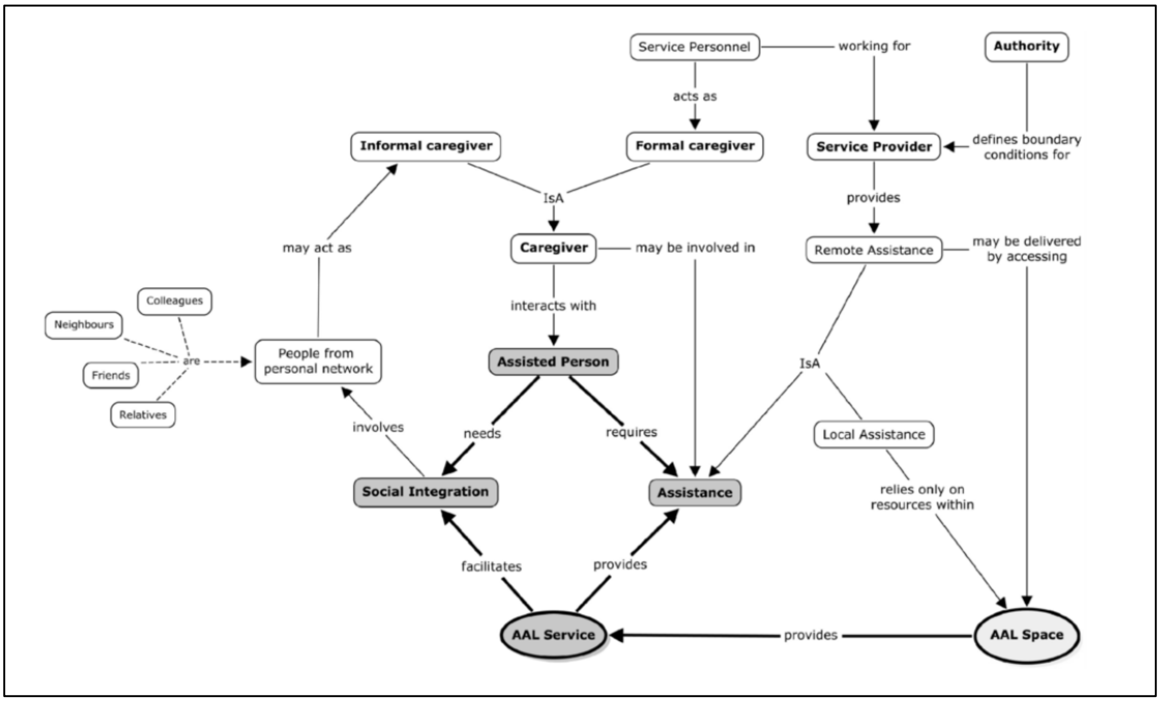

Figure 3-3: AAL Services-Domain specific context (Tazari et al., 2012).

Figure 3-3 illustrates how the various components of the UniversAAL framework may be used to the benefit of a disabled individual. A caregiver may be described as either informal (relative), or formal (care-home), and may use technology to provide assistance such as helping a disabled person to communicate with their friends.

UniversAAL provides a set of software development tools that aim to assist developers in developing AAL services. UniversAAL has community support built around the concept of uStore, a shop where end users (elderly and their care providers) can find complete AAL services, including all necessary software, hardware and human resources. Although UniversAAL was primarily developed with a focus on the elderly, it is a generic framework, which may be used as a basis for providing AAL services for disabled individuals.

3.5.2. OpenAAL

The open source middleware for ambient-assisted living (OpenAAL) is an ontology-based middleware for AAL scenarios. It lays the foundation for an AAL service market ecology in which different market participants can contribute in ways such as (Wolf, Schmidt, Otte, Klein, Rollwage, & König-Ries, 2010):

i) Software developers can develop new methods to analyse sensor-level data and detect situations, e.g., for activity detection, and plug into the Context Manager.

ii) Healthcare consultants can develop system workflows for an adequate system reaction to certain situations, based on the domain knowledge.

iii) Care providers can configure the system behaviour by activating and deactivating procedures, and by providing information about preferences and impairments of the assisted person(s).

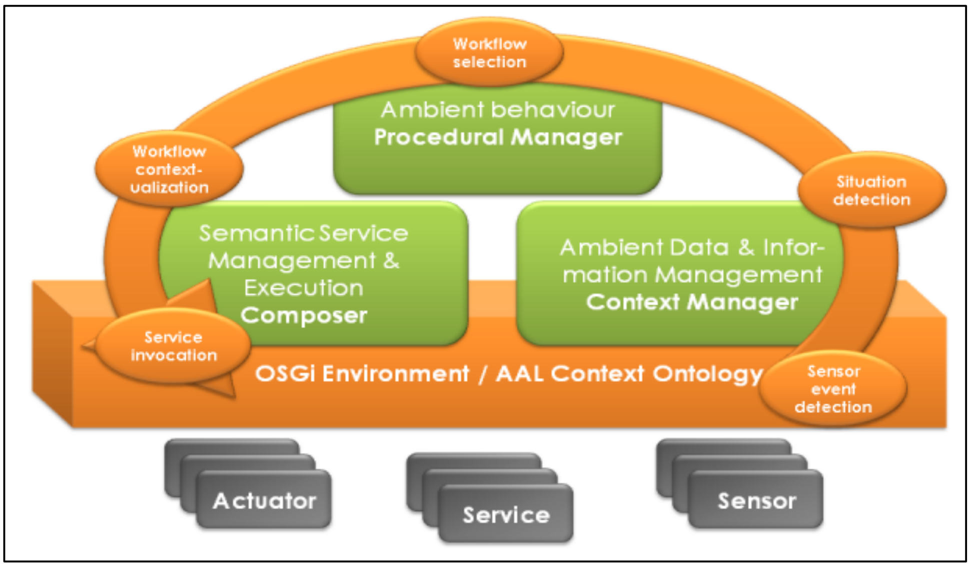

Figure 3-4: OpenAAL middleware (Wolf et al., 2010).

Figure 3-4 illustrates the OpenAAL middleware. Below is a description of the key components in the middleware:

i) **The Context Manager**: Provides an ontology-based information storage that captures sensor information and user input. Internally, a blackboard architecture facilitates the use of different algorithms to derive situations of interest based on procedural rules, logical reasoning, or Bayesian networks.

ii) **The Procedural Manager**: Manages and executes easy to define, and installation independent workflows, which react to situations of interest. In general, these workflows define the system's reaction to certain situations as identified within the Context Manager, and can be defined to automatically resolve critical situations, or inform a responsible person. Workflow specification should be done collaboratively by people with extensive general knowledge about the AAL domain, and people who share the life of the assisted person(s).

iii) **The Composer**: Analyses services, which are available in a certain installation and selects and combines those services to achieve the (abstract) service goals as outlined within the Procedural Manager.

OpenAAL v2.0 is based on UniversAAL, which was discussed earlier. Unlike UniversAAL, the documentation about OpenAAL was last updated in 2012, and there is limited community support for software developers and researchers.

3.5.3. Discussion

OpenAAL and UniversAAL were initiated and implemented between 2005 and 2012, and aimed to make it easier to bring AAL services to individuals. They partially achieved this by proposing AAL frameworks. The AAL frameworks are generic in nature and hence can be modified as needed, and also used to build AAL services that address unique challenges faced by the physically disabled. The next section provides a detailed review of the UniversAAL Framework.

3.6. UniversAAL Framework

One of the components of the UniversAAL framework is the platform component. This section discusses the various components of the platform in detail. A platform refers to the hardware and operating system that is used to run UniversAAL.The Middleware is the core part of Universal AAL (uAAL) platform, and ensures that all uAAL nodes in a Space can cooperate and communicate with each other (UniversAAL, 2015).

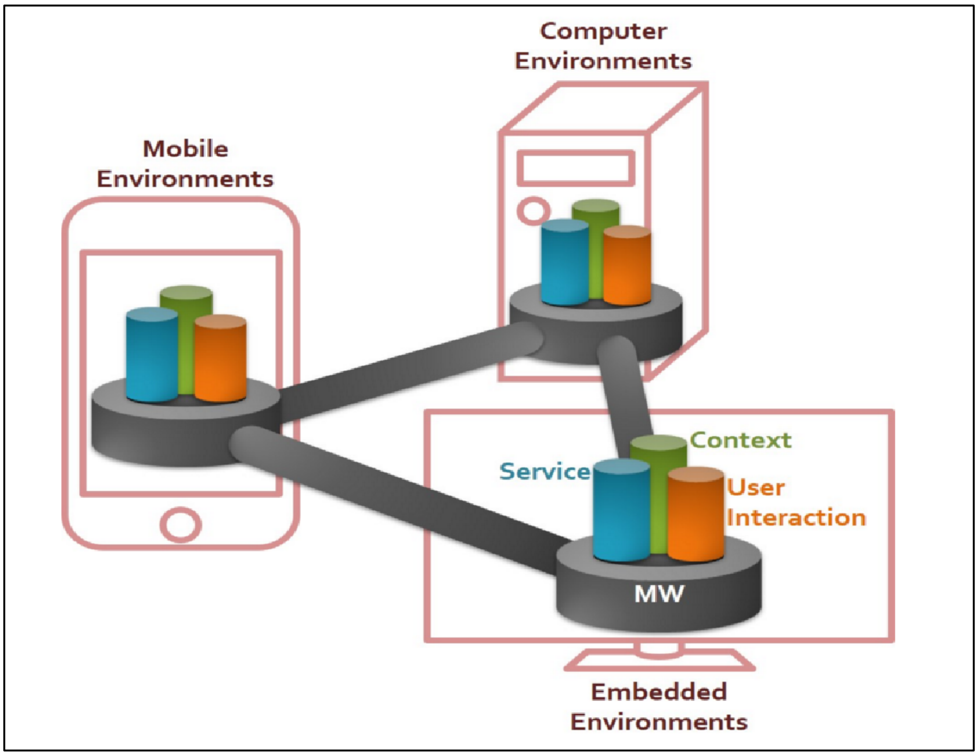

Figure 3-5: UniversAAL Middleware (UniversAAL, 2015).

Figure 3-5 illustrates the UniversAAL middleware. Knowledge is shared in uAAL in the form of ontologies. Ontologies are a way to represent real-life information so it can be understood by computers, and may be described as a network of concepts linked by properties. Below is a discussion of the different types of communication techniques used in the UniversAAL middleware.

3.6.1. Service

Services are request/response interactions between applications. They are semantic, which means that you don´t need to call a service like "turn on a light by ID", which you can, but you can ask for services that "turn on all lights in a given location", without knowing them in advance. This is possible because services are described with the Ontological model.

3.6.2. Context

Context information represents the environment of the system, from physical surroundings, including users, to system information. Context communication is event-based, forwarding updates of the context. This is done in the form of Context Events, which are sent by Context Publishers, and can be consumed by Context Subscribers.

1. **Context Events:** Are the minimal units of context information sharing, and are built on the Ontological model of uAAL.

2. **Context Publishers:** Are applications that are capable of sending Context Events. They build these events with the Ontological model and broadcast them.
3. **Context Subscribers:** Are any applications that are interested in consuming Context Events. They define a filter to restrict which types of events they are interested in.

Accurate contextual information about a disabled individual can improve the usefulness of software artefacts for disabled individuals.

3.6.3. User Interaction

Direct User Interaction is achieved by uAAL applications in a decoupled fashion. UAAL applications do not handle how this information is presented to the user, only what is being presented (and handled in return). To do so, the interaction information is abstracted by representing it with an Ontological model.

1. User Interaction Callers: Are the applications that want to have some kind of direct interaction with the user. They build a form that represents exactly what they want to show to the user, and what they want in return. Forms are the ontological representation of the typical user interaction components, like textual inputs, multiple selections, buttons, and so on. Forms are created by UI Callers and sent to UI Handlers to be rendered, filled by the user, and sent back to UI Callers to be processed.
2. User Interaction Handlers: Are special types of applications in charge of translating the forms sent by UI Callers to a physical rendering that a user can interact with, such as a GUI, a sound output, or a web page. They interpret the user responses to fill in the information requested by UI Callers into the Form, and send it back. There can be several UI Handlers in different locations, with different modalities, and the UI Callers are oblivious to them, thus achieving multi-modal and multi-location interaction.

For disabled individuals, various types of user interaction handlers might be necessary, depending on the functional capabilities of the intended user. That is, an individual without hands can benefit from voice user interaction.

3.6.4. AAL Space

The concept of an AAL space (Smart Environments centred on human users) was introduced in Section 3.5.1. The devices embedded in such environments operate collectively using information and intelligence that is distributed in the infrastructure connecting the devices. AAL Spaces are classified in space profiles, each identifying the typical set of devices used in a specific AAL scenario. UniversAAL distinguishes between private space profiles, such as homes, versus public space profiles, such as supermarkets (Furfari, Tazari, & Eisemberg, 2011).

3.7. Example Applications of the UniversAAL Framework

The UniversAAL platform consists of three main parts: runtime support, development support, and community support. Runtime support is a software environment that provides core AAL services for the execution of AAL applications. Development support includes documentation, tools and an online developer depot of various development resources. Community support includes training, and an online uStore, providing a one-stop shop for AAL services and applications (UniversAAL, 2010).

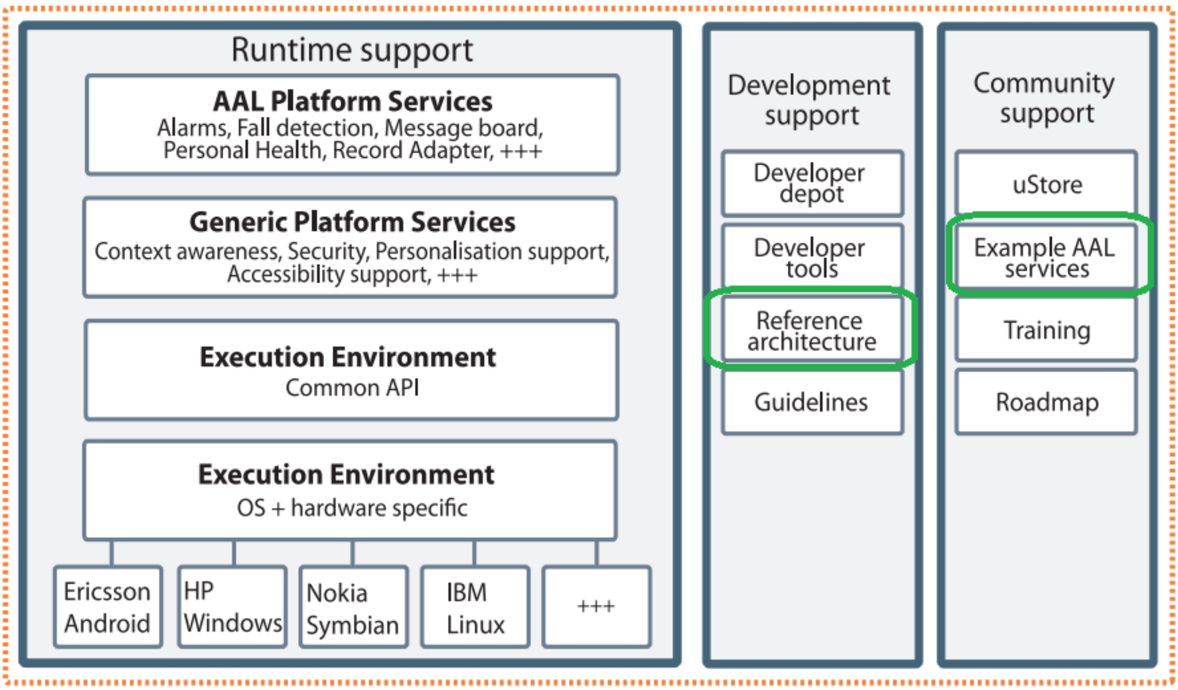

Figure 3-6: UniversAAL Platform (UniversAAL, 2010).

Figure 3-6 illustrates the various components of the UniversAAL Platform. The UniversAAL platform provides more than ten examples of AAL services (UniversAAL, 2014). The instantiation process from a Reference Architecture (RA) to a Concrete

Architecture (CA), includes the identification of necessary components and their responsibilities, interactions, control and data flow. The instantiation process also identifies the non-functional architectural concerns such as security, reliability and other crosscutting concerns. The instantiation process includes the following possible steps (Guillén, 2014):

- Identification of specific stakeholders for the target Concrete Architecture;
- Identification of specific interconnection and interaction among the stakeholders for the target Concrete Architecture;
- Identify/learn of reference use cases and stakeholders' interest;
- Designation reference architecture services using the mapping with reference use cases and high level requirements;
- Decomposition of services for Concrete Architecture;
- Atomization of the component model for Concrete Architecture;
- Concrete deployment scheme for Concrete Architecture;

Stakeholders are the people/organisations involved in AAL, and how they relate to some of the concepts introduced in the UniversAAL reference architecture (AAL Spaces, AAL Platform, Network artefacts and AAL services). Stakeholders may include:

- **End users**: A non-technical group of AAL community members that directly benefit from AAL Services, e.g., Assisted Persons, Professional Caregivers, Informal Caregivers (such as friends, neighbours, and family members).
- **AAL Service Providers**: Organizations that provide AAL Services to the end users by combining and publishing the resources provided by Developers.
- **Developers**: People with technical skills in the design, production, testing and deployment of computer software and associated hardware (computers, sensors, actuators etc.) needed to provide AAL Platforms and AAL Services.
- **Deployers**: People with technical skills, responsible for installation, configuration, customization, and maintenance of integrated AAL solutions.

The next section discusses examples of applications based on the UniversAAL framework, with the aim of showing the usefulness of the framework.

3.7.1. Personal Safety

Personal Safety is an AAL service that detects risky situations of an elderly person when they are at home, and act accordingly: local communication of the risk and remote communication of the risk. It will handle falling situations, by validating the event perceived by the system before alerting health insurance, emergency services, and relatives. This service also allows the user to intentionally request for help in case of an emergency (UniversAAL, 2014).

Stakeholders and Benefits Derived

- UniversAAL end users: Assisted persons/Elderly Informal caregivers/Family Members-Relatives. Benefits: The aim of the system is to maintain the safety of the inhabitant. To this end it is able to detect if user activity is absent for a long period of time. As a result, an alarm can be raised to a third party using the most appropriate interaction technique.
- UniversAAL Service providers: e.g. deployers, and assistance providers (Care service providers, Hospitals, Nursing homes). Benefits: The remote provision of this kind of service increases the efficiency of the management of the assistance services and their automated management, by setting a set of personalized rules and procedures.
- UniversAAL Developers: Application developers, IT developers, Monitoring device developers, Middleware service developers and Researchers. Benefits: The provision of clear and open standards in the AAL world will promote the development of new and better service components for monitoring vital signs of chronic patients, data mining and analysis.

Use cases

The following use cases have been taken into consideration:

- **UC1 Detect Risk Situation**: The system detects a risky situation, or abnormal behaviour of the Assisted Person.
- **UC2 Confirm Risk Situation**: The system asks for confirmation about the risk situation to the AP locally.
- **UC3 Notify Risk Situation**: After the risky situation is confirmed, the system alerts the informal caregiver sending a SMS.
- **UC4 Compile Activity Information**. The system stores and processes the AP’s activity information.

- **UC 5 Access Activity and Alert Report**.
- **UC6**. Configuration and personalisation.
- **UC7**. Message delivery.

Components of the Personal Safety AAL Service

The main modules of the Personal Safety service are the Report Manager, Risk Manager, Timed form, and several Data Bases, that contain the data necessary to provide intelligence to the service: Strategies Rule, Activity Rule, Device Rule, Risk Data and Risk Rule.

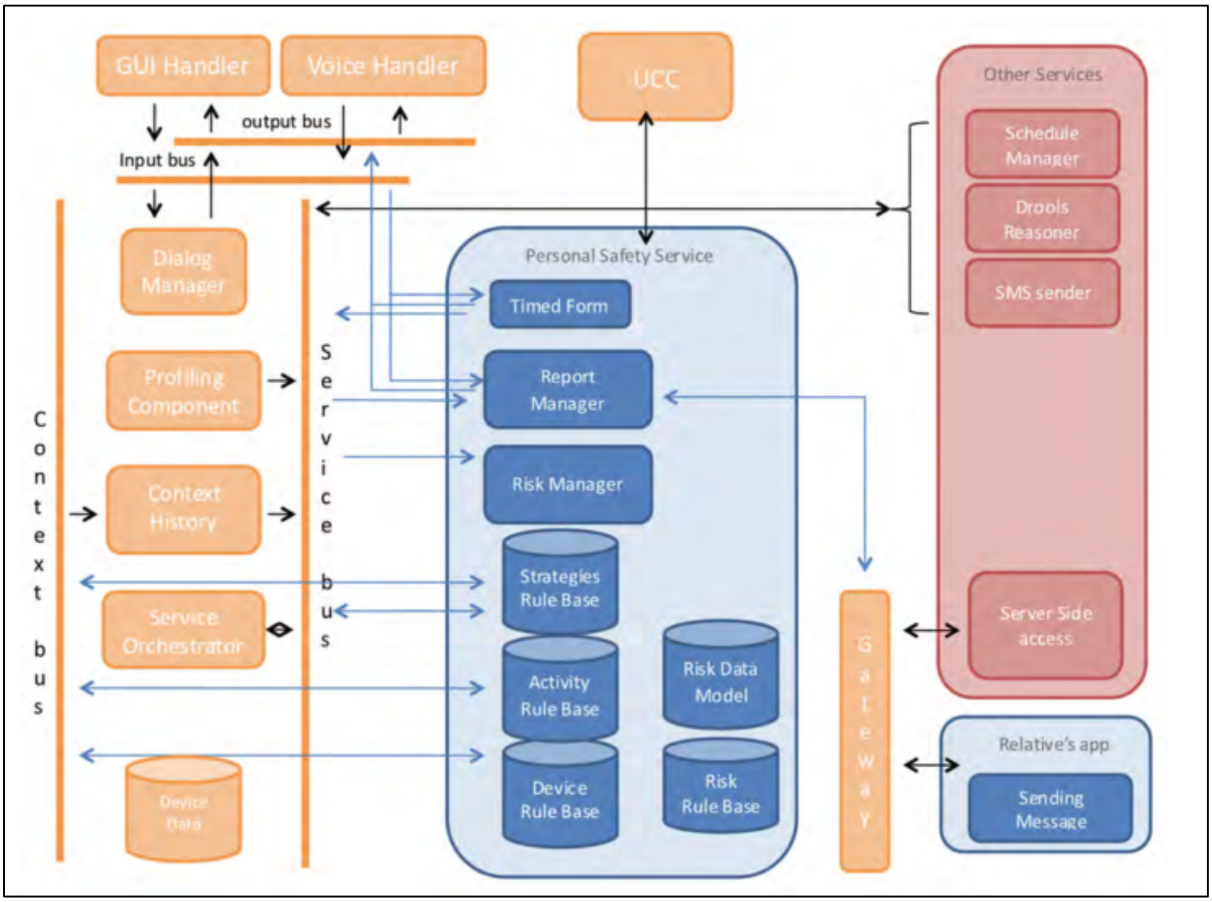

Figure 3-7: Personal Safety AAL Service Concrete Architecture (UniversAAL, 2014).

Figure 3-7 illustrates the Personal Safety Service components, UniversAAL platform components, and other service components. A discussion of the various components is given below:

- User interaction and its adaptation are achieved by means of the UI Framework and the AAL Space Gateway. The UI Framework is able to translate inputs and outputs for the assisted person at home, adapting these inputs and outputs to the user behaviour and situation, while the AAL Space Gateway serves as the entry point for the formal caregiver, using a web-based application, or any other commercial application, and for other external applications. It is assumed that proper identification and security measures are implemented within the AAL Space Gateway.

- The Dialog Manager is used as a kind of an intermediate dealer between user and Personal Safety components, when standard dialogs are involved. It is also used when an assisted person requests interaction with the system.
- The Personal Safety AAL Service makes use of the Profiling component from the UniversAAL platform, whenever the Health and Personal Profile information is needed
- Drools Reasoner, a business rules management system, is used to generate events. Events triggers come from ambient sensors in an AAL Space.
- Service Orchestrator is the component that executes formal workflow descriptions connected to rule management system to execute the appropriate steps once a certain alert is detected. The business logic of the service mostly relies on the workflow.

The discussion above explains how the UniversAAL framework can be used to design practical solutions.

3.7.2. Medication Manager

The Medication Manager aims to assist patients in the timely taking of their prescribed medications. The service features an internal schedule for management of the intake time. This schedule could be accessed remotely by authorized caregivers (doctor), or locally over the available AAL Space user interface. Bearing in mind that the assisted person could be distracted by some activity (watching TV, listening to music loud etc.), the system will issue reminders that are presented in an appropriate manner to capture attention (e.g. by pop-up message on the TV if the patient is watching TV). The Medication Manager Service keeps track of the inventory of available medications and issues a warning in case of insufficiency. The service is able to advise unscheduled intake of medication in case of urgent situations reported by the Health Manager.

Components of the Medication Manager AAL Service

Figure 3-8 illustrates the main components of the Medication Manager.

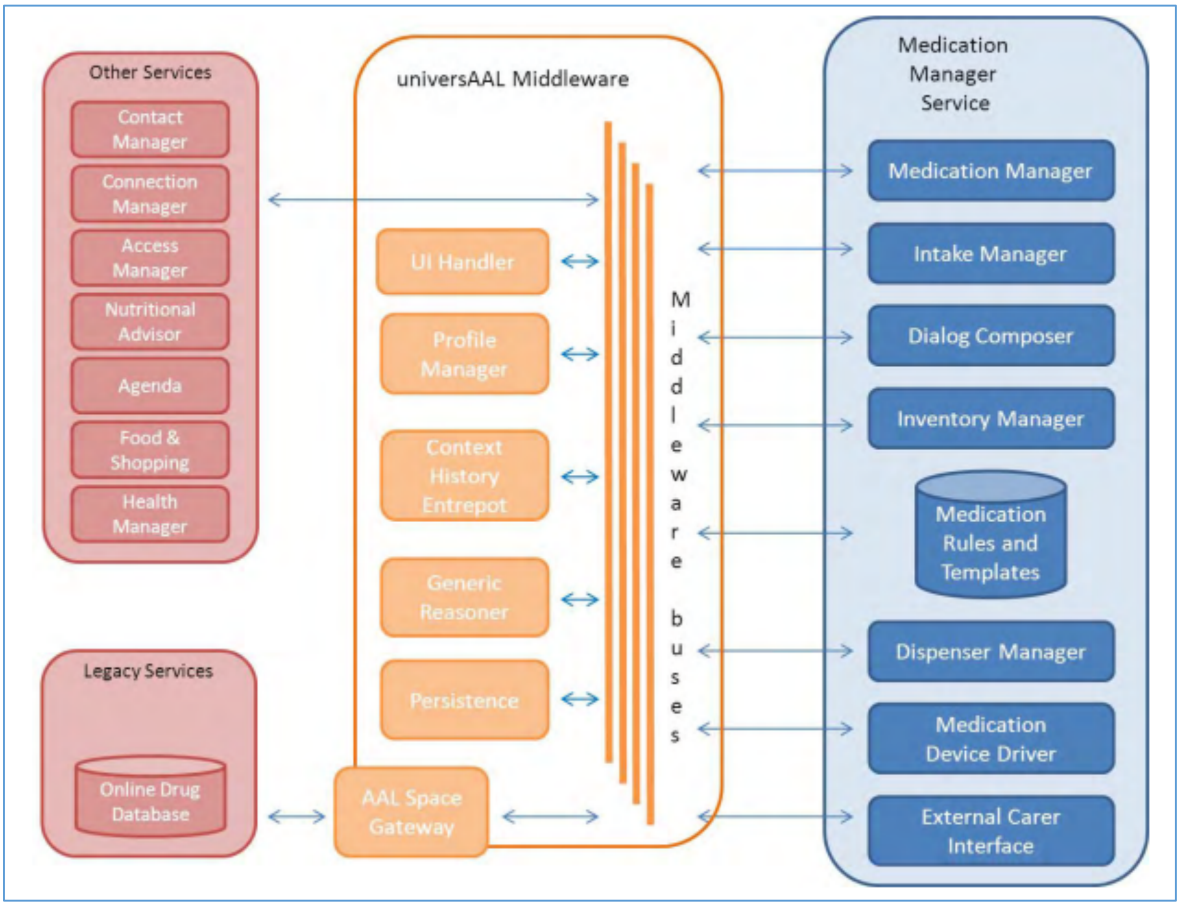

Figure 3-8: Medication Manager AAL Service Concrete Architecture (UniversAAL, 2014).

Proper, and confidential handling of the medications offered to the assisted person, is critical. The patient is able to decide who is going to have access to his medication data and configure the access properties for doctors and relatives. The Medication Manager Service consists of local (deployed on the AAL platform) and remote components as follows:

- The Medication Manager implements the business logic of the Service. It is the component that executes the workflows and acts as interface to the other components of the Service.
- The Intake Manager handles the intake plan (when/ what medicine should be taken). It can operate with, or without, a pill dispenser.
- The Dialog Composer takes care of the composition of the proper message content for end-user dialogs. It dispatches this content to the UI Handler.
- The Inventory Manager keeps track of the acquired and consumed medicine. It can operate with, or without, a pill dispenser. Upon receipt of a new prescription, or

modification, it decides if the available quantities are sufficient and, if needed, triggers the process for acquirement of new medicine.

- The Medication Rules and Templates component provides a means for creation and management of internal rules. For example, notification rules (who, and under which conditions, will be notified upon certain identified risk). It should assist and support the decision taking.
- The Dispenser Manager communicates with the pill dispenser. It identifies the device and its functionality. It represents the device to the other components.
- The Medication Gateway represents the Medication Manager Service to components and functional entities out of the current AAL Platform. The Medication Device Driver provides basic communication with the pill dispenser.

Other examples of AAL services based on the UniversAAL framework are: Health Management, Nutritional Advisor, Agenda, Help when outdoors, Long Term Behaviour Analyser and Medication Manager, which all follow a similar design process.

3.7.3. Discussion

Figures 3-7 and 3-8 illustrate two different AAL services that are built using the UniversAAL framework. The AAL services are *Personal Safety,* and *Medication Manager*. The personal safety AAL service (Figure 3-7) makes use of the context and service bus components from the UniversAAL framework in order to fulfil its main aim, which is to detect risky situations of an elderly person in a home environment, and act accordingly. The medication manager AAL service (Figure 3-8) also makes use of the context and service bus UniversAAL components to fulfil its main aim, which is to assist patients in the timely taking of their prescribed medications. The two AAL services (Sections 3.7.1, and 3.7.2) make use of the same UniversAAL framework components to fulfil different requirements.

The choice of which UniversAAL components to use for a given AAL service, and how to use them, should be motivated by the AAL service requirements. UniversAAL may be used as a tool to guide technology decisions when designing technological solutions for assisted living. However, it may also be used as a technological foundation for innovative solutions.

3.8. Conclusions

Disabled individuals who require assistance with activities of daily living may receive this assistance in either a care home, or in their personal homes. The choice of caregivers usually depends on the financial status of a disabled person. Those who can afford to, often make use of paid personal care assistants, while those who cannot afford to, make use of relatives and friends.

The research objective of this chapter was: "*To understand the concept of Assisted Living and explore assisted living technologies that can benefit disabled individuals*". This objective was addressed by:

1. Defining the concept of assisted living; and
2. Identifying the UniversAAL framework as a suitable guide for reviewing and designing assisted living technologies for disabled individuals.

The UniversAAL framework provides a conceptual way of thinking about various technologies that may assist disabled individuals in an assisted living environment, and identifies the most suitable technologies for a given task. Solution design using the UniversAAL framework assumes a clearly defined problem with various interested stakeholders. Chapter 2 identified some of the challenges that are faced by physically disabled individuals in a home environment. These challenges lack contextual information, however, as to how disabled individuals experience and cope with these challenges. The next chapter reports on the findings of interview studies done with disabled individuals that were carried out with the goal of identifying requirements for this research study.

Chapter 4: Interview Study to Identify Challenges Experienced by Physically Disabled Individuals

4.1. Introduction

Some of the challenges experienced by physically disabled individuals were discussed in Chapter 2, and a review of support aids that may be used to improve the quality of life of disabled individuals were also discussed. Chapter 3 discussed the concept of assisted living. A review of some of the assisted living technologies that may benefit disabled individuals was carried out. A key aspect identified from Chapter 3 is the need to have a clearly defined set of requirements, and stakeholders when designing assisted living solutions.

Conditions in the developing world may provide distinct challenges for disabled individuals. For this reason, it was deemed necessary to investigate how individuals experience the challenges discussed in Chapter 2 in Sub-Saharan Africa, and to learn how they currently cope with these challenges. This chapter addresses Research Objective 3 (RO3) which is: *To identify the challenges faced by disabled individuals in a home environment that can be addressed using ICT.* RO3 was addressed by carrying out interview studies with disabled individuals and their personal assistants. The findings from the interview studies were used to identify the functional requirements for this study.

4.2. Interview Method

Interviewing is a prominent data collection tool in qualitative research. It is a good way of accessing people's perceptions, meanings, and definitions of situations and constructions of reality (Punch, 2009). While interviews involve asking questions and receiving feedback, they may have been organised and carried out in a number of different ways. Below is a discussion of the different types of interviews:

1. **Structured Interviews:** Interview questions are standardized in advance. Respondents are asked a series of pre-established questions.
2. **Unstructured Interviews:** Interview questions are not pre-planned and standardized, but instead general questions are used to start an interview going. Specific follow up questions will then emerge as the interview unfolds.

3. **Semi-structured interviews:** Involves a list of questions relating to specific topics that are to be covered. The questions may be referred to as the interview guide. The interviewer has an opportunity to explore particular themes or responses further (Bryman, 2008).

Semi-structured interviews are ideal if you are beginning the investigation with a fairly clear focus, and the desire is to discover more specific issues related to a subject. Semi structured interviews were conducted with both disabled individuals and their personal assistants.

4.2.1. Participant Selection

Participant selection in qualitative research is purposeful. Participants are selected who can best enlighten the interviewer about the research questions and enhance an understanding of the phenomenon under study. A sample size is sufficient when additional interviews, or focus groups, do not result in identification of new concepts, an end point called data saturation. To determine when data saturation occurs, analysis ideally occurs concurrently with data collection in an iterative cycle. This allows the researcher to document the emergence of new themes and also to identify perspectives that may otherwise be overlooked. The sampling method employed was purposive sampling; this involves selecting cases that will best enable the research question to be answered, or objectives to be met. Eighteen disabled individuals, and 12 personal assistants were interviewed. The interviews were conducted in two different African urban cities namely: Kampala, Uganda, and Port Elizabeth, South Africa. The two countries were selected because of the different levels of support that they offer disabled individuals. South Africa offers a disability grant, whereas Uganda does not (Abimanyi-Ochom & Mannan, 2014).

4.2.2. Data Collection and Analysis

As mentioned above, primary data was collected through interviews with 18 disabled individuals, and 12 personal assistants. Table 4.1 lists the interview questions for disabled people.

Table 4-1: Interview Questions for Individuals with Physical Disabilities.

#	Questions for Individuals with Physical disabilities
1	What challenges do you deal with on a daily basis, and how do you cope with them?
2	What support aids do you normally use, and how do you use them?
3	What are some of the limitations of the support aids?
4	How would you address some of the limitations of these support aids?

The four interview questions were supported with probing follow up questions in order to obtain more information from the participants in situations where they gave brief responses to the main questions (Table 4-1). An audio recorder was used to record the interviews. Ethics clearance for the interview studies was obtained from Nelson Mandela University (Appendix A-1), and each of the participants signed a consent form before participating (Appendix F). The interview questions were limited to activities carried out in living room and kitchen environments. This was done so that participants did not have to share experiences that might have made them feel uncomfortable. Table 4-2 lists the interview questions put to the personal assistants. Four interview questions were formulated, and probes used to get more information from the participants.

Table 4-2: Interview Questions for assistants to Individuals with Physical Disabilities.

#	Questions for personal assistants
1	What kind of assistance do you offer physically disabled individuals?
2	How often do you provide assistance remotely, and what technology do you use?
3	What kind of assistance do you offer remotely?
4	What other ways do you think technology can help you to provide better assistance?

The interviews were carried out over a two month period. The interviews were recorded and transcribed. Transcriptions were verbatim. Computer-assisted qualitative data analysis using Atlas.ti version 8 was employed to organize the data and facilitate coding and identification of themes. Table 4.3 provides a summary of the themes identified from the interview studies.

Table 4-3: Research Themes.

Theme	Sub-themes
Personal Care	- Care Home - Care by Family Member/s
Mobility	- Manual support aids - Battery powered support aids
Social and Economic	- Government support - Emotional well being
Communication	- N/A

Personal Care and mobility stood out in both the literature study and interviews as the main challenges facing disabled individuals. A detailed discussion of the interview findings is provided below.

4.3. Ugandan interview Study

Nine physically disabled individuals, and nine personal assistants were interviewed; four of the disabled participants were female, while five were male. All the disabled participants live in private homes and are cared for by their relatives. Five of the disabled participants have spinal cord related injuries. Table 4-4 provides a summary of the disabilities of the participants. Where applicable, the spinal cord injury levels introduced in Chapter 2 were used to categorise participant disabilities.

Table 4-4: Summary of Uganda participant disabilities.

Participant	Disability
U-P1	No lower limbs due to accident (female)
U-P2	L1 Spinal Cord Injury (female)
U-P3	T6 Spinal Cord Injury (male)
U-P4	No Lower Limbs (male)
U-P5	No Lower Limbs (female)
U-P6	Immobile Limbs (male)
U-P7	L1 Spinal Injury (female)
U-P8	L1 Spinal Injury (male)
U-P9	C6 Spinal Cord Injury (male)

U-P1 is unable to climb stairs without assistance; she relies on assistance to get items that she cannot reach, for example, cooking items that are on shelves. She wants a self-drive wheelchair, one she can use without assistance.

U-P2 has difficulty bending to do things such as washing clothes and picking up items from the ground. She does not have any support aids. She said that her life would be made easier if she could get a washing machine and a dishwasher. She currently relies on her teenage daughter for assistance.

U-P3 feels emotional pain and abandoned by his family, since he needs continuous support. He is unable to find meaningful employment. He was a motorcycle taxi operator before he suffered an accident.

U-P4 experiences discrimination by the public, he needs a tricycle, which he can use by himself without assistance.

U-P5 crawls since she has no wheel chair. She relies on her nephew for assistance with activities such as cooking and cleaning.

U-P6 has trouble walking without assistance, he currently uses a crude wooden walking stick. He wants a modern walking stick.

UP-7 cannot walk; she doesn't want a wheel chair, or a walking stick, because she wasn't born lame but became paralysed due to sickness. She experiences discrimination from some members of the public.

UP-8 uses a walking stick; his wife helps him with most of the household activities, so that he does not have to move around unnecessarily.

UP-9 has no wheelchair so he crawls to move about. He would like a battery powered wheelchair so that he can move without assistance. He relies on relatives for meal preparation.

The participants have trouble in moving from one place to another, suffer emotional pain and difficulty carrying out personal care activities. Personal Care and Mobility are two of the challenges identified from literature (Section 2.6.3). The nine personal assistants reported that the primary assistance they provide are related to mobility and personal care.

The interviewer discussed Ambient Assisted Living (AAL) technology with the participants. The participants agreed that AAL services such as turning on/off lights without assistance, and controlling TV sets without assistance, may be helpful to them. They emphasized that their most important needs are support aids such as wheel chairs, walking sticks, prosthetics and battery powered wheelchairs. These would help them to be less reliant on assistance from relatives. They attributed the lack of these essential aids to poverty.

4.4. South African interview Study

Nine physically disabled individuals and three personal assistants were interviewed in Port Elizabeth. Seven of the disabled individuals were male, while two were female. Six of the participants are residents of a disability home, while three are students at Nelson Mandela University. Six of the disabled participants have spinal cord related injuries. Table 4.5 provides a summary of participant disabilities.

Table 4-5: Summary of South Africa participant disability.

Participant	Disability
S-P1	T6 Spinal Cord Injury (male)
S-P2	C5 Spinal Cord Injury (male)
S-P3	C6 Spinal Cord Injury (male)
S-P4	C7 Spinal Cord Injury (female)
S-P5	C6 Spinal Cord Injury (male)
S-P6	C7 Spinal Cord Injury (male)
S-P7	Short limbs due to Polio (male)
S-P8	Cerebral Palsy (male)
S-P9	Short limbs due to Polio (female)

S-P1's lower body is immobile (waist downwards). He uses a wheel chair to move around. He does not want a battery powered wheel chair because he says that it will make him lazy. He drives himself to and from school using a specially modified car. He needs assistance in cooking; he says that whereas he is able to use his arms, they usually become tired because he uses them for everything. He said that he would find it beneficial if he could use voice commands and gestures to interact with electronic devices such as a TV.

S-P2 lives in a disability care home, he is unable to speak clearly. He uses a head mounted device to interact with a computer. He relies on caregivers to assist him with putting on and removing the head gear.

S-P3 is unable to use his phone fully since he has limited control of his hands and cannot press the buttons. He is able to interact with a computer using a mouth stick (UK General

Medical Council, 2007). He needs to be fed by a caregiver. S-P3 complained that he normally uses loud speakers on his phone because he cannot hold the phone to his ears.

S-P4 has difficulty using the phone and also experiences difficulty when using a computer.
S-P5 is unable to use his left hand. He currently uses a manual wheel chair; he would like an electric wheelchair but he cannot afford one. He needs assistance to get out of the wheelchair. He is also unable to cook for himself.
S-P6 is unable to use his hands fully. He says that voice commands and gestures would be very useful. He occasionally uses a tablet computer. He says that tablets are much easier to use because they use gestures, but it takes time and is frustrating.
S-P7 can fully use his hands, but he is confined to a wheelchair due to polio. He uses a picker to pick up items from the ground, but he needs assistance to get items such as books from shelves.
S-P8 is unable to answer his mobile phone without assistance since he cannot hold the phone. He uses special magnifying software on his computer. He says that a voice-operated system would be helpful to him. He uses a custom battery-powered wheelchair, which has a working area (table), where he places his laptop and study books. He needs assistance to get his laptop to and from his work area. He uses a special program, called the GRID (Smart Box Assistive Technology, 2003), to enable him to use a computer.
S-P9 needs assistance to get items such as plates from shelves. She has a wheelchair, but cannot self-propel.

4.5. Discussion of Challenges

It was noted that individuals with the same disability experience similar challenges, but require different levels and types of support. Some of the activities that can be addressed using ICT are:

- Answering a phone call without assistance (S-P2 and S-P8).
- Having a phone conversation without using a loud speaker (S-P3).
- Using a mobile phone or tablet computer without the need to use swipe gestures (S-P6).
- Using a mouth stick to interact with a computer (S-P3).
- Improving the efficacy of a head mounted pointer to control the keyboard of a computer (S-P2).

- Enable individuals to communicate with others, physically and electronically (S-P2).
- Turning lights on or off, controlling a TV and controlling a radio (S-P2 to S-P6).

S-P6 said that: "Head gestures and voice commands will help a wide variety of individuals with disabilities to do small things without assistance". The participants discussed how their support aids help them to be less dependent on others. The Ugandan study revealed that the main challenge disabled people experience is a low quality of life, as they are unable to afford support aids such as wheel chairs and walking sticks. They said that technology support would be good, but would not meet their immediate need for basic support aids. In contrast, the South African participants, having essential support aids, were more positive that AAL could improve their lives.

4.6. Functional Requirements

The challenges identified from the interview studies that could be addressed using ICT were summarised as requirements, and listed in Table 4-6.

Table 4-6: Requirements for the prototype.

#	Challenge in using Technology	Requirements
1	Answering a phone call without assistance	Using a mobile phone
2	Having a phone conversation without using a loud speaker	Using a mobile phone
3	Using a mobile phone or tablet computer without the need to use swipe gestures	Using a computing device, using a mobile phone
4	Using a head mounted pointer to control a computer's keyboard	Using a computing device
5	Facilitating communication	Using a mobile phone
6	Turning on/off lights	Controlling an electronic environment
7	Controlling a TV	Controlling an electronic environment

Using technology was one of the four challenges affecting disabled individuals that were identified from literature. Using technology is a broad term, hence the "using technology challenges" listed in Table 4-6 were categorised into three high-level requirements namely: using a mobile phone, using a computing device, and controlling an electronic environment.

The specific nature of the requirements helped to identify AAL services that meet a specific need of disabled individuals.

Individuals with C5 and C6 injuries have limited control of their arms, and no control of their lower body. Their limited hand use makes individuals with C5 and C6 injuries unable to carry out the activities specified in Table 4.6. Individuals with T6 and L1 injuries have full control of their arms, and limited control of their lower bodies. These individuals can carry out the activities in Table 4.6 without assistance. The scope of this research is narrowed down to focus on assisting C5 and C6 individuals with the requirements in Table 4.6.

4.7. Conclusions

This chapter has answered Research Objective Three (RO3), which is: *To identify the challenges faced by disabled individuals in a home environment that can be addressed using ICT.*

The second stage of the DSR methodology is about outlining an artefact and defining requirements. This chapter has achieved this objective by defining the software requirements for this study. Interaction is a way of framing the relationship between people and objects designed for them, and thus a way of framing the activity of design (Dubberly, Pangaro, & Haque, 2009). Whereas able-bodied individuals are able to freely use their hands to interact with technology using keyboards, computer mice, and swipe gestures, physically disabled individuals may not be able to use these listed interaction techniques. Innovative interaction techniques may need to be considered. For example, UP-9 and SP-2 are both unable to freely use their hands, but they are both able to speak, and also make head movements. One possible interaction technique may include the use of head gestures such as head nod and shake to interact with a computer. Head nod and shake gestures may be easier for UP-9, as compared to SP-9, due to their different injury levels. That is, SP-2 may easily get tired as compared to UP-9, hence making the interaction technique functional, but not ideal for long term use. When designing solutions for disabled individuals, the target beneficiaries should be involved in the design process, because an able-bodied person’s assumptions about how disabled individuals interact with technology, maybe wrong.

The next chapter reviews various interaction techniques that may be used by disabled individuals to interact with software artefacts that implement the identified requirements.

Chapter 5: Interaction Techniques

5.1. Introduction

The fourth research objective (RO4) and the aim of this chapter is: "*To review different interaction techniques that may be used by physically disabled individuals to interact with their environment*". This, specifically with regard to individuals with C5 and C6 spinal cord injuries, as they have limited hand use, but they can make facial gestures and also use their voices. Figure 5-1 illustrates the sections that make up this chapter:

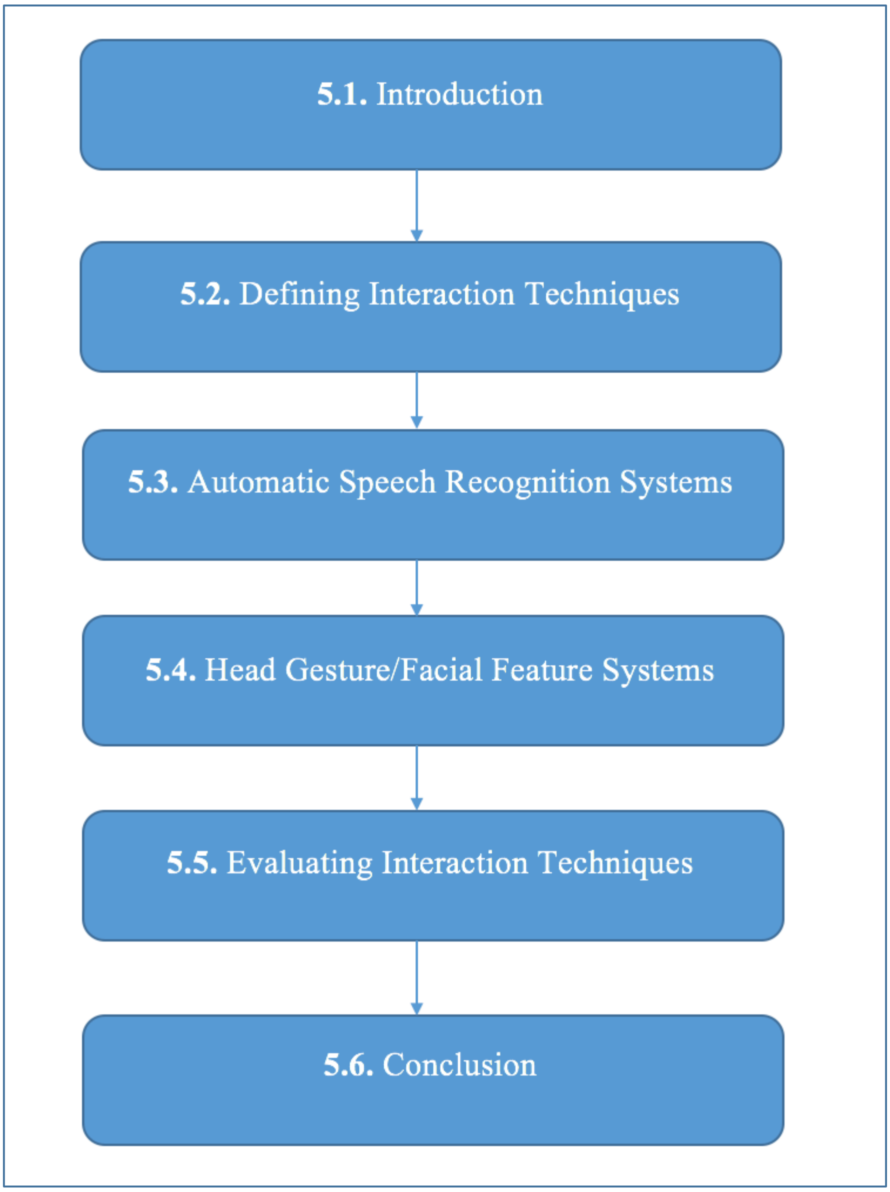

Figure 5-1: **Structure of interaction techniques chapter.**

5.2. Defining Interaction Techniques

Interaction is a way of framing the relationship between people and objects designed for them, and thus a way of framing the activity of design (Dubberly et al., 2009). Interaction techniques fall under two categories, namely: Unimodal communication, and multimodal communication. Below is a discussion of the two categories:

- **Unimodal communication:** Data is communicated between humans and computers through a single mode, or channel e.g., keyboard or mouse input (Karray, Alemzadeh, Saleh, & Arab, 2008).
- **Multimodal communication**: This type of communication leverages at least two or more natural human capabilities to communicate via speech, gesture, touch, facial expression, and other modalities in an interactive way. People naturally connect with the world multi-modally, through both parallel and sequential use of multiple perceptual modalities. Multimodal HCI research has sought for decades to endow computers with similar capabilities (Turk, 2014).

Table 5.1 lists modalities relevant to HCI and some examples. The modalities are closely associated with three of the five classical human senses, namely vision, hearing and touch.

Table 5-1: **Human sensory modalities relevant to multimodal HCI** (Blattner & Glinert, 1996).

Modality	**Example**
Visual	Face location, Gaze, Facial expression, Sign language
Auditory	Speech input, Non-speech audio
Touch	Pressure, Location and selection, Gesture
Motion Sensors	Sensor-based motion capture

The rest of this chapter will refer to the four modalities in Table 5-1, rather than specific examples of a given modality. This will ensure consistent use of the terms during discussions.

5.2.1. Unimodal Interaction

Karray et al., (2008) divide unimodal interaction techniques into three categories, namely: visual-based, audio-based and sensor-based. These three categories are similar to the modalities listed in Table 5-1, hence no new definitions are introduced.

Table 5-2: Examples of unimodal interaction techniques (Karray et al., 2008).

Device	**Category**
Mouse	Input
Keyboard	Input
Joystick	Input
Camera	Input
Speaker	Output
Monitor	Output

Individuals with disability, especially quadriplegia, may not be able to use the devices in Table 5.2 due to limited hand functionality. Innovative devices, such as a head mounted pointer and a mouth stick can allow disabled individuals to interact with computing devices, albeit with difficulty. A unimodal system is one that supports only one modality. Individuals with quadriplegia may experience challenges when using a unimodal system since they have limited hand use.

5.2.2. Multimodal Interaction

The literature on multimodal interaction is categorised into two sub-sections, namely: Automatic Speech Recognition (Section 5.2.2.1) and Facial Gesture Interaction (Section 5.2.2.2). The review is limited to these two categories because of the capabilities of the intended users.

5.2.2.1. Automatic Speech Recognition

Automatic Speech Recognition (ASR) is the problem of deciding: "*how to represent a speech signal, how to model the constraints, and how to search for the most optimal answer*" (Glass & Zue, 2003). A speech signal is the audio that is to be transcribed. The speech input signal can either be an audio stream, or a pre-recorded audio file. Acoustic, Lexical, and language model constraints help to identify the most accurate transcription by narrowing down the word search space.

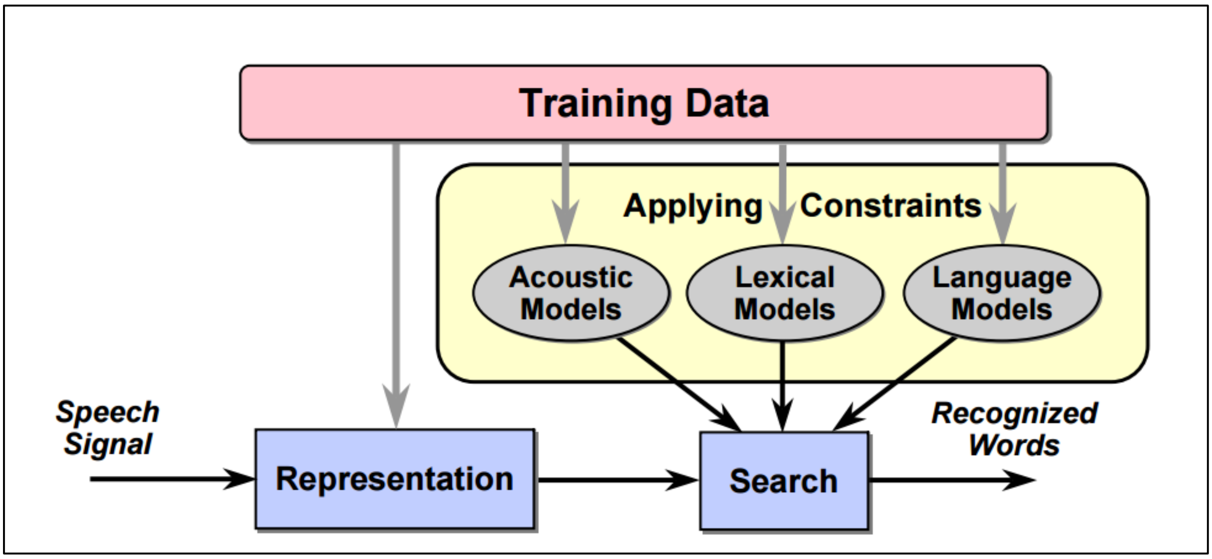

Figure 5-2: Major components in a speech recognition system (Glass & Zue, 2003).

Figure 5-2 illustrates the main components of a speech recognition system which are (Glass & Zue, 2003):

- **Acoustic Model**: Is a statistical representation of sounds which makes up words. Creating an Acoustic Model involves the detection of a spoken phoneme (word uniqueness), and using audio recordings of speech and their text scripts.
- **Lexical Model:** Provides the pronunciation of each word in a given language. A lexical model defines various combinations of phonemes to give valid words for the recognition.
- **Language Model:** Used by ASR systems to search for correct word sequence by predicting the likelihood of the n^{th} word on the basis of the n-1 preceding words.
- **Training Data:** Speaker training data may be used to improve the accuracy of the recognised words. ASR systems are trained from lots of data. A system only trained on short phrases will tend to do poorly on long sentences, and vice versa. A system trained only on strings of numbers, will not work well on strings of letters (Picheny, 2015).

ASR research has been carried out over 50 years, and various authors provide theoretical and mathematical discussions (Furui, 2005; Juang & Furui, 2000). The use of ASR in this research is limited to the implementation of the identified functional requirements. ASR is used as a commodity technology, and hence theoretical and mathematical discussions are kept at a minimum.

5.2.2.2. Head Gesture Interaction for physically disabled individuals

A large part of human body language communication is the use of head gestures and facial expressions. Almost all cultures use subtle head movements to convey meaning (Paggio & Navarretta, 2011). Two of the most common and distinct head gestures are the head nod and the head shake gestures. Much work has been done on head nod and shake detection during the last decade (Davis & Vaks, 2001; Wei, Scanlon, Li, Monaghan, & O'Connor, 2013). The interest by researchers shows the potential role that these gestures can play in enabling disabled individuals to interact with their environments. Below is an example of how other researchers have made use of head gestures:

Non-verbal Communication with a Humanoid Robot

Saleh & Berns (2015), propose an interaction model for facilitating communication between a humanoid robot and a human, both verbally and nonverbally. Head gestures are used as feedback for the robot to adapt the interaction scenario.

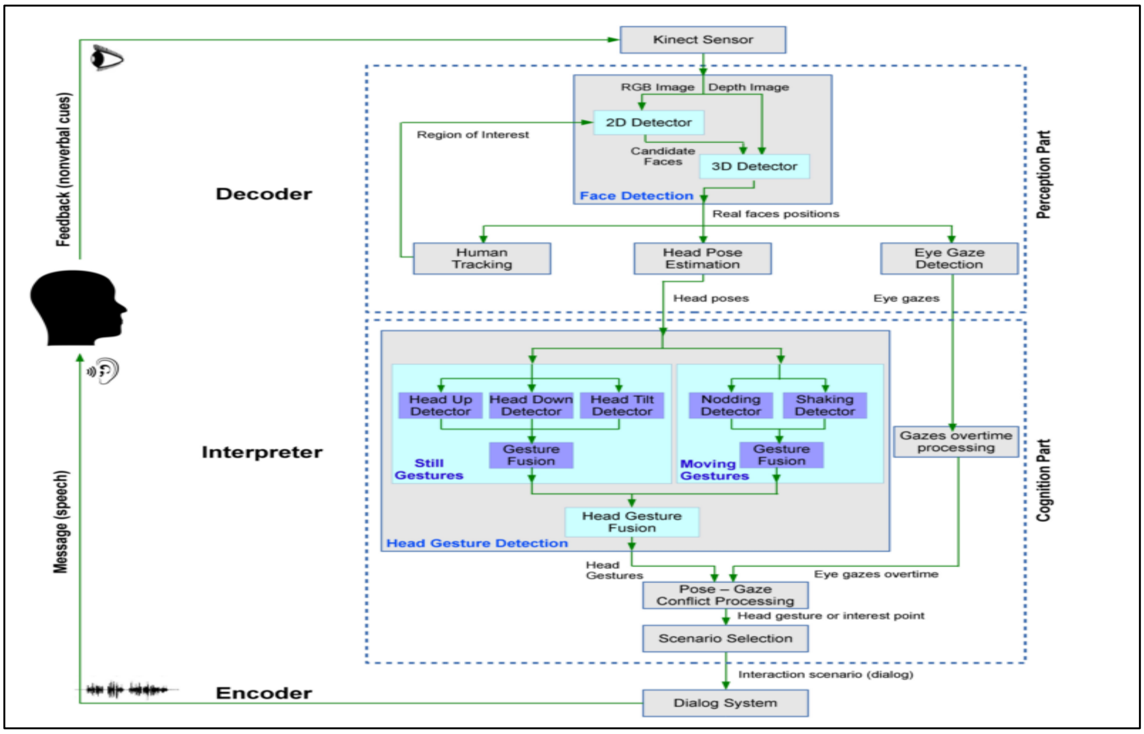

Figure 5-3: **Non-verbal Communication with a Humanoid Robot (Saleh & Berns, 2015).**

Figure 5-3 illustrates the system overview. The system can detect the following gestures:

1. **Nodding**: If the robot receives a nodding signal after a question from the robot, then it will be regarded as a "Yes" answer. If it is received during the conversation and it was slow, then it will be regarded as "I am interested in your talk", or, "I understand you". Fast nodding is interpreted as "finish your talk, it is my turn".

2. **Shaking**: If the robot receives a shaking signal after a question from the robot, then it will be regarded as a "no" answer. If it is received during the robot's talk, then it will be regarded as "I disagree with you", or, "I do not believe in what you are saying". Fast shaking can also be interpreted as "I think that your information is not true".
3. **Head Up**: Signifies a neutral attitude about what is being said. It can also refer to superiority, fearlessness, or arrogance when the head is lifted high.
4. **Head Down:** Signals disapproval, or dejection. It shows that a negative, judgmental, or aggressive attitude exists.
5. **Head Tilt**: Means that the person is quite comfortable and interested in what is being said. It is a positive sign because it means that the listener is in tune with the speaker.

The example discussed in Section 5.2.2.2 shows a real world application of using head gestures to communicate with a robot. A researcher has to assign meaning to each gesture in order to help in processing the responses. Using head gestures in isolation does not provide meaningful information to complete a task. They need to be used with other modalities such as auditory, and touch.

5.2.3. Discussion

People may interact with systems in several ways, some of which are:

- **Fixation:** A user may focus on a point of interest on a computer screen.
- **Navigation:** A user may need to interact with various elements on a user interface to complete a task. Hence, they move between the elements with the help of navigation devices, such as a computer mouse.
- **Confirmation:** The system may prompt a user to confirm an action before it is carried out, such as deletion of an item.
- **Clutch:** A clutch mechanism is required to confirm the intentions of a user in situations when a given command may have different interpretations (A. Wilson & Pham, 2003).

The above interaction types may be used in combination to achieve a desired end result. For example, assume we have a system that detects head gestures (nod and shake). When a user nods his/her head, the system turns on the lights. When he/she shakes their head, the system turns off the lights. A user may shake their head while sharing a joke with friends and the system may incorrectly switch off the lights. One way of overcoming this is by introducing a clutch mechanism, which can be: a user shaking their head while pressing the home button on their phone. This way, the system will be less likely to incorrectly turn off the lights. Wilson & Pham (2003) discuss how clutch mechanisms can be used to enhance the usability of a system.

5.3. Automatic Speech Recognition Systems

Below is a review of various speech recognition systems that may be used to assist individuals with quadriplegia.

5.3.1. Simon

Simon is an open source ASR solution that makes use of the HTK and CMU Sphinx tool kits (Grasch, 2011). Simon provides a unique do-it-yourself approach to speech recognition. Instead of predefined, pre-trained speech models, Simon does not ship with any model whatsoever. Instead, it provides an end-user interface to create language and acoustic models. Additionally, an end-user can easily download use cases by other users and share his/her own. Simon can be used to set up command-and-control solutions, especially suitable for disabled people. However, because of the amount of training necessary, continuous, free dictation is neither supported nor reasonable with current versions of Simon.

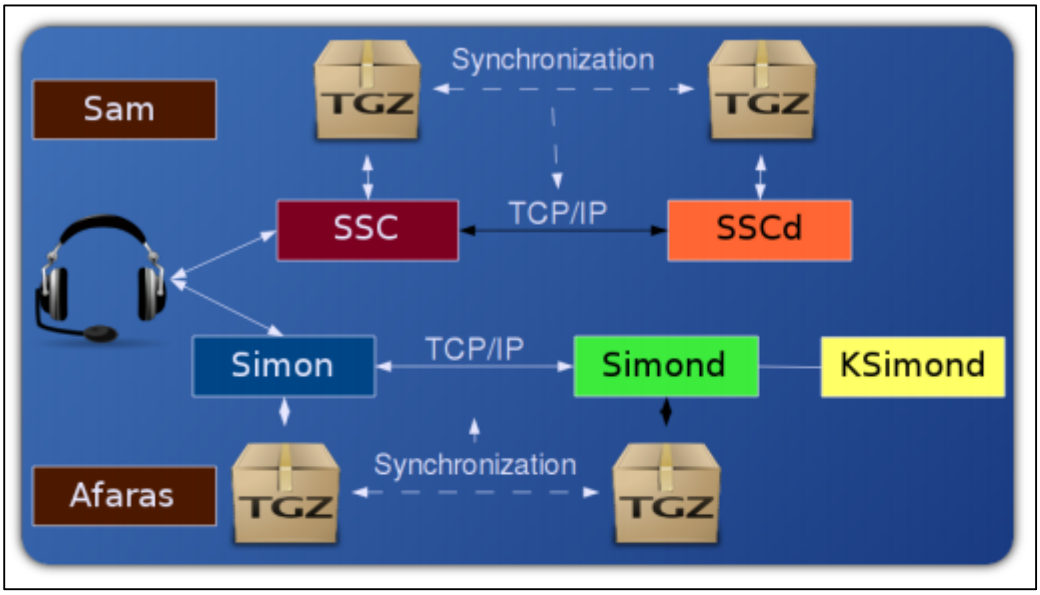

Figure 5-4: Architecture of Simon Speech Software.

Figure 5-4 illustrates the architecture of Simon. The main components are:

- **Simon:** This is the main graphical interface. It acts as a client to the Simond server;
- **Simond:** The recognition server;
- **KSimond:** A graphical front-end for Simond. It adds no functionality to the system, but rather provides a way to interact with Simond graphically;
- **Sam:** Provides more in-depth control to the speech model and allows testing of the acoustic model;
- **SSC / SSCd:** These two applications can be used to collect a large amount of speech samples from different persons more easily;
- **Afaras:** Allows users to quickly check large corpora of speech data for erroneous samples.

Simond identifies its connections with a user/password combination, which are completely independent from the underlying operating system and its users. By default, a standard user is set up in both Simon and Simond, so the typical use case of one Simond server per Simon client will work 'out of the box'. Every user maintains his own speech model, but may use it from different computers (different, physical Simon instances) by accessing the same Simond server.

Simon uses modular software components known as scenarios to carry out specific tasks. Third party developers can create scenarios to satisfy their unique needs. An instance of Simon was compiled for a UNIX desktop computer, and a scenario for controlling a browser (Firefox) was tested.

The Firefox scenario has over 60 commands, but only 4 of these were tested, as shown in Table 5-3. The aim was to get an idea of how Simon functions, and how easy it is to use. Simon was trained to recognize the expert user's pronunciation of the voice commands in Table 5-3. The recognition results in Table 5-3 show that the expert user managed to complete the first three tasks with ease, while he experienced difficulty with the fourth task due to Simon incorrectly interpreting the book marking command.

Table 5-3 provides a summary of the test results by one expert user.

Table 5-3: Results of Simon Firefox browser scenario.

Task	Voice Command/s	Number of attempts	Successful attempts	Success Rate (%)
Opening a New Browser Window	- Window New	20	15	75%
Switching Between Tabs	- Tab Next - Tab Previous	20	17	85%
Zooming In/Out of a web page	- Zoom In - Zoom Out	20	16	80%
Book marking a page	- Book This	20	12	60%

With training, Simon performs relatively well when navigating using a web browser, and may benefit disabled individuals. Setting up Simon, however, is easier for technologically able users.

5.3.2. IBM Speech API

IBM provides a cloud based ASR API that can be used by third party developers (IBM, 2016). An ASR web application that makes use of the ASR API was set up for evaluation purposes (Section 5.5).

5.3.3. Voice Actions

Google provides a speech user interface for Android. The speech interface is known as Google Now. Google allows third party developers to use the speech interface by providing an API named Voice Actions. Table 5-4 lists the operations that are currently supported by the Voice Actions API (Google, 2016a).

Table 5-4: Voice Actions supported operations.

Action Category	Supported Actions	Example Commands
Alarm	Set alarm Set timer	set an alarm for 6 am
Communication	Place a phone call	call mom call 555-5555
Fitness	Start/stop: [a bike ride, a run, a workout] Show heart rate	start a bike ride show heart rate
Local	Book a cab	book a cab
Media	Play music Take a picture	play some music
Open	Open URL Open application	open twitter.com
Productivity	Take a note	take a note to buy groceries
Search	Search using a specific app	search for cat videos on YouTube

Fulfilment is defined as the successful execution of a given user command. Google Now can handle the fulfilment of the actions specified in Table 5-4. However, when a third-party application registers its ability to fulfil a given action, Google Now prompts the user to choose an application, which will handle a given action. The chosen application is set as the default for that given action. Voice Actions on their own are insufficient to enable a disabled person to use a mobile phone independently. For example, a user is unable to answer, reject, or cancel a phone call.

5.3.4. Voice Access

Voice Access is an accessibility application by Google that allows users to control their devices with spoken commands (Google, 2016b). Voice Access was released in April 2016 and is currently still uses beta software. Once started, Voice Access associates a number with each button on the user interface (UI). A user can then say a given number, and a tap event is emulated in the region of that device. Figure 5-5 illustrates such a UI with numbered options. For example: To select the End call button, the user can say any of these commands: “3”, “End call”, “Click 3”, or “Click End call”.

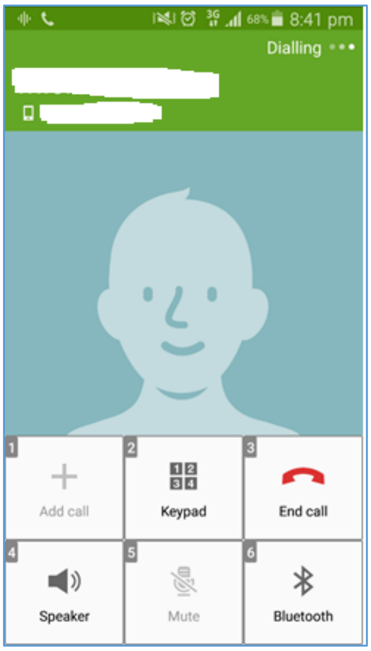

Figure 5-5: Screen illustration of Voice Access.

Voice Access can be used within most applications on the phone. The configuration of Voice Access can be managed from a phone's accessibility settings. The approach of numbering clickable regions helps to address the limited action vocabulary of Voice Actions – not to be confused with Voice Access.

5.3.5. Discussion

Speech recognition is a mature field as shown by the commercial and open source systems discussed, namely IBM Speech API, Voice Access, Voice Actions, and the open source Simon system. As an interaction technique, speech recognition is being used by Apple in iOS, and Google in Android, among other uses. Whereas these implementations may come in handy for able-bodied individuals, and some individuals with disabilities, individuals with quadriplegia may still face difficulty in using them since they require some element of hand use. For example, a user may have to tap on a button in order to start and stop speech recognition.

5.4. Head Gesture/Facial Feature Systems

Three systems are reviewed in this section namely: Camera Mouse (Section 5.4.1), Navigation using a Facial Feature (Section 5.4.2), and Tongue controlled assistive devices (Section 5.4.3).

5.4.1. Camera Mouse

Using a webcam, Camera Mouse tracks the movement of a given body feature in order to control a mouse. A click is made by dwelling on an icon for a certain period of time (Gips & Margrit, 2007). Examples of body features that can be tracked are: nose, finger, or lip. The feature to be tracked is initialized by the user (or caregiver). Figure 5-6 illustrates an example of an initialization screen.

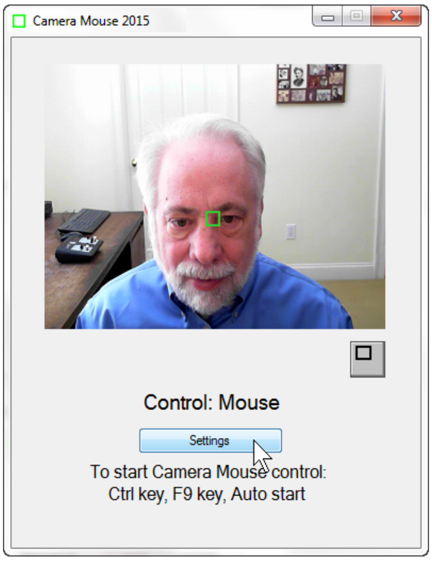

Figure 5-6: **Camera Mouse (Gips & Margrit, 2007).**

When a user selects a feature to be tracked, a square is drawn around the feature and the sub-image within this square is cropped out of the image frame. The cropped sub image is used as a "template" to determine the position of the feature in the next image frame (Betke, Gips, & Fleming, 2002). Camera Mouse was made available to the public in 2007, and has been downloaded over 3 million times to date. The high interest in Camera Mouse highlights the need for developing innovative ways to enable disabled individuals to interact with computing devices (Camera Mouse is evaluated in Section 5.5).

5.4.2. Face Position/Gesture Detection

Bian, Hou, Chau, and Magnenat (2014) proposed a system that makes use of facial features and gestures as input techniques. The detection of face position and gesture is based on a randomized decision tree (RDT) classifier using a single image (Shotton, Fitzgibbon, Cook, Sharp, Finocchio, Moore, Kipman, & Blake, 2013). The system tracks the position of a nose and uses it to control a cursor, along with commands provided by movement of the mouth (Bian et al., 2014). The authors use the following mouth gesture commands:

1. *Open Mouth:* Disable movement of mouse cursor.

2. *Close Mouth:* Enable the movement of cursor.
3. *Mouth Open-Close-Open sequence:* Triggers single click if sequence is made in short time frame.
4. *Mouth Open-Close-Open-Close sequence:* Triggers double click.

The determination of a nose's position and mouth status is based on the per-pixel classification results of the RDT classifier.

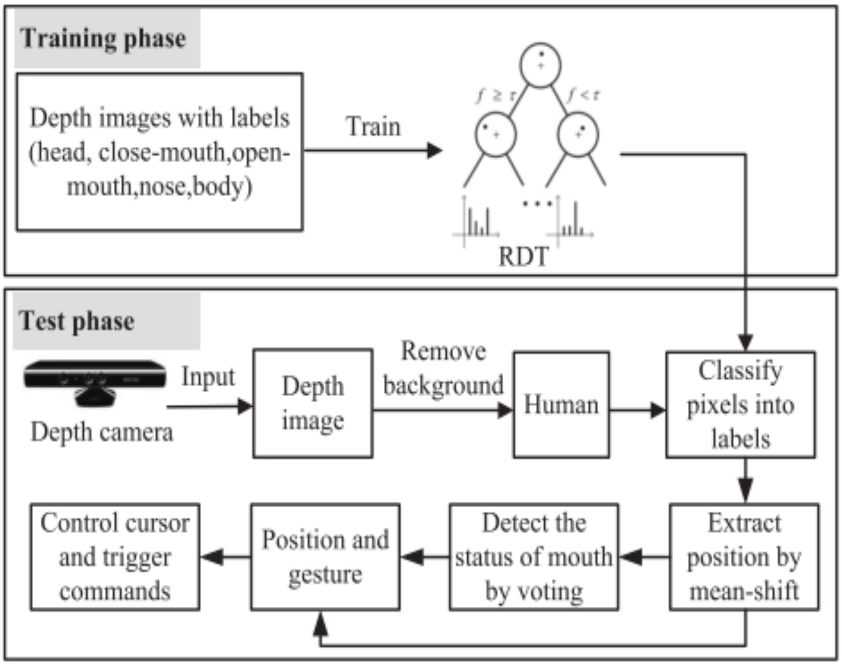

Figure 5-7: System Flow Chart (Bian et al., 2014).

Figure 5-7 illustrates the system. The mouth gesture commands proposed seem to be impractical for everyday use, since a mouth is multipurpose: eating, and communicating among other uses. One limitation of the system is that a user will not be able to comfortably have a conversation with a friend, and at the same time interact with the system.

5.4.3. Tongue Controlled Device

Abbas et al. (2016) propose a tongue operated assistive device that consists of the following key components:

1. *Magnetic tracer:* A magnet that is attached to the tip of a tongue. It is used to create a magnetic field.
2. *Magnetic sensor:* A sensor used to detect a magnetic field created by a magnetic tracer attached to a tongue.

3. *Microcontroller:* Wirelessly transmits signals to a compact computer carried on a user’s clothing, or wheelchair. The signals are then processed to extract a person’s instructions.

A user is able to control a mouse cursor by moving his or her tongue along an implanted tracer. The tongue driven system may be able to address some of the computing needs of individuals with quadriplegia, but it is intrusive and uncomfortable for users.

5.4.4. Discussion

The systems reviewed in Sections 5.3 – 5.4 highlight the need to create custom interaction techniques for disabled individuals. For example, some individuals with quadriplegia may not be able to use the Camera Mouse, or the face gestures, but they may be able to use the tongue control device.

The Camera Mouse and Gesture detection system both track body part movements, albeit using different approaches. The former uses the relative position of a tracked sub-image in a sequence of images, while the latter uses absolute pixel position. The tongue controlled device is an example of a physiological assistive technology. This technology is intrusive since it requires external objects to be inserted into the mouths of individuals.

5.5. Evaluating Interaction Techniques

Sections 5.5.1 – 5.5.3 explore the practicality of using head gestures, facial features, and voice to interact with a mobile phone, use a computer, and control electronic devices. A formative evaluation was carried out. A formative evaluation is usually carried out by a usability expert and is iterative in nature, with the goal of making improvements to the design. A formative evaluation was chosen for the interaction techniques because it would help identify the most suitable interaction technique for a particular task.

5.5.1. Prototype Development

Figure 5-8, illustrates the various components that constitute the system used to evaluate the efficacy of the various interaction techniques that were reviewed in Sections 5.3 and 5.4. The input techniques are: Camera (built into laptop), Microsoft Kinect, and a Microphone. A camera is used to track a selected body feature such as a nose, which is used for navigation and control of a computer using the Camera Mouse software. The Kinect is used to track a person’s head pose in real-time. A user’s head pose is captured by three angles: pitch, roll, and yaw. The angles are expressed in degrees, with values ranging from -90 degrees to +90 degrees (MSDN, 2012). The head pose is obtained from the Kinect SDK.

The head pose is analysed as a sequence of head movements using a Hidden Markov Model (HMM). A HMM is a tool for representing probability distributions over a sequence of observations (Ghahramani, 2001). HMMs are ideal for classifying a sequence of head movements. Wei et al. (2013) describe how to achieve real time head nod and shake detection using the Microsoft Kinect. Two HMMs are used to detect the presence of head shake and head nod in a recent sequence of head movements. By comparing the difference of pitch and yaw in adjacent frames, the direction of head movement can be determined. The Accord machine learning framework was used to implement the HMMs (Souza, 2008). Two distinct HMMs were trained: one to recognise head nods, and another to recognise head shakes. Recorded sequences of 60 head gestures were used to train the HMMs. These included 20 head nods, 20 head shakes, and 20 head movements that were neither nods nor shakes.

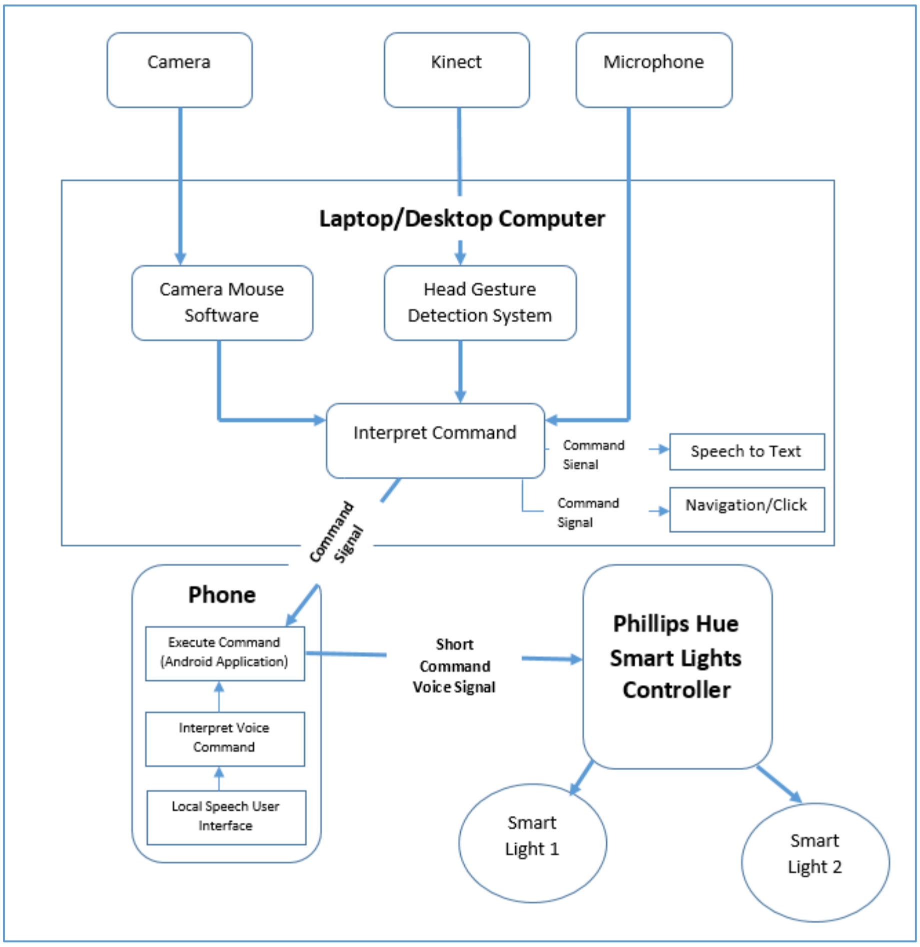

Figure 5-8: **Components of Interaction Techniques System.**

The microphone is used to capture audio input; if the IBM speech to text service is running, the audio is transcribed into text into real-time. If the Simon software is running and a recognized command is issued, Simon executes the given command. Starting Simon and IBM speech to text software can be done by using the Camera Mouse software to navigate to the desired software icon and clicking on it.

Command signals from Camera Mouse, or the Kinect, can be sent to the mobile phone for execution. Figure 5-9 illustrates a desktop application that receives input from both the Camera Mouse and the Kinect head gesture detection system.

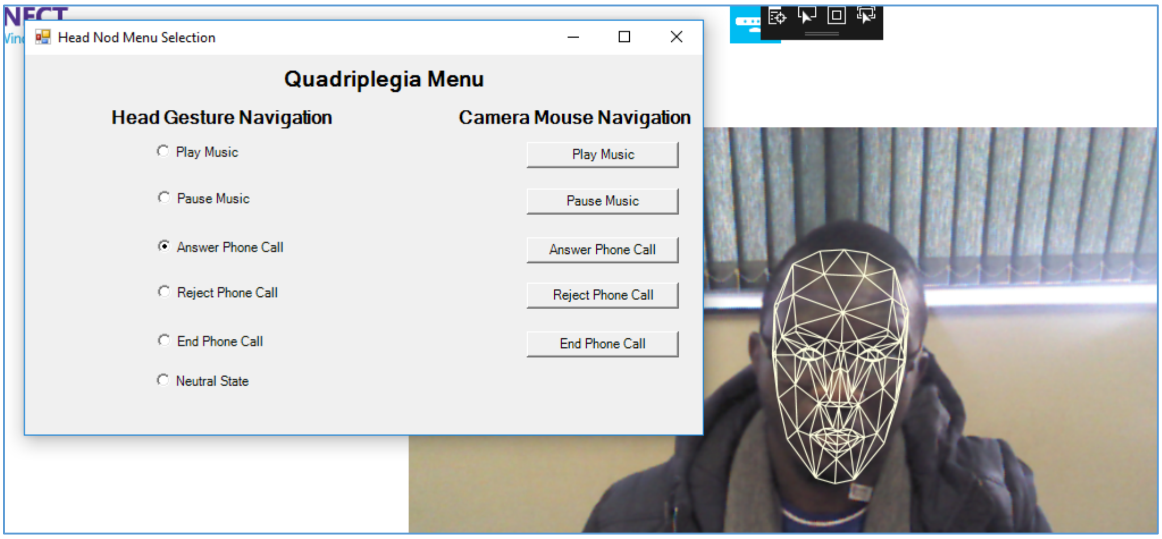

Figure 5-9: **Using a Mobile phone.**

Head nods are used to scroll through the left side menu as illustrated in Figure 5-9, and an item is considered selected if a user dwells on it for more than 2 seconds. The right hand menu illustrates action buttons that can be pressed by the user when they navigate to them using the camera mouse, and dwell on them for more than 2 seconds. The menu items are:

1. *Play music:* A signal to play music is sent out
2. *Pause Music:* A signal to pause music is sent out.
3. *Answer Phone Call:* A signal to answer a phone call is sent out.
4. *Reject Phone Call:* A signal to end a phone call is sent out.
5. *End Phone Call:* A signal to end a phone call is sent out.

The command signals sent by the system illustrated in Figure 5-10 are executed on a mobile phone by an Android software application that runs in the background. The phone is also used to issue short voice commands to control two Philips hue smart lights. Once an action is triggered, an Android application running on the user's mobile phone is alerted to execute the command. The notification signals between a phone and computer are sent using Google Cloud Messaging (OneSignal, 2014). However, a Bluetooth connection between the phone and computer can also be explored as a possible way of reducing network latency.

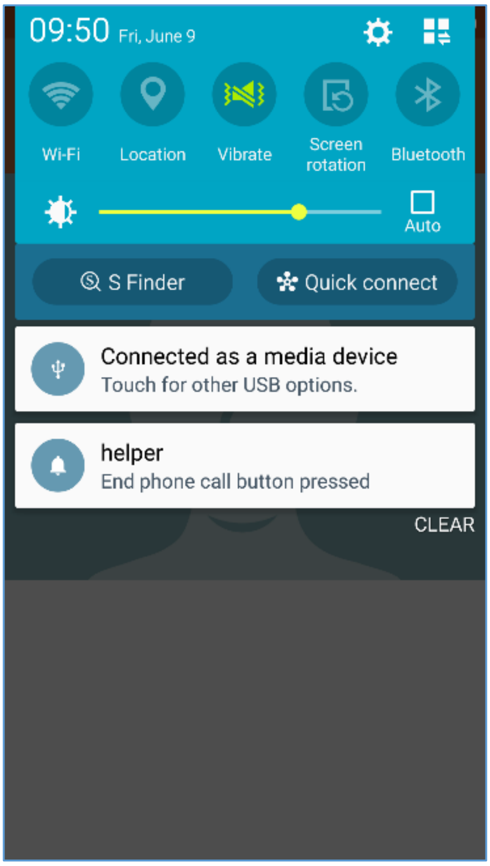

Figure 5-10: **Ending of a phone call.**

Figure 5-10 illustrates an example of a command signal that is sent to a mobile phone. The notifications are cleared after a delay of 5 seconds in order to avoid filling up the screen. An alternative is to use silent notifications that execute in the background and do not provide visual feedback. It was deemed necessary to inform the user, however, that their command was received, and is being executed.

Figure 5-11 illustrates the configuration of the Camera Mouse software, which was discussed in Section 5.4.1. A nose is used as the navigation facial feature.

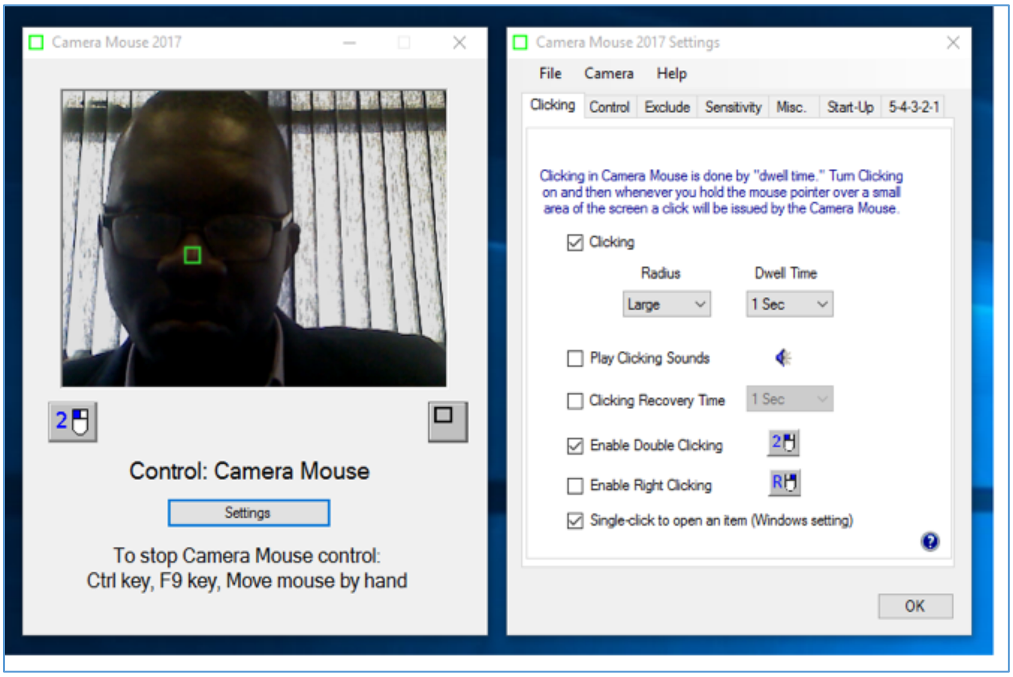

Figure 5-11: **Configuration of the Camera Mouse Software.**

A dwell time of one second before a click is triggered was found to be ideal as it is not too short to trigger false clicks, while also not too long to negatively affect the user experience.

Figure 5-12: **Phillips Hue Smart Lights.**

Figure 5-12 illustrates two Philips hue smart lights, a wireless router, and a smart lights controller. The wireless router is used to facilitate communication with a mobile phone on the same local network.

5.5.2. Experiment Design

The main objective of the evaluation was to determine if the system could support individuals with quadriplegia interacting with their home electronics without physical human assistance. Nielsen Norman (2014) maintain that good usability tasks should:

1. *Be realistic:* The tasks should emulate the real-world usage of the system.
2. *Be actionable:* Tasks should have a clear end goal.
3. *Avoid clues and describing steps:* Tasks should not assist participants with task completion.

Most empirical evaluations of interaction techniques are comparative. A new device, or technique, is compared against alternative devices, or techniques. One design for such experiments is the "within-subjects" design, also known as a repeated-measures design (MacKenzie, 2013). In a within-subjects design, each participant is tested under each condition. The conditions are, for example, "technique A", "technique B", etc. For each participant, the measurements under one condition are repeated for the other conditions. One advantage of the within-subjects design is that fewer participants are needed, since each participant is tested on all levels of a factor. The evaluation used a within-subjects experiment design whereby each participant was exposed to all the treatments being tested. A within-subjects approach was chosen because a limited number of representative participants (5) was available.

5.5.2.1 Task Design

The above guidelines were applied in developing the tasks. The tasks were:

1. Make a phone call
2. End a phone call
3. Reject a phone call
4. Accept a phone call
5. Play music
6. Pause music
7. Turn TV Off
8. Turn TV On
9. Increase TV volume
10. Decrease TV volume

11. Navigate One Channel forward
12. Navigate One Channel backward

5.5.2.2 Usability Metrics

The prototype should be able to complete the tasks accurately, consistently and with good performance. Accessibility measurement is often polarised around two choices: A compliance/conformance based approach that usually involves a checklist of criteria, or some form of user testing by disabled individuals (Hudson, 2011). Both approaches lead to more accessible applications. This study measured the following metrics:

1. Accuracy: Does the system correctly interpret a given user command?
2. Task Completion Time: Measures how long it takes for an individual to complete a given task.

The experiments were conducted in a well-lit computer lab environment. A laptop computer, a Microsoft Kinect, and two mobile phones, a Samsung TV, and two Phillips hue smart lights were used to complete the tasks. Five disabled individuals were involved in the experimental evaluation. For each task, three attempts were made. Three rounds of evaluations were carried out. The first round required each participant to complete all the tasks using only voice interaction. The second round required participants to complete all tasks using both voice and head gesture interaction techniques. The third round required participants to complete the tasks using Camera mouse and Voice. The voice commands used in the experiment are included in Appendix C.

5.5.3. Evaluation Results

Only attempts that worked on the first try were marked as successful. Attempts that required more than one try before correctly interpreting a given command, were marked as unsuccessful.

5.5.3.1 Round One

The participants were required to use voice in order to complete the tasks. Tasks that were initiated with the phone in a silent state were found to yield more successful outcomes as compared to tasks, which were initiated when the phone was already outputting audio.

The evaluation results of Round 1 are listed in Table 5-5. Only successful attempts were recorded.

Table 5-5: Round One Evaluation Results.

	VOICE						
#	**Task**	**P 1**	**P2**	**P3**	**P4**	**P5**	**Mean**
1	Make a call	2	0	3	1	1	1.4
2	End a call	1	1	0	0	1	0.6
3	Reject a call	1	1	1	1	0	0.48
4	Accept a call	1	1	0	1	1	0.48
5	Play music	2	0	1	2	1	1.2
6	Pause music	1	2	2	1	0	1.2
7	Turn TV Off	2	1	3	1	1	1.6
8	Turn TV On	3	2	1	0	1	1.4
9	Increase TV volume	2	3	2	1	0	1.6
10	Decrease TV volume	0	2	1	2	0	1.0
11	Navigate One Channel forward	0	1	0	3	0	0.8
12	Navigate One Channel backward	0	2	1	2	0	1.0
	Total Task Completion Time (minutes)	**8**	**10**	**13**	**7**	**20**	**11.6**

Participants one and five experienced difficulty in having their voice commands translated using the speech to text software. On average, each participant spent a total of 11.6 minutes carrying out the tasks.

The phone also kept on attempting to interpret music as voice commands. The unsuccessful calling associated tasks, namely, *"making a call, ending a call, rejecting a call, and accepting a call",* were directly attributed to the unresponsiveness of the voice command recognition in the presence of background sound. This explains the low mean scores for Tasks 2, 3, and 4.

5.5.3.2 Round Two

The participants were required to use both voice and head gesture navigation in order to complete the same tasks.

Table 5-6: Round Two Evaluation Results.

	VOICE AND HEAD GESTURES						
#	**Task**	**P1**	**P2**	**P3**	**P4**	**P5**	**Mean**
1	Make a call	2	1	2	3	3	2.2
2	End a call	2	1	2	3	2	2.0
3	Reject a call	1	2	1	2	0	1.2
4	Accept a call	3	2	2	1	1	1.8
5	Play music	2	3	3	2	3	2.6
6	Pause music	3	3	3	3	1	2.6
7	Turn TV Off	2	3	3	1	2	2.2
8	Turn TV On	3	3	3	2	1	2.4
9	Increase TV volume	1	2	3	0	2	1.6
10	Decrease TV volume	2	3	1	0	3	1.8
11	Navigate Up One Channel	3	2	2	n/a	3	2.5
12	Navigate Down One Channel	3	3	2	n/a	3	2.75
	Total Task Completion Time (minutes)	**20**	**16**	**23**	**11**	**17**	**17.4**

The head gesture input signals used were able to successfully accomplish the tasks as shown in Table 5-6. The mean scores for tasks 2, 3, and 4 were better than those of round one (Section 5.5.3.1). This is because of the absence of background competing audio, hence the voice commands were able to be correctly interpreted. The mean task completion time, however, was higher for round two as compared to one.

It was observed on some occasions that the head nod was picked up after the desired menu item had already been deselected. In such situations, participants had to cancel the selection and wait for that menu item to be selected again. This explains some of the unsuccessful attempts shown in Table 5-6, and the high task completion time. Two of the participants noted how tiring it was to nod their heads in order to select an item. Three of the participants noted that head gesture navigation comes in handy when voice commands are un-responsive. They found the process of having to first track a face, however, tiring.

5.5.3.3 Round Three

The participants were required to use both voice and camera mouse in order to complete the same tasks.

Table 5-7: Round Three Evaluation Results.

	VOICE AND CAMERA MOUSE						
#	**Task**	**P1**	**P2**	**P3**	**P4**	**P5**	**Mean**
1	Make a call	3	1	2	2	1	1.8
2	End a call	3	2	3	3	2	2.6
3	Reject a call	3	3	3	3	3	3.0
4	Accept a call	3	2	3	3	3	2.8
5	Play music	3	3	3	2	2	2.6
6	Pause music	3	3	3	3	3	3.0
7	Turn TV Off	3	3	3	3	1	2.6
8	Turn TV On	3	3	3	3	2	2.8
9	Increase TV volume	3	3	3	2	3	2.8
10	Decrease TV volume	3	3	3	3	3	2.8
11	Navigate Up One Channel	3	2	3	3	3	2.8
12	Navigate Down One Channel	2	2	3	3	3	2.6
	Total Task Completion Time (minutes)	**7**	**12**	**9**	**6**	**13**	**9.4**

The Camera Mouse input signals used could successfully accomplish the tasks as shown in Table 5-7. Round three had the best mean scores for tasks 2, 3, and 4 as compared to Rounds two and three, and it also had the lowest task completion time. This was attributed to the availability of a different interaction modality that wasn't affected by background sound. Participants could use the Camera Mouse software with ease. The unsuccessful attempts were due to the delay in sending command signals to the appropriate device. All five participants noted that they enjoyed using Camera Mouse the most. For Round three, voice was only used to initiate a call.

5.5.3.4. Discussion of Evaluation Results

Automatic Speech Recognition (ASR) researchers have reported on the effects of noise on ASR (Li, Deng, Gong, & Haeb-Umbach, 2014). The effects of noise were evident in Round One of the experiments. Round Two helped to reduce these effects by using head gesture interaction in situations where background noise was present. However, the participants generally found it to be tiring.

Table 5-8: **Mean Number of Successful Attempts.**

	MEAN SCORES			
#	Task	Round One	Round Two	Round Three
1	Make a call	1.4	2.2	1.6
2	End a call	0.6	2.0	2.6
3	Reject a call	0.8	1.2	3.0
4	Accept a call	0.8	1.8	2.8
5	Play music	1.2	2.6	2.6
6	Pause music	1.2	2.6	3.0
7	Turn TV Off	1.2	2.2	2.6
8	Turn TV On	1.6	2.4	2.8
9	Increase TV volume	1.4	1.6	2.8
10	Decrease TV volume	1.6	1.8	3.0
11	Navigate One Channel forward	1.0	2.0	2.8
12	Navigate One Channel backward	0.8	2.2	2.6
	Task Completion Time	**11.6**	**17.4**	**9.4**

Table 5-8 presents the mean scores of the successful attempts. For Tasks 1 - 12, a high mean value implies that more participants were able to successfully complete the task, whereas a lower value implies difficulty experienced by participants when completing the task. Task completion time is the total number of minutes that participants spent on a given set of tasks. A low value for task completion time signifies a better user experience as compared to a high value.

Round One had the least mean scores, while Round Three had the highest mean scores meaning that participants were more successful in completing Round Three tasks as compared to Rounds One and Two. Furthermore, for Rounds Two and Three, network latency affected the number of successful attempts. Some signals to execute a given command were received after a long delay. The results of the experimental evaluation are promising, and show that head gestures and Camera Mouse software can be used in conjunction with a mobile phone to interact and control electronic devices.

The participants preferred Camera Mouse to head gestures when completing tasks that would otherwise need a user to tap (touch) the screen. This is envisioned to be a useful interaction technique for individuals with quadriplegia. Camera Mouse and voice interaction are used to implement the final prototype that is discussed in Chapter 6.

5.6. Conclusion

The objective of this chapter was to meet Research Objective 4 (R04) which was: "*To review different interaction techniques that may be used by physically disabled individuals to interact with their environment"*. This was achieved by carrying out a literature review on interaction techniques, and an experimental evaluation aimed at identifying suitable interaction techniques to meet the requirements of this research.

The following interaction techniques: Head Gestures, Voice, and Camera Mouse were discussed. Head gestures, specifically head shake and nod, were found to be unreliable because the ambient lighting in the environment affected the accuracy of facial detection. The involvement of disabled individuals in the evaluation process was important as it helped identify some of the usability issues with the selected interaction techniques. The system discussed in Section 5.4.2 proposes the use of mouth gestures in order to enable disabled individuals to interact with the environment. One of the limitations of the system (Section 5.4.2) is that their experiments were carried out with able-bodied participants.

The third phase of the DSR process is concerned with the design and development of an artefact. This chapter started on this process by identifying suitable interaction techniques that may be used by physically disabled individuals with limited hand use.

Chapter 6: Design and Implementation of AAL Services for Physically Disabled Individuals

6.1. Introduction

Chapter 5 identified and motivated voice and Camera Mouse as the interaction techniques that are best suited for this study. This chapter addresses Research Objective 5 (R05), which is: *To design and implement a software solution that addresses the identified challenges*. The chapter is organised as follows: Section 6.2 discusses how the three AAL software services are inter-related. Sections 6.3 – 6.5 discuss the implementation details of the AAL three software services namely: Using a mobile phone, controlling an electronic environment, and using a computer respectively. The AAL software services are a result of the functional requirements that were identified after conducting interview studies with disabled persons (Chapter 4). The AAL software services were introduced in Section 4.6.

6.2. System Architecture Design

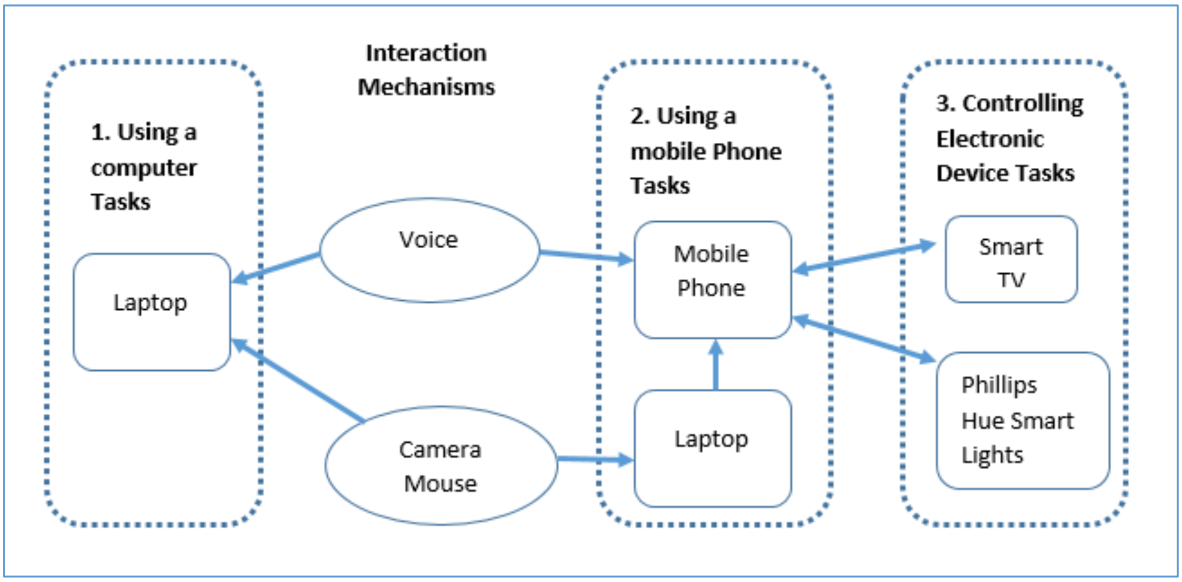

Figure 6-1: **Architecture of the three software services.**

Figure 6-1 illustrates the different system components, and how they work together. The key components are:

1. **Interaction Techniques:** Voice, and camera mouse software will be used as the primary interaction techniques for the system. Voice is primarily used to issue

commands and dictate text, while camera mouse is used for navigation and clicking on a selected point of interest on a computer screen.

2. **Using a mobile phone:** Voice is the primary interaction technique. In situations where voice is not sufficient, Camera Mouse is used to interact with a mobile phone by clicking on buttons located on a Windows form application. For example, in noisy environments.
3. **Controlling electronic devices:** A Samsung smart TV, and a pair of Phillips hue lights are controlled using voice and Camera Mouse. The mobile phone is used to pass control signals to the electronic devices.
4. **Using a computer:** The Camera Mouse software is used to navigate to various points of interest on a computer. Points of interest include software icons and menus. By dwelling on a point of interest for a specified time period (1 second), a click is simulated. The IBM speech to text API is used to transcribe audio input.

Concurrency is a property of a system in which many entities act and interact at the same time. The system illustrated in Figure 6.1 is concurrent in nature. Petri nets are a tool to model concurrent systems, and reason about them, and they can capture various system properties such as synchronization and parallelism (Denaro & Pezz, 2003). Petri nets are represented as a bipartite directed graph populated by three types of objects namely places, transitions, and directed arcs. Directed arcs connect places to transitions, or transitions to places. A Petri net is formally defined as a 5-tuple N = (P, T, I, O, M_0) (Wang, 2006):

- **P** = {p_1, p_2, …, p_m} is a finite set of places;
- **T** = {t_1, t_2, …, t_n} is a finite set of transitions, $P \cup T \neq \emptyset$, and $P \cap T = \emptyset$;
- **I**: $P \times T \rightarrow N$ is an *input function* that defines directed arcs from places to transitions, where N is a set of nonnegative integers;
- **O**: $T \times P \rightarrow N$ is an *output function* that defines directed arcs from transitions to places; and
- **M_0**: $P \rightarrow N$ is the initial marking (token assignment).

A marking in a Petri net is an assignment of tokens to the places of a Petri net. Tokens reside in the places of a Petri net. The number and position of tokens may change during the execution of a Petri net. The tokens are used to define the execution of a Petri net.

Figure 6.2 illustrates a Petri net of the system. The Petri net has 16 places and 20 transitions. The system was designed in such a way that there is smooth transition and communication between all the devices. For example, a user can receive a phone call while they are listening to music. In such a case, the music will stop, and the user will be prompted to answer the phone call.

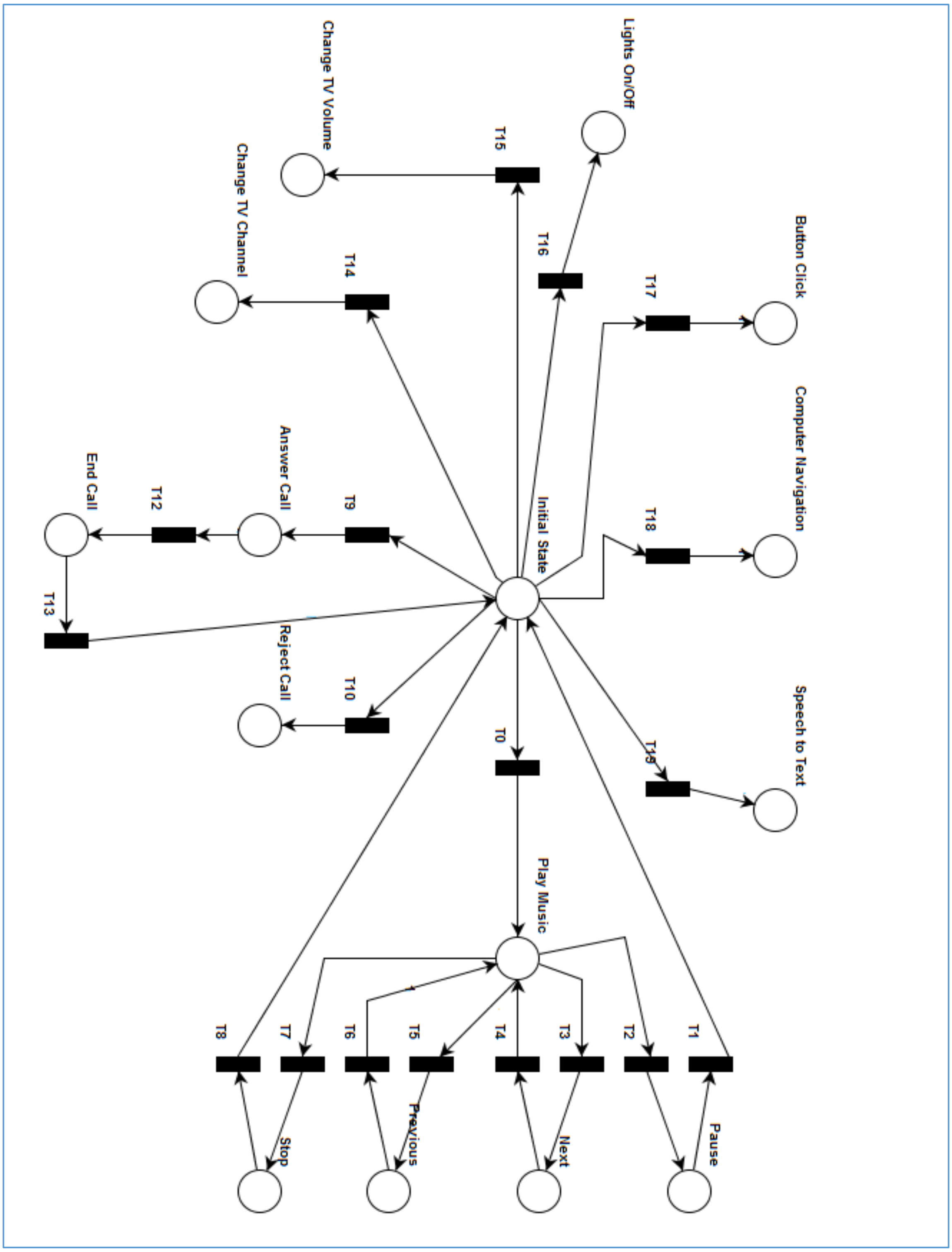

Figure 6-2: **Petri net of the proposed system.**

Below is a discussion of the Petri net illustrated in Figure 6-2. The discussion is grouped into three categories, namely, *mobile phone design, electronic environment design, and computer use design.*

6.2.1. Mobile Phone Design

A phone is central to the prototype design as it is used to process command signals that are sent by sub-system components (computer), and also perform all phone related tasks that may interrupt the operation of the AAL service for using a phone. The Android application made use of the Google Speech Android SDK, and the phrase "OK Google", in order to activate the listening state. The user is then able to initiate functions such as making a phone call, sending a text message, or issuing a voice command. Sending a text message and making a phone call is handled by the Google Speech SDK, while interpreting speech to text voice commands is handled by the IBM speech to text API.

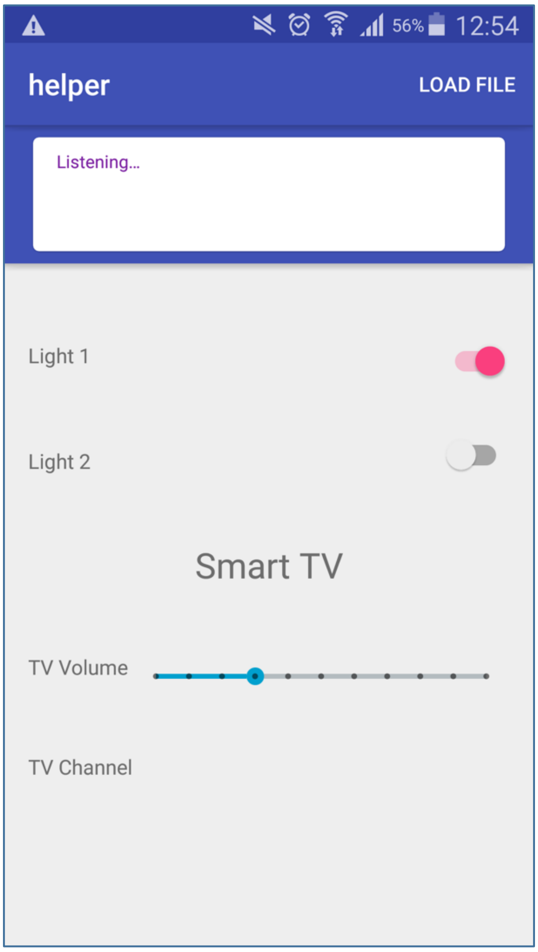

Figure 6-3: **Mobile phone listening state.**

Figure 6-3 illustrates the user interface of the Android app when it is listening for user commands. The commands are listed in Appendix C.

6.2.2. Electronic Environment Design

The states of electronic devices (Smart lights, and Smart TV) in a home environment can be changed by issuing command signals through a mobile application. The mobile application does not have to be open in order for the command signals to be executed. Users can either use voice commands (Appendix C), or Camera Mouse Control Buttons, illustrated in Figure 6-4.

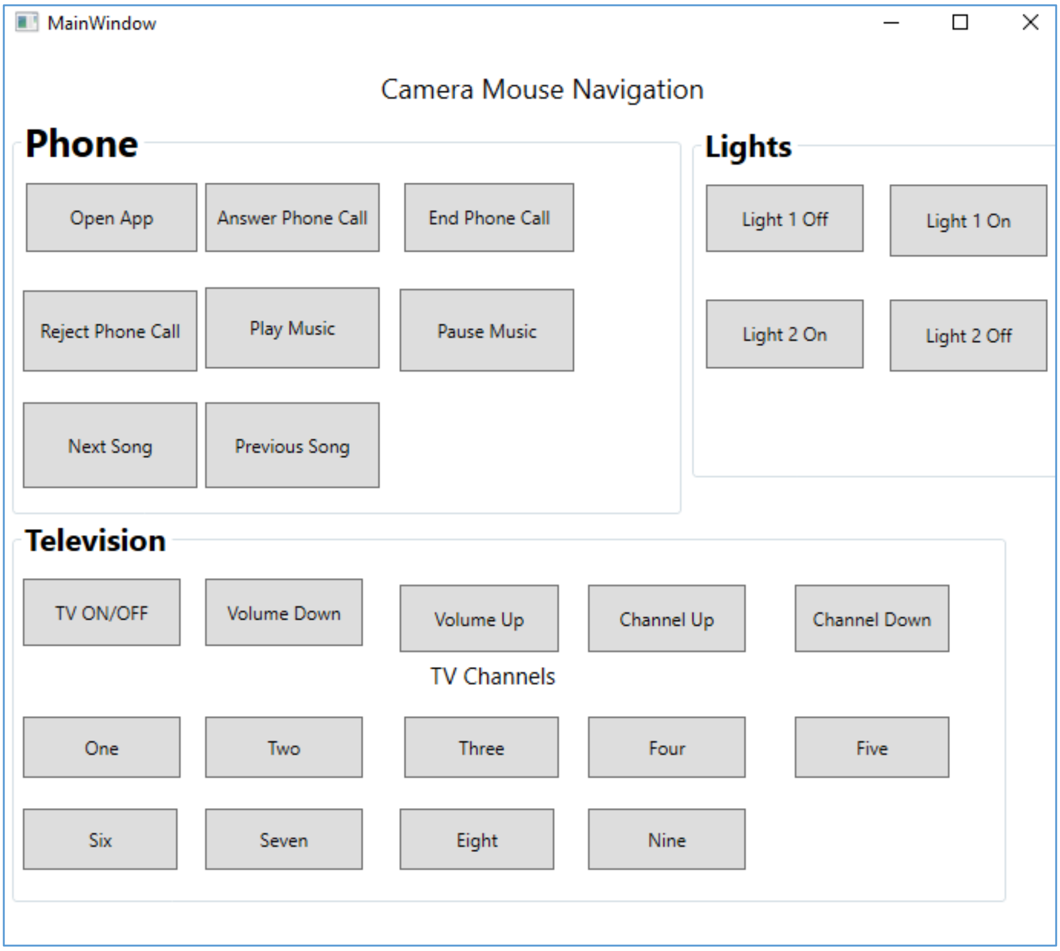

Figure 6-4: **Camera Mouse Panel for the three AAL services.**

6.2.3. Computer Use Design

Using a combination of the IBM speech to text API and Camera Mouse, users are able to navigate the computer desktop and open apps that they want. For example, a user can open the Google Chrome application and transcribe a URL that they want to browse. Users can then click a button in order to open the URL in a new tab. Figure 6-5 illustrates a screen that facilitates audio transcription.

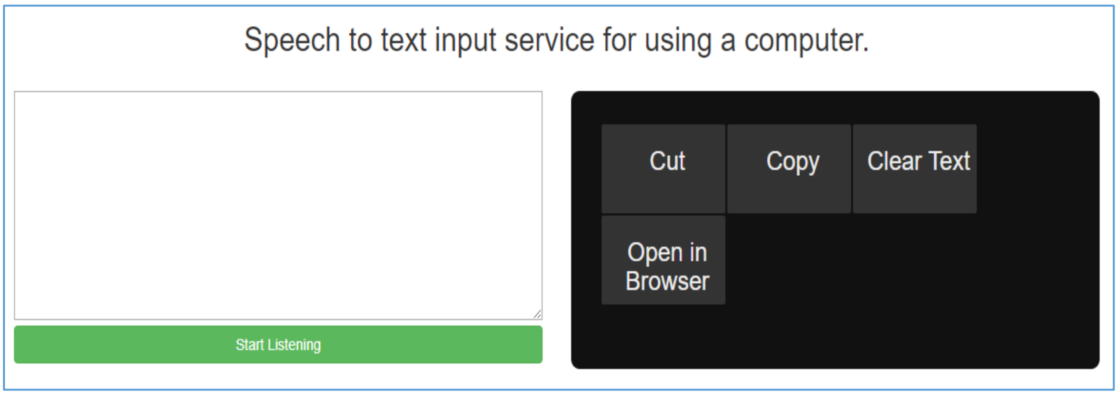

Figure 6-5: **Computer Speech to text transcription.**

6.3. Using a mobile phone

Mobile phones are ubiquitous in society, and they can be used to accomplish a wide range of tasks such as making phone calls, listening to music, chatting to friends, creating documents, and watching movies. The way individuals use their phones partly depends on their needs, which may differ from one user to another. The tasks that are categorized as using a mobile phone for this study are: *making a phone call, ending a phone call, answering a phone call, cancelling a phone call, playing music, pausing music, and sending a text message.*

A phone can also be used as a hub for connecting and transmitting command signals to smart lights, and a smart TV. The tasks discussed in this section pertain only to the use of some of a mobile phone's standard features as discussed in the previous paragraph.

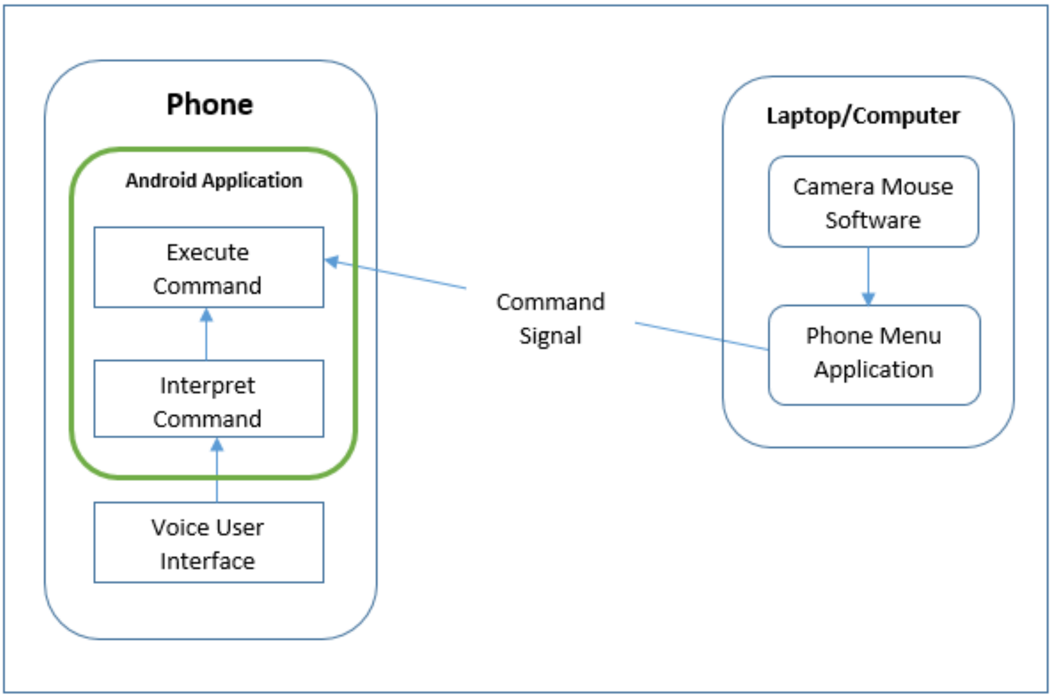

Figure 6-6: **Using a mobile phone.**

Figure 6-6 illustrates the various components that comprise the using a mobile phone task. There are two main modes of interaction, and these are: Camera Mouse, and voice commands. A Windows desktop application that consists of various menu items was developed. The menu items are:

1. *Play music:* A signal to play music is sent out;
2. *Pause music:* A signal to pause music is sent out;
3. *Answer phone call:* A signal to answer a phone call is sent out;
4. *Reject phone call:* A signal to end a phone call is sent out;
5. *End phone call:* A signal to end a phone call is sent out;
6. *Send a text message:* Using google voice actions, a user is prompted to send a text message to one individual;

Using Camera Mouse, a user is able to click on a specific button to execute a given function. Once a function is triggered, an Android application running on the user's mobile phone is alerted to execute the command. The notification signals between a phone and computer are sent using Google Cloud Messaging (OneSignal, 2014). No performance issues were identified during testing. However, a Bluetooth connection between the phone and computer can also be explored as a possible way of reducing network latency. Google Now and Voice Actions are used to listen for user input voice commands. The input voice commands are interpreted locally on a phone, and the Android application executes the identified commands.

6.4. Controlling the Environment

A living room may have a number of electronic devices such as a TV, radio, lights, air conditioner, and electric fan. This section discusses how an individual with quadriplegia may interact with a TV and household lights without physical human assistance. Figure 6-7 illustrates how the electronic devices can be controlled using voice commands. A pair of Phillips Hue smart lights, a Samsung smart TV, and a mobile phone were connected to the same local WiFi network. An Android application, which is able to translate speech to text was installed on an Android phone. A user is then able to issue voice commands that control the smart TV and lights from the mobile phone. A phone was chosen for these tasks over a Camera Mouse powered computer, because individuals are often within close proximity of their phones, whereas this is not the case with a computer.

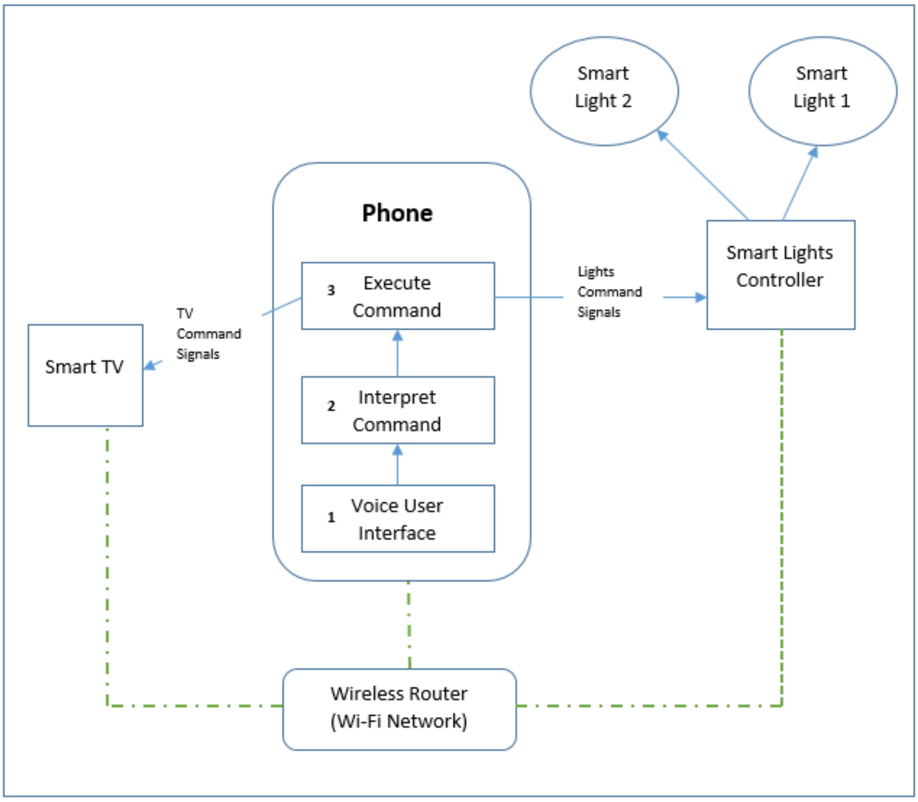

Figure 6-7: **Controlling an electronic environment.**

The Smart TV voice commands are: *Volume up, Volume down, Channel next, Channel previous, and Channel N (were N is an integer representing the desired channel number).* The voice commands for the smart lights are: *Lights on, and Lights off*. Samsung provides a software development kit (SDK) for their smart TVs (Samsung, 2013). Some of the controls that the SDK supports are the channel and volume controls; these allow third party developers to assign different functionality to the channel and volume controls respectively. The smart lights are part of a Phillips Hue smart lighting system, which consists of the following core components (Philips Electronics, 2014):

1. **Software Applications**: These are ways to control the lights as needed, e.g., turn them on and off, or adjust their brightness levels. They are not limited to smartphone apps. It is basically everything that makes use of the hue system APIs. It could be a website, or an Arduino board.
2. **Bridge** – This is used to enable the smart lights to communicate with each other and the Portal via the Internet. The bridge provides a set of APIs, which allows third party developers to control various settings of the smart lights.
3. **Portal** – This is a web based control panel, which connects a home to the internet. It delivers control commands from outside and keeps the software in the bridge up-to-date. The portal presents a utility API that helps to discover the address of a connected bridge.
4. **Lights** – This is the output of the system. Lights create a mesh network with each other, which enables each light to pass on messages to the next, extending the range. The lights are connected to the bridge via an open standards protocol called ZigBee Light Link.

6.5. Using a computer

Computers are multi-purpose devices that are used by individuals of all age groups ranging from children playing games, to software engineers building business applications. Some of the common activities carried out include sending and reading emails, and creating business documents. Table 6-1 summarizes some of the tasks that can be accomplished using a computer, which this research addresses for individuals with quadriplegia.

Table 6-1: **Computer Navigation Commands.**

Task	Command	Usage
Open Software	Nose	Move nose to desired point on screen and dwell on point for more than 1 second.
Enter Text	Voice User Interface (VUI)	Transcribe speech to text in real-time using the IBM speech to text API.
Search	VUI and Nose	VUI is used to transcribe search terms. The nose is used to click on a search button.
Play Music	Nose	Use the nose to navigate to and click on the play button.
Pause Music	Nose	Use the nose to navigate to and click on the pause button

Figure 6-8 illustrates the main researcher guiding one of the participants on how to use the equipment.

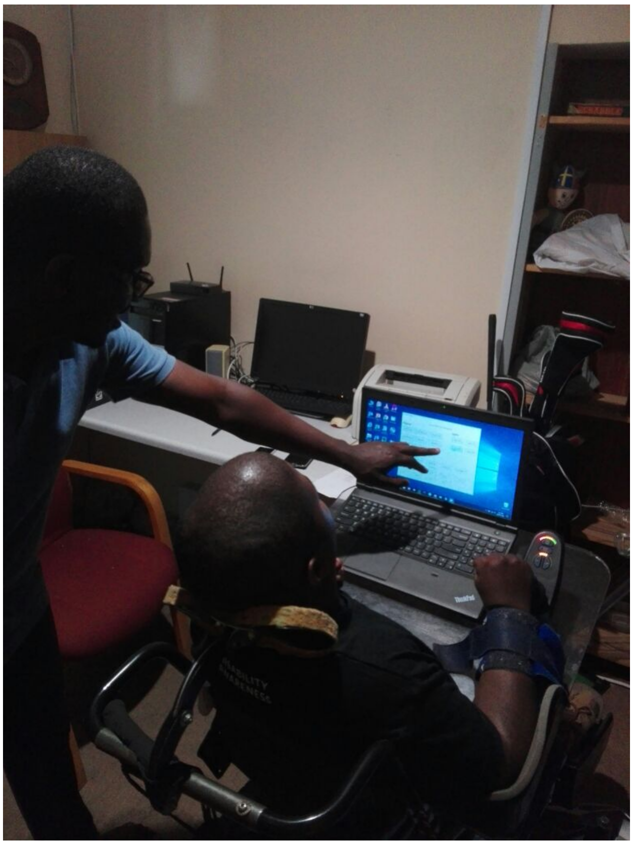

Figure 6-8: **A participant being shown how to use a computer.**

Figure 6-9 illustrates one of the participants using the prototype equipment.

Figure 6-9: **A participant using a mobile phone.**

Figure 6-11 illustrates the main components of using a computer system. The camera and microphone are the input mechanisms. The Camera Mouse interprets a given command as either navigation, or a click, depending on the dwell time on a particular screen point.

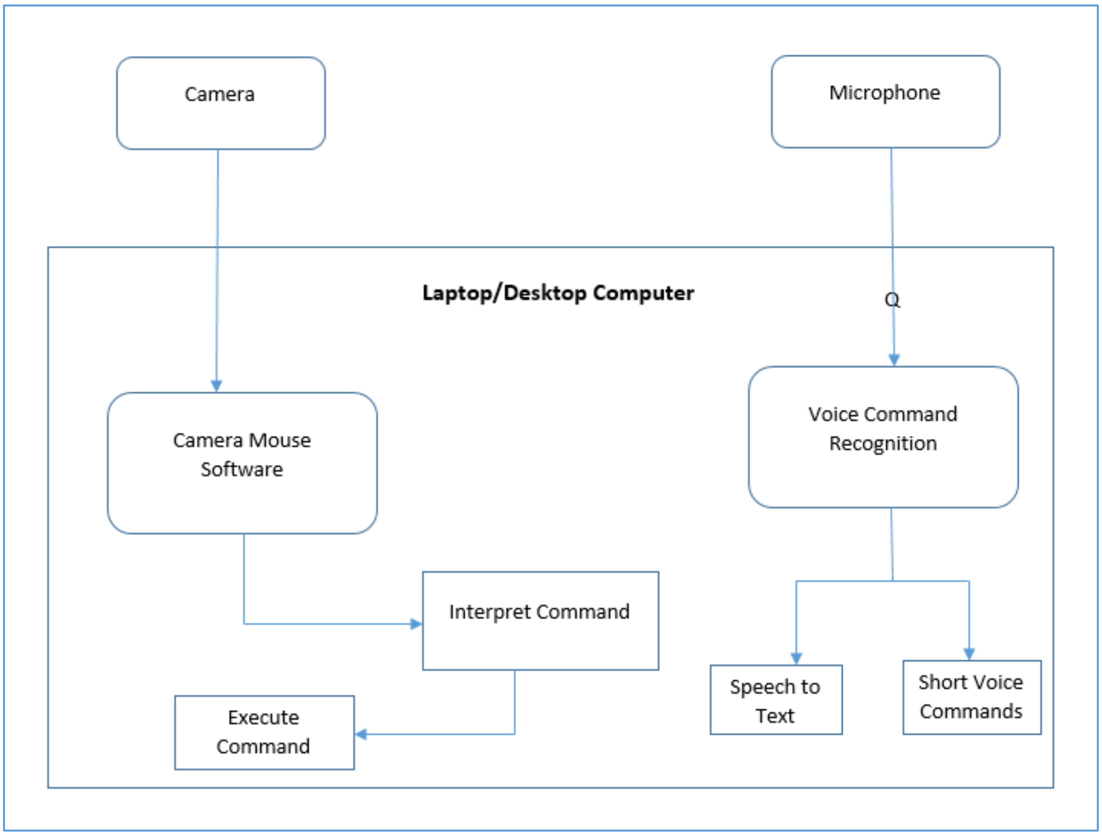

Figure 6-10: **Controlling an electronic environment.**

6.6. Conclusion

This chapter has extended the work done on interaction techniques in Chapter 5 by designing and implementing a prototype system that is comprised of three AAL services that interoperate. This addresses Research Objective 6, which was: *To design and implement a software solution that addresses the identified challenges.*

This chapter has fulfilled the third phase of the DSR methodology, which is concerned with the design and development of an artefact to address. The next chapter discusses the evaluation of the prototype.

Chapter 7: Evaluation Design and Results

7.1. Introduction

The objective of this chapter is to evaluate the effectiveness, usefulness, and usability of the prototype discussed in Chapter 6. Specifically, the chapter seeks to meet Research Objective 7 (RO7), which is *"To evaluate the effectiveness and usefulness of the prototype"*. Chapter 6 discussed the design and development phase of the Design Science Research Methodology (DSRM). The solution discussed in Chapter 6 was iteratively developed to produce a usable prototype. The next phase of the DSRM is the evaluation of a solution to rigorously demonstrate its utility, quality and efficacy. To fulfil this aim, a field study was conducted with fifteen disabled participants in Port Elizabeth over a period of four weeks. The results of the field study demonstrate and validate the design decisions made in the development of the prototype applications. Section 7.2 describes the evaluation method in detail, including discussions on the aim of the field study, the participants involved, the evaluation metrics, the tasks required and the evaluation procedure. Section 7.3 discusses the results of the field study. Section 7.4 discusses the design implications of the field study. Section 7.5 presents the conclusions of the field study.

7.2. Evaluation Method

A field study (see Appendix A for Research Ethics Approval) was used to evaluate the effectiveness of the developed prototype. Metrics captured for the field study included effectiveness, satisfaction, errors and qualitative comments.

7.2.1. Approach

There are several methods that can be used to evaluate the interaction between users and mobile systems (Kjeldskov & Graham, 2003). Table 7-1 provides a summary of these methods. The prototype system can be evaluated using one of these methods, which are grouped by the type of settings used during the study, namely natural, artificial and environment-independent settings. Natural settings are used for testing theories and hypotheses. The benefit is the production of rich data that is useful to test hypotheses. The setting sometimes makes it difficult to collect data, and Ethics clearance is required to prevent a negative impact on participants. Artificial settings are controlled and used for theory and product testing. It is difficult to generalise the results of such studies, because laboratory conditions are not the same as those in practice. Environment-independent settings are also used for product development and theory building. It is often easy and inexpensive to conduct such studies, but the shortcomings include a high risk of failure, the possibility of redesign, and outcomes influenced by opinions.

Table 7-1: Mobile Human-Computer Interaction (HCI) Research Methods (Kjeldskov & Graham, 2003).

Methods		Strengths	Weaknesses	Use
Natural settings	Case studies	Natural setting, rich data	Time demanding, Limited generalisability	Descriptions, explanations, developing hypothesis
	Field study	Natural setting, replicable	Difficult data collection, unknown sample bias	Studying current practices, Evaluating new practices
	Action research	First-hand experience, applying theory to practice	Ethics, bias, time, unknown generalisability	Generate hypothesis/theory Testing theories/hypothesis
Artificial settings	Laboratory experiments	Control of variables, replicable	Limited realism, unknown generalisability	Controlled experiments, Theory/product testing
Environment independent settings	Survey research	Easy, low cost, can reduce sample bias	Context insensitive, no variable manipulation	Collecting descriptive data from large samples
	Applied research	The goal is a product, which may be evaluated	May need further design to make the product general	Product development, testing, hypothesis/concepts
	Basic research	No restriction on solution, solve new problems	Costly, time demanding, may produce no solution	Theory building
	Normative writing	Insight into first-hand experience	Opinions may influence outcomes	Description of practices, building frameworks

A field study was selected as an appropriate method to evaluate the prototype system because participants would be more comfortable in their normal environment, and this would yield valuable data.

7.2.2. Aim and Objectives

The aim of the field study was to determine the usefulness of the developed prototype in supporting the independence of disabled individuals. The field study was also used to analyse subjective experiences when using the prototype.

7.2.3. Participants

Each participant of the field study completed a biographical questionnaire (Appendix E). A research assistant helped participants to complete the questionnaires as participants had limited hand use. The requirements of participants for the field study included that the participants had limited hand use, but could use their voice and also make facial gestures. The field study was conducted with disabled students from Nelson Mandela University, and residents of the Cheshire care home in Summerstrand. Initially, 17 participants agreed to participate in the field study, although only 15 participants completed the entire field study. Two participants were unable to make it due to personal issues. Figure 7-1 shows the age range of participants.

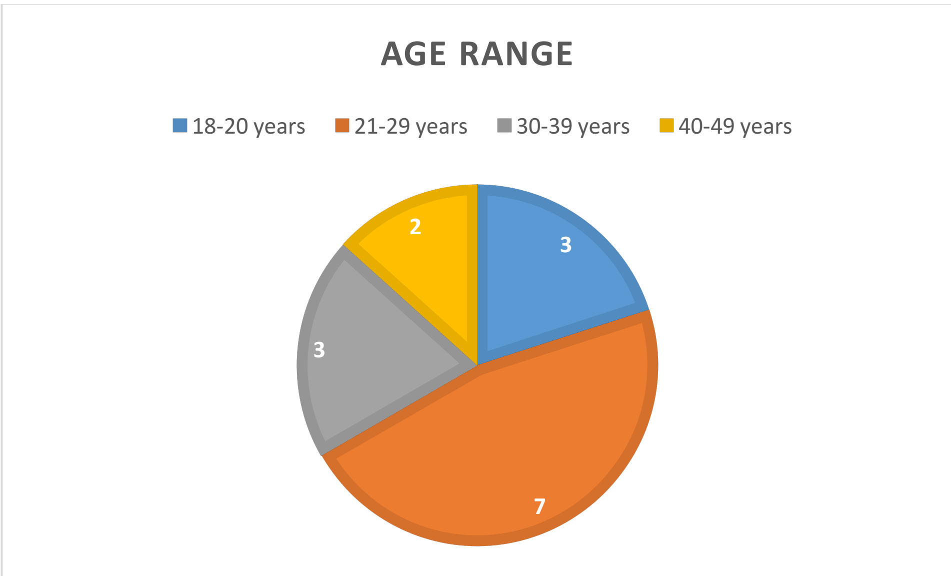

Figure 7-1: Age range of the participants (n=15)

Table 7-2 shows the spinal cord injuries of the participants. The participant names are anonymised for privacy reasons.

Table 7-2: Spinal cord injuries of the participants.

Participant	Disability
P1	Extreme case of Cerebral Palsy affecting both arms and legs
P2	Cerebral Palsy affecting both legs and right hand
P3	C5 incomplete quadriplegic
P4	C4 incomplete quadriplegic
P5	Cerebral Palsy affecting both arms and legs
P6	C7 incomplete quadriplegic
P7	C5 incomplete quadriplegic
P8	Cerebral Palsy affecting both arms
P9	Cerebral Palsy affecting right hand
P10	C6 incomplete quadriplegic
P11	C5 incomplete quadriplegic
P12	C5 incomplete quadriplegic
P13	C6 incomplete quadriplegic
P14	C5 incomplete quadriplegic
P15	C6 incomplete quadriplegic

An incomplete injury means that the ability of the spinal cord to convey messages to, or from the brain, is not completely lost. Additionally, some sensation (even if it is faint) and movement is possible below the level of injury. A complete injury is indicated by a total lack of sensory and motor function below the level of injury. Appendix B provides a summary of some of the challenges that individuals with the spinal code injuries listed in Table 7-2 experience.

7.2.4. Evaluation Measures

Usability metrics are a way of measuring, or evaluating an object of interest. They are observable and quantifiable (Tullis & Albert, 2008). Metrics for evaluating the usability of the prototype are categorised as follows:

a) Effectiveness – Questionnaire;
b) User Satisfaction – Questionnaires;

c) Qualitative comments – Questionnaires.

Effectiveness was captured using the After-Scenario Questionnaire (ASQ) (Lewis, 1995), with the addition of an open-ended section for general comments. Post-test questionnaires were provided for the three categories of tasks namely: Using a computer, using a mobile phone, and controlling an electronic environment. The post-test questionnaires used the NASA-TLX form (Hart & Staveland, 1988) to measure cognitive load, and the Computer Satisfaction Usability Questionnaire (CSUQ) (Lewis, 1995) to capture overall satisfaction, usability and general comments. These questionnaires used 5-point Likert items for simplification purposes, to make it easier, and simpler, for participants to complete the questionnaires. Descriptive statistics, including the mean, and median, were calculated for each question. Each value of the 5-point Likert-scale had an associated meaning, i.e. 1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree and 5: Strongly Agree. Thus, a mean rating with a value of greater than 3.4 indicated that the result was strongly positive, i.e., equivalent to either a four or five rating on the Likert scale.

7.2.5. Tasks

According to Stone *et al.* (2005), various levels exist controlling the participants' tasks. These levels of control include ensuring that each task is predefined by the facilitator, participants can comment on suggested tasks, participants can add additional tasks, participants are offered a choice between predefined tasks and their own tasks, and participants are required to suggest their own tasks. Allowing participants to create their own tasks restricts the evaluation, because the results from different participants cannot be compared uniformly, and thus venture into an explorative domain. Providing a predefined set of tasks to the participants may allow increased control, and ensure that participants evaluate each aspect, but there is little room to explore the system, and thus it is too restrictive. Offering participants a choice between task lists also makes it difficult to compare results between participants. Thus, the alternative, and most appropriate level of task control, was to provide participants with a task list and encourage participants to further explore the prototype, as the functions of the prototype are well defined. Additionally, this control level is the most balanced, as it ensures that each aspect of the prototype is evaluated, and comparison is possible between participants. Participants were provided with a task list (Appendix D).

7.2.6. Equipment

The following equipment was used during the evaluation study:

1. **Samsung Smart TV**: A 40 inch Samsung smart TV was used to complete all TV related tasks;
2. **Phillips Hue Smart Lights:** A pair of Philips hue smart lights and associated bridge network control device;
3. **Android Phones:** Two Android phones were used. One was used to primarily to make phone calls during the evaluation while a second one was used to accomplish phone related tasks, and also acted as a connectivity device to transmit command signals to the smart TV and the smart lights;
4. **Laptop Computer:** A Dell laptop was used to accomplish computer related tasks, and also to transmit control signals to a mobile phone device;
5. **Lamp Holders:** Two lamp holders were used to hold the smart light bulbs
6. **NetGear WiFi Extender:** Enabled Ethernet to WiFi connectivity of the smart lights network bridge device. This enabled the smart lights to be connected to a local network**;**
7. **Router:** A router was used to provide a wireless network, which facilitated the connection and communication of all the devices.

The evaluations were carried out in two different places, namely: A computer laboratory at Nelson Mandela University, and a living room environment at Cheshire Home, Summerstrand. The two venues were chosen because they were convenient and comfortable for the participants.

7.2.7. Procedure

For Nelson Mandela University participants, initially emails were sent out to prospective applicants with the assistance of the Disability Unit on campus. After a three week period with only one response, the principal researcher contacted a colleague (research assistant) who has experience of being a care taker for disabled students on campus. The research assistant identified potential participants, who were then approached by both the principal researcher, and the research assistant. The evaluation studies were organised according to each participant's schedule and availability.

Cheshire Home participants were recruited with the help of the Cheshire Home administration and the research assistant. The participants were required to consent to participate in the study by completing a consent form (Appendix F). The participants were also requested to complete a biographical questionnaire (Appendix E). The research assistant helped to explain the information contained in the consent and biographical forms to the participants. He also assisted them in completing the forms since they had limited hand use. Prior to each evaluation, the principal researcher explained the goal of the study and the procedure to follow. Participants were encouraged to ask any questions before commencing with the evaluation study.

7.3. Evaluation Results

The field study results are discussed in terms of effectiveness and satisfaction. The qualitative results captured from the post-test questionnaires conclude the Results section.

7.3.1. Effectiveness

The discussion on effectiveness is separated into three sections depending on the type of tasks, i.e., using a mobile phone, using a computer, and controlling an electronic environment.

7.3.1.1 Using a mobile phone

Figure 7-2 illustrates the responses of the 15 participants. Participants were generally happy with information provided to them before commencing the study and the time and ease of tasks.

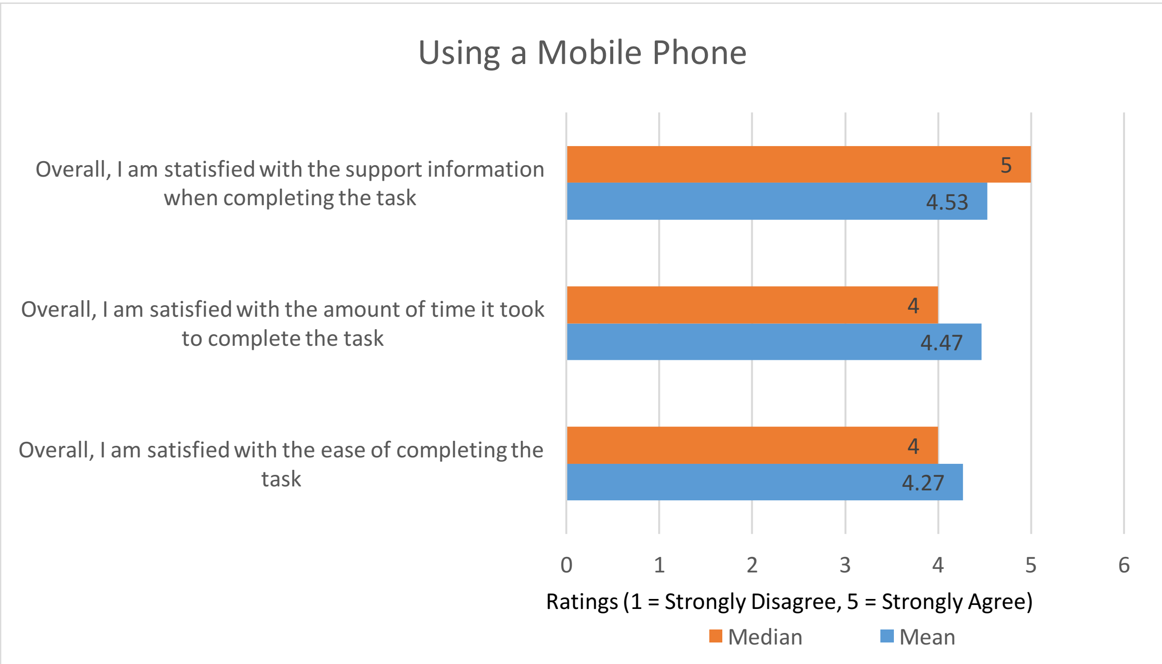

Figure 7-2: Effectiveness: Using a mobile phone (n=15)

The means in Figure 7-2 are all greater than 4 out of a maximum of 5; this signifies that participants were able to effectively use a mobile phone to complete tasks.

7.3.1.2. Using a computer

Participants were happy with the support information that was provided to them. However, tasks associated with using a computer took a bit longer as compared to tasks of using a mobile phone. This was mainly attributed to participants having to first adjust to how the Camera Mouse software (facial tracking) worked. Once participants became comfortable with the facial feature tracking, they interacted with the system with more ease. Figure 7-3 illustrates the responses from the participants. The mean scores show that the participants were satisfied with the support information, amount of time and ease of completing the using a computer tasks.

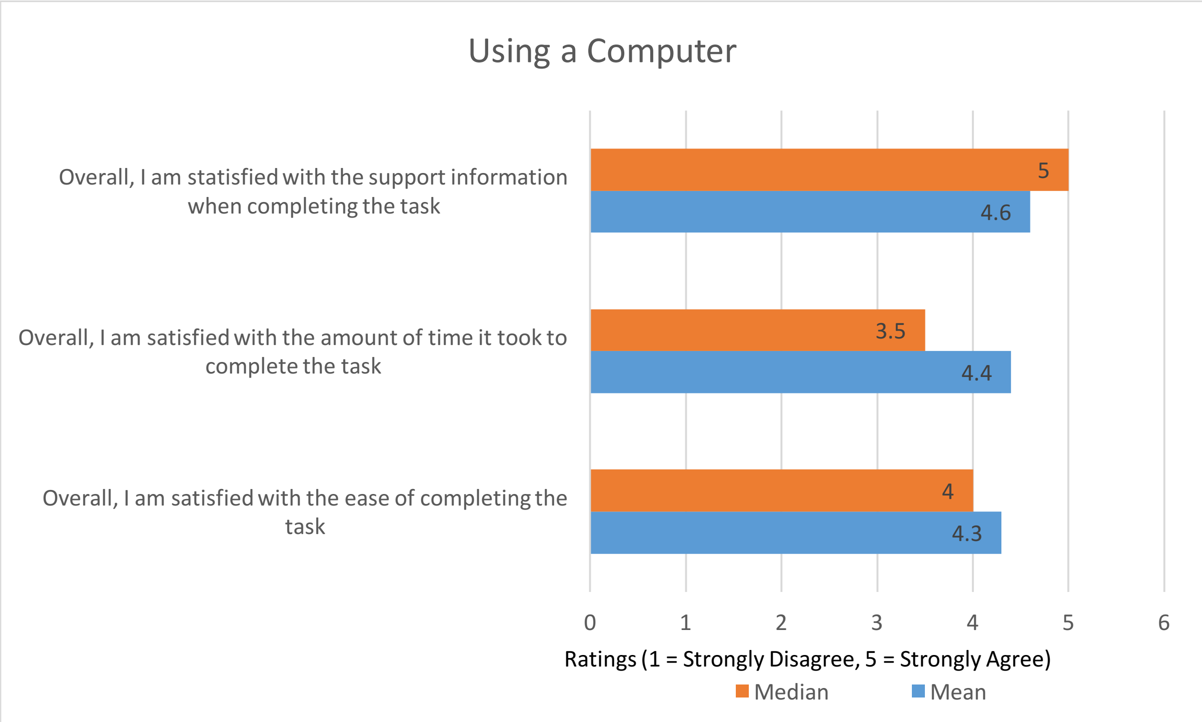

Figure 7-3: Effectiveness: Using a computer (n=15).

7.3.1.3. Controlling an Electronic environment

Figure 7-4 illustrates the responses from participants associated with controlling an electronic environment. Participants were more satisfied with tasks associated with controlling an electronic environment as compared to using a mobile phone and using a computer.

This may be attributed to two reasons:

1. The order of the tasks. Participants completed tasks in the following order: Using a computer, using a mobile phone, and controlling an electronic environment. By the time participants completed the using an electronic environment tasks, they had become more comfortable with the system.
2. Excitement: Most participants were quite excited about the possibility of controlling lights and a TV using their voices and facial commands.

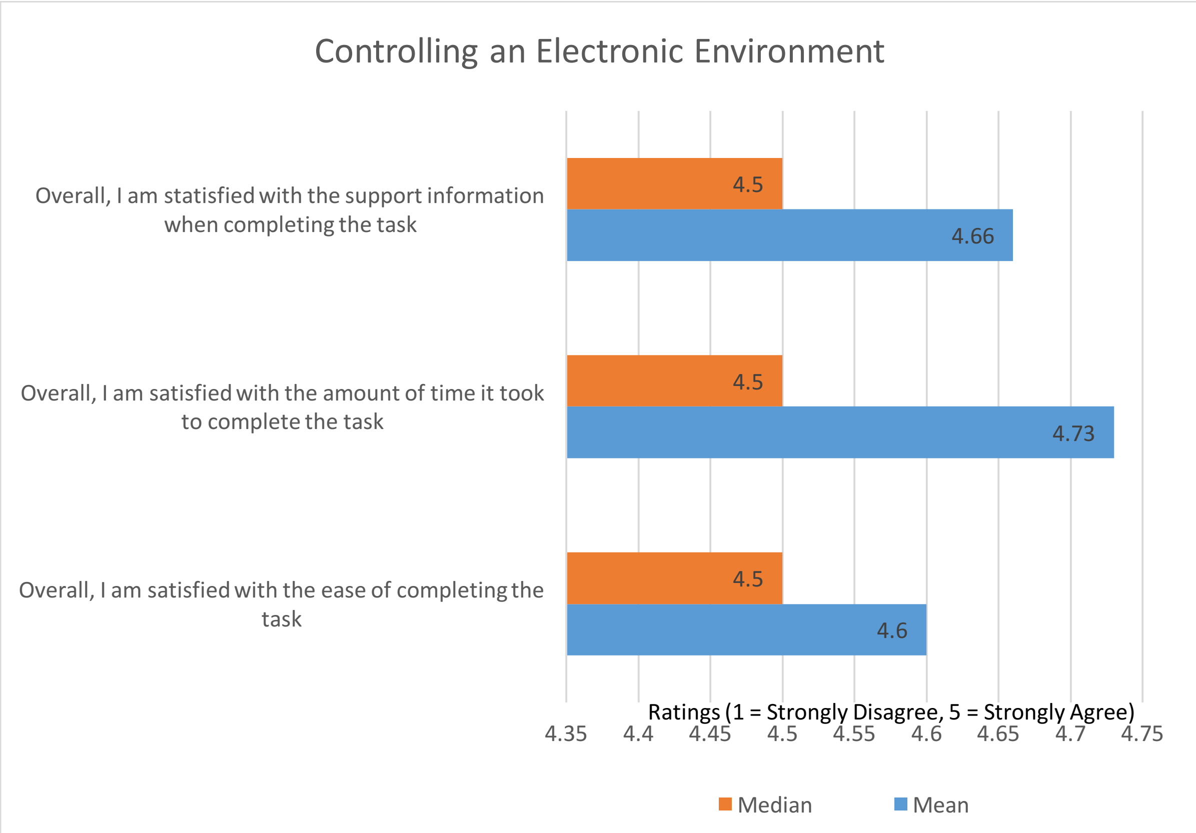

Figure 7-4: Effectiveness: Controlling an Electronic Environment.

Tasks associated with controlling an electronic environment had the highest mean scores as compared to using a phone, and using a computer tasks. This was attributed to the way participants easily related to how they experience these challenges in their daily lives.

7.3.2. Satisfaction

Satisfaction was measured using a combination of the NASA-TLX for cognitive load and the CSUQ for capturing overall satisfaction, usability and qualitative comments (Section 7.3.3). Similar to the effectiveness results presented in Section 7.3.1, satisfaction results were categorised into three categories, namely: using a mobile phone, using a computer, and controlling an electronic environment.

7.3.2.1. Using a mobile phone

Figure 7-5 depicts the mean, and median ratings for cognitive load for using a mobile phone. The key questions of Frustration, Effort, Performance, Temporal Demand, Physical demand, and Mental Demand are defined as (Hart & Staveland, 1988):

1. **Mental demand:** How mentally demanding were the tasks?
2. **Physical demand:** How physically demanding were the tasks?
3. **Temporal demand:** How hurried, or rushed, was the pace of the tasks?
4. **Performance:** How successful were you in accomplishing what you were asked to do?
5. **Effort:** How hard did you have to work to accomplish your level of performance?
6. **Frustration:** How insecure, discouraged, irritated, stressed, or annoyed were you?

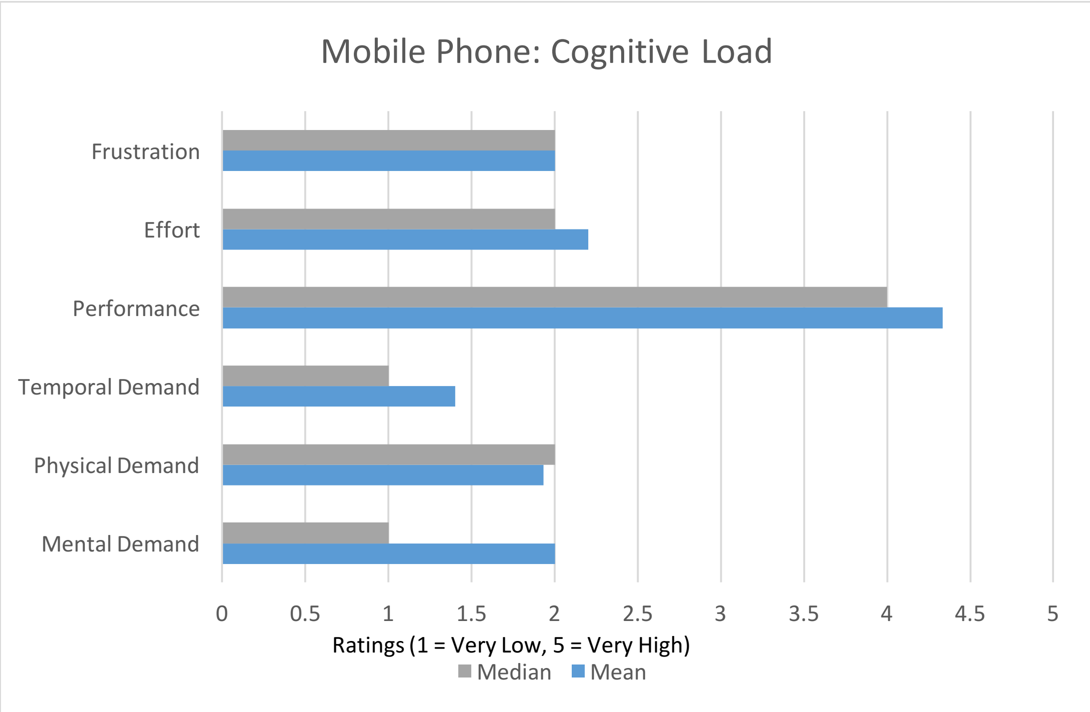

Figure 7-5: Cognitive Load: Using a mobile phone.

For frustration, effort, temporal demand, physical demand, and mental demand, the lower the values the better, while for performance, a higher value signifies a better experience. A few participants experienced frustration with using a mobile phone. This was mainly attributed to voice accents not being correctly interpreted on the first attempt. The overall mean score for performance was 4.3 out of a maximum of 5, which implies that participants were successful in completing the tasks that were asked of them. The frustration, temporal, physical, and mental demand all have mean scores less than 2, which implies that the tasks were intuitive. Effort had a mean score of 2.2, which is slightly higher than frustration, temporal, physical, and mental demand. This is attributed to the fact that some participants had to repeat the voice commands more than once before they could be correctly interpreted. Figure 7-6 illustrates the overall satisfaction of mobile phone related tasks using a radar chart. The perceived usefulness of the prototype had a mean score of 87%, which indicates that the participants thought that the prototype could have a positive impact on their lives. The satisfaction score was 92%. This indicates that the system provided a highly positive user experience. The ease of use received a mean score of 96%. The ease of learning received a score of 92%. The square shape of the radar chart in Figure 7-6 reflects the fact that the participants thought the system was easy to use, easy to learn, useful and were generally satisfied with the system.

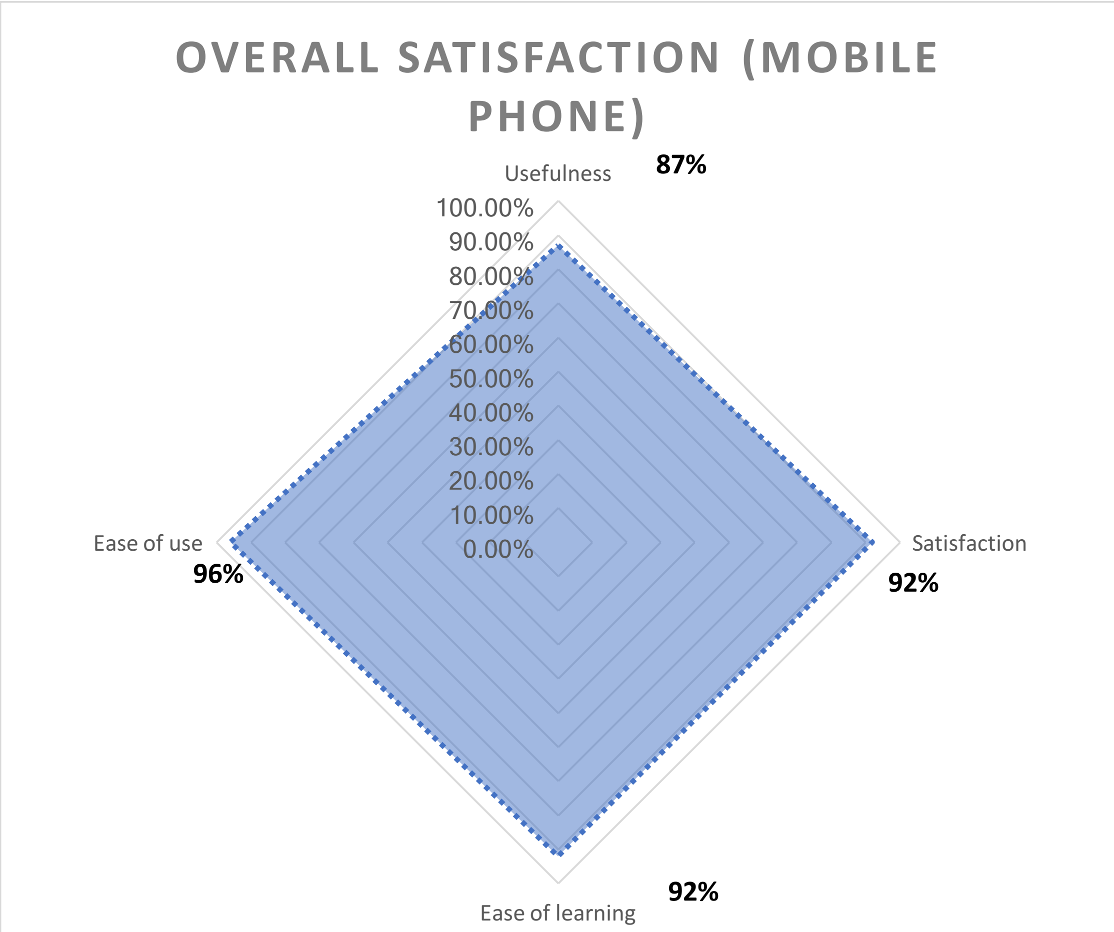

Figure 7-6: Using a Mobile Phone: Ease of Use, Usefulness, Ease of Learning and Satisfaction (n=15).

7.3.2.2. Using a computer

Figure 7-7 depicts the mean, and median ratings for cognitive load for using a computer.

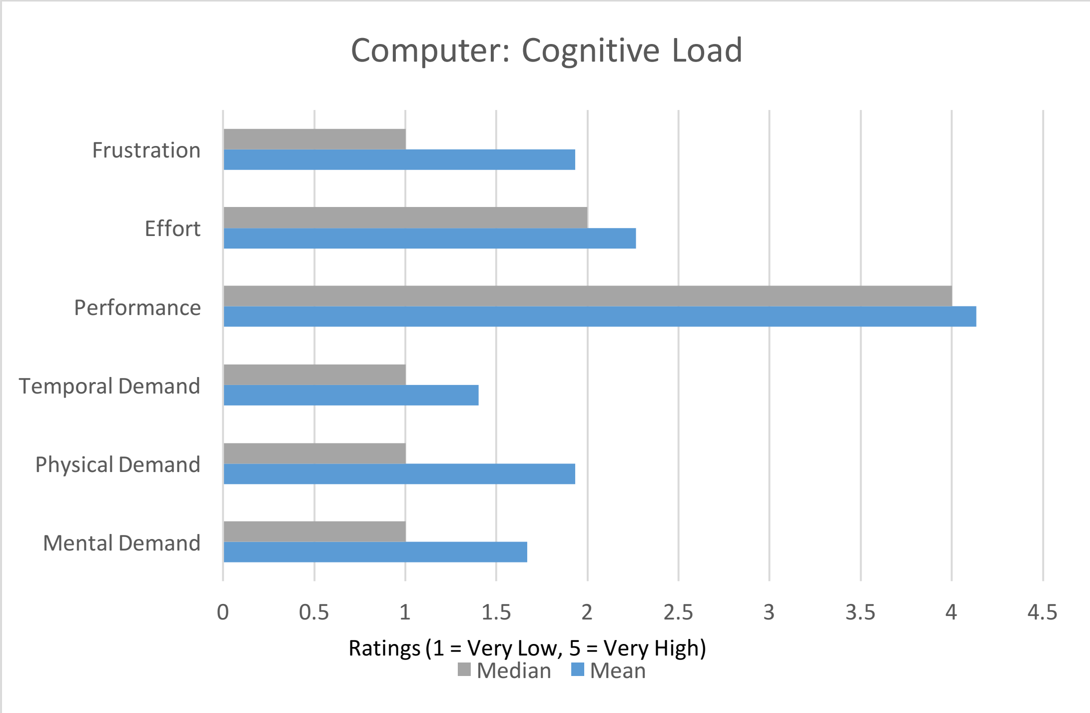

Figure 7-7: Cognitive Load: Using a computer (n=15).

Two participants were frustrated with the time it took to correctly configure the facial tracking software, and also experienced difficulty in moving their heads due to the nature of their disability. Performance had a mean score of 4.1**,** which implies that participants were successful in completing the tasks that were asked of them. Frustration, temporal, physical, and mental demand all had mean scores less than 2, which implies that the tasks were intuitive. Similar to the using a mobile phone tasks, some participants had accuracy problems with voice recognition, and this explains the mean score of 2.2 that was associated with effort.

Figure 7-8 illustrates the overall satisfaction of using a computer related tasks using a radar chart. The perceived usefulness of the prototype had a mean score of 92%, which indicates that the participants thought the prototype could have a positive impact on their lives. The satisfaction score was 89%, which is slightly lower than the using a mobile phone score. The ease of use received a mean score of 89.30%. The ease of learning received the lowest score of 85.30%; this is because a few participants experienced difficulty in using a computer. The square shape of the radar chart in Figure 7-8 reflects the fact that the participants thought the system was easy to use, easy to learn, useful and were generally satisfied with the system.

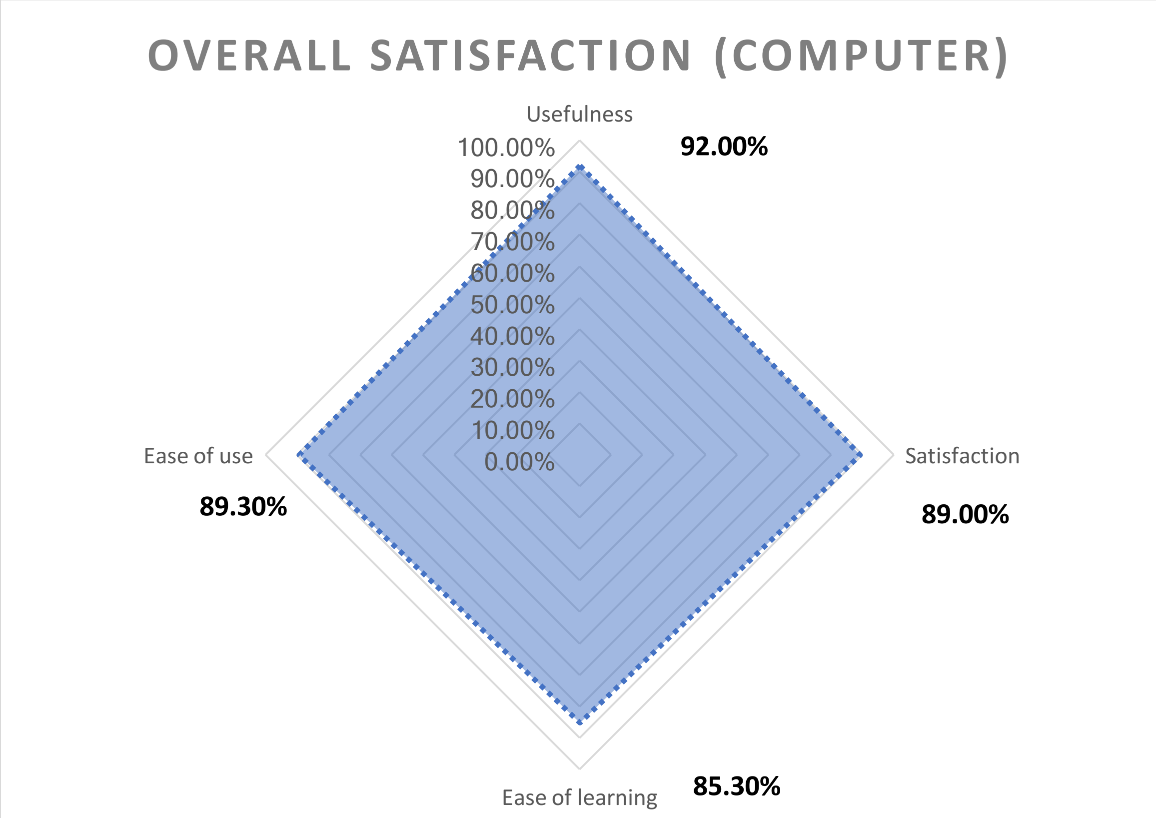

Figure 7-8: Using a Computer: Ease of Use, Usefulness, Ease of Learning and Satisfaction (n=15).

7.3.2.2. Controlling an Electronic Environment

Figure 7-9 depicts the mean, and median ratings for cognitive load for using a computer.

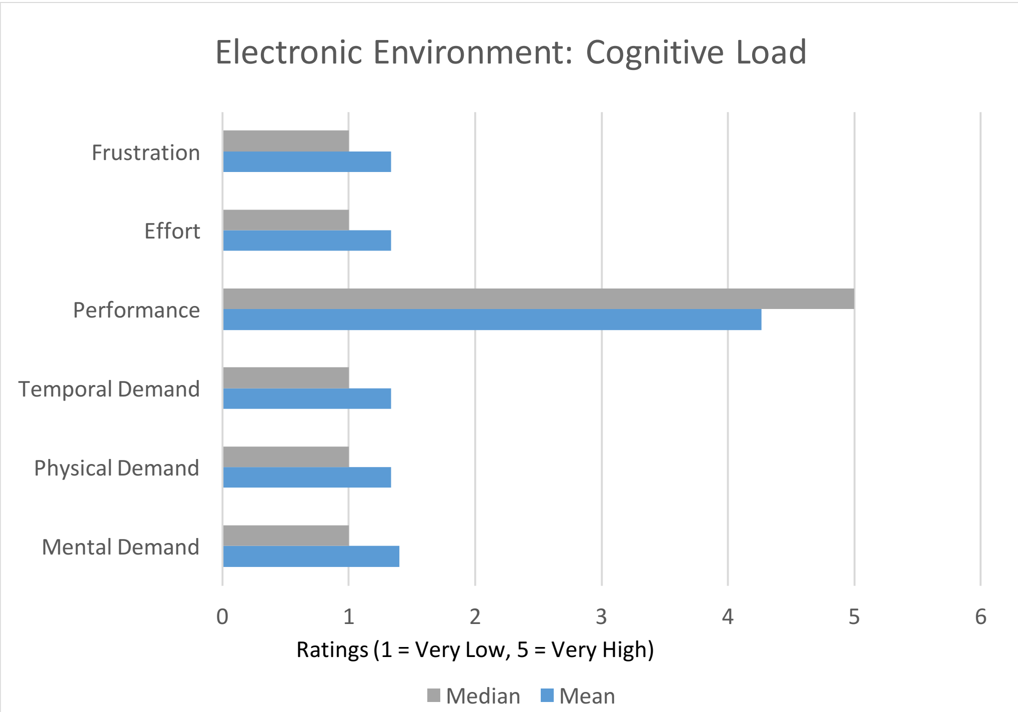

Figure 7-9: Cognitive Load: Electronic Environment (n=15).

Performance had a mean score of 4.2, which implies that participants were successful in completing the controlling an electronic environment tasks. Frustration, effort, temporal, physical, and mental demand all had mean scores less than 2, which implies that the tasks were intuitive. Tasks associated with controlling an electronic environment had the best cognitive load results as compared to the tasks associated with using a computer and a mobile phone. This can be partly attributed to the fact that these tasks were performed last, and participants had learnt how to use the various modes of interaction.

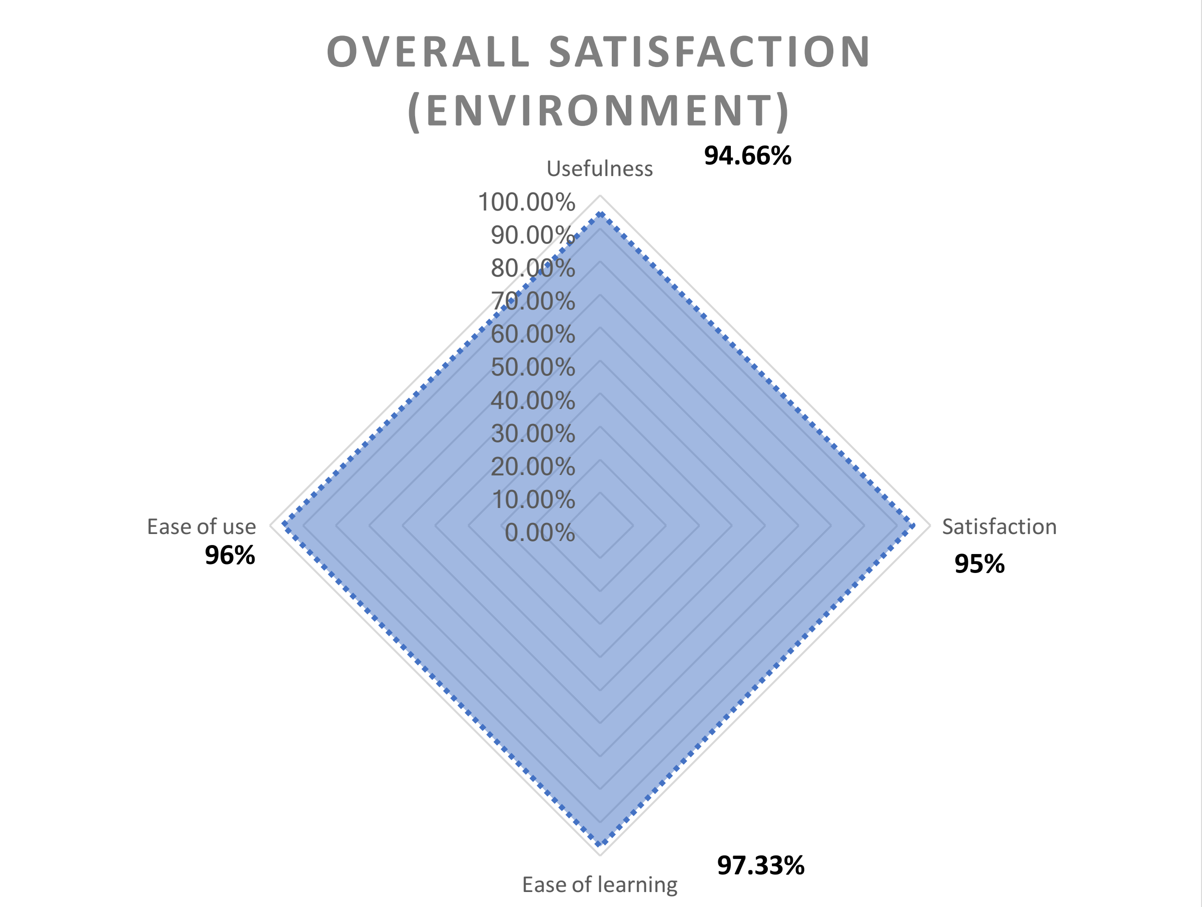

Figure 7-10: Electronic Environment: Ease of Use, Usefulness, Ease of Learning and Satisfaction (n=15).

The perceived usefulness of the prototype had a mean score of 94.66%, which indicates that the participants thought that the prototype could be beneficial to their lives. The satisfaction score was 95%. This indicates that the prototype provided a highly positive user experience. The ease of use received a mean score of 96%. The ease of learning had a score of 97.33%. The square shape of the radar chart in Figure 7-10 reflects the fact that the participants thought the prototype was easy to use, easy to learn, useful and were generally satisfied with the system.

7.3.3. Qualitative Findings

Qualitative data was captured from open-ended questions in the post-test questionnaire and comments from participants during the evaluation study. The feedback was categorised into positive, negative and general feedback. Table 7-3 shows the feedback for the mobile phone task.

Table 7-3: Feedback on using a mobile phone.

Positive Feedback	**Frequency**
It will help a lot of people that can only speak	1
It could definitely make you more independent.	1
That I can switch everything on and off with the phone	1
It is very easy and convenient	4
Very accessible	1
Negative Feedback	
When the software didn't recognize my voice	4
Took a lot of time to complete the tasks	1
General Comments for Improvements	
Should have pre-recorded sentences spoken in a user voice to recognize it and be able to execute commands successfully.	1
Suggestion to create a task to open and close curtains	1
Try to make it work with other objects	1

A few participants experienced difficulty in having their voices recognised, but the system was generally well received by all participants and they mentioned how it could have a positive impact on their lives. Three of the participants (P1, P2, and P5), who complained about voice recognition issues, had extreme cerebral palsy, and their voices were quite low as compared to other participants. This reinforces the argument that the unique nature of an individual's disability should be taken into consideration when designing solutions for them.

Table 7-4 shows the qualitative responses about using a computer. The possibility of interacting with a computer using their noses excited the participants.

Table 7-4: Feedback on using a computer

Positive Feedback	**Frequency**
The task is very original. I never thought that something like that ever existed.	1
Everything	4
It makes life simpler for those who can use it properly	2
It can assist independency and by being independent, it creates a positive mind set.	1
The computer can track my nose	1
You can use your nose	1
Negative Feedback	
Face recognition didn't allow the individual to move their head properly	1
General Comments for Improvements	
Mouse clicks too quickly and I wanted it to be slower	1

Table 7-5 provides a summary of the responses from participants as regards to controlling an electronic environment.

Table 7-5: Feedback on controlling an electronic environment.

Positive Feedback	**Frequency**
It's easy to use	3
I can use the phone to switch on the light	2
Enjoyed using it	2
Better have it patented	1
The idea is quite good	1
Not necessary to use fingers or hands	1
Negative Feedback	
It doesn't accurately recognize the voice commands	2
General Comments for Improvements	
None	

7.4. Discussion

The evaluation study went well with minimal incidents apart from the initial difficulty of recruiting participants that was experienced by the principal researcher. The difficulty was attributed to the non-personal recruitment option of emails. It is probable that potential participants were not convinced to turn up volunteer to different mobility problems. It was reported that the system was simple, easy to use and that its different functions were well integrated. The effectiveness of the prototype was rated highly by the participants (Section 7.3.1). Participants were also generally satisfied with the prototype. The good results could partly be attributed to the fact that an experimental evaluation aimed at identifying suitable interaction techniques for physically disabled individuals with limited hand use, was previously carried out (Chapter 5, Section 5.5). The experimental evaluation helped to eliminate head gesture navigation, which may have negatively affected the effectiveness and satisfaction results. However, some suggestions were made in order to add support for more household objects such as the ability to open and close curtains. It was also suggested to improve the voice recognition so that users do not have to repeat a given command more than once.

7.5. User Experience Questionnaire (UEQ) Results

The User Experience Questionnaire (UEQ) allows a quick assessment of the user experience of interactive products (Laugwitz, Held, & Schrepp, 2008). The format of the questionnaire assists users to express feelings, impressions, and attitudes that arise when they use a product. The scale of the questionnaire covers a comprehensive impression of user experience, i.e., measuring both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation). The questionnaire specifically measures the following:

1. Attractiveness: Overall impression of the product. Do users like or dislike it?

2. Perspicuity: Is it easy to get familiar with the product?

3. Efficiency: Can users solve their tasks with the product without unnecessary effort?

4. Dependability: Does the user feel in control of the interaction?

5. Stimulation: Is it exciting and motivating to use the product?

6. Novelty: Is the product innovative and creative?

The UEQ questionnaire is shown in Appendix E. The UEQ does not produce an overall score for the user experience. Because of the construction of the questionnaire, it makes no sense to build such an overall score (for example by calculating the mean for all scales), since this value cannot be interpreted properly due to the format of the questionnaire, which is included in Appendix E. The values for the single items are listed to allow researchers to detect outliers in the evaluations. If an item shows large deviations from the evaluations of the other items on the same scale, this can be a hint that the item was misinterpreted (for example because of a special context in the evaluation) by a large number of participants. The range of the scales is between -3 (horribly bad) and +3 (extremely good).

7.5.1. UEQ: Using a mobile phone

Figure 7-11 provides a summary of the UEQ results for using a mobile phone. All the tasks had positive scores for all the UEQ scales. This confirms the evaluation results that were discussed in Section 7.3.

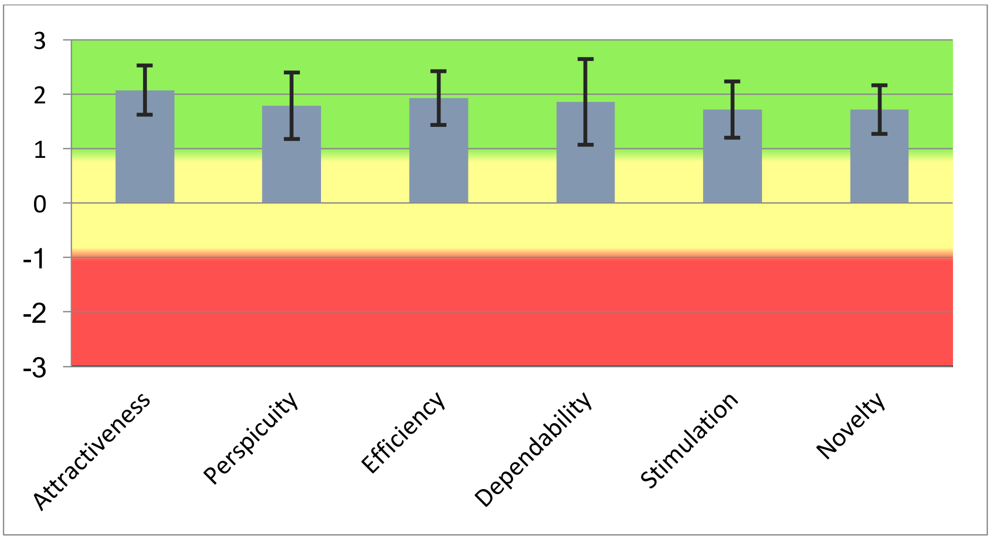

Figure 7-11: UEQ for using a mobile phone (n=15).

Table 7-6 shows the UEQ scales associated with using a mobile phone. The participants found the AAL service to be attractive. The scores for perspicuity, efficiency, dependability, simulation, and novelty were also positive. This signifies that the AAL service was well received by the participants.

Table 7-6: UEQ scales for using a mobile phone.

UEQ Scales	Mean
Attractiveness	2.071
Perspicuity	1.786
Efficiency	1.929
Dependability	1.857
Stimulation	1.714
Novelty	1.714

7.5.2. UEQ: Controlling an electronic environment

Figure 7-12 illustrates the UEQ results for tasks associated with controlling an electronic environment. The Novelty, Stimulation, Efficiency, and Attractiveness had higher scores as compared to 7.4.1. This also confirms the evaluation results presented in Section 7.3.

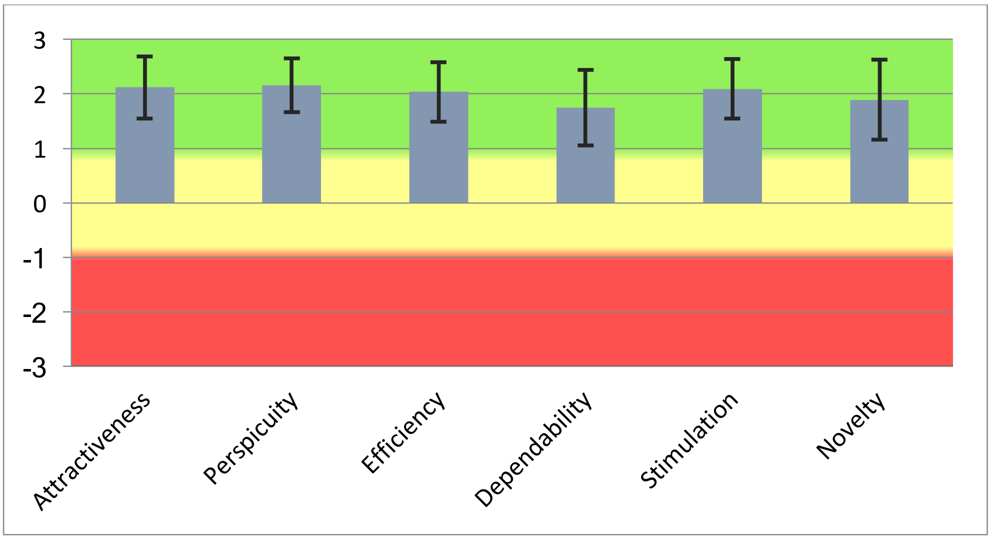

Figure 7-12: UEQ for controlling an electronic environment (n=15).

Table 7-6 shows the UEQ scales associated with controlling an electronic environment. The participants found the AAL service to be attractive. The scores for perspicuity, efficiency, dependability, simulation, and novelty were also positive. This signifies that the AAL service was well received by the participants. The participants also found this AAL service to be more stimulating as compared to the one of using a mobile phone (Section 7.5.1). Dependability had the lowest score, which was attributed to errors in voice recognition.

Table 7-7: UEQ scales for controlling an electronic environment.

UEQ Scales	Mean
Attractiveness	2.119
Perspicuity	2.161
Efficiency	2.036
Dependability	1.750
Stimulation	2.089
Novelty	1.893

7.5.3. UEQ: Using a computer

Figure 7-13 illustrates the UEQ results for using a computer. The tasks had positive scores. However, the novelty score was the lowest as compared to using a mobile phone and controlling an electronic environment. This can be attributed to the fact that participants had been already exposed to different ways in which to interact with a computer, such as using a mouth stick. However, using a mobile phone and controlling an electronic environment was new to them.

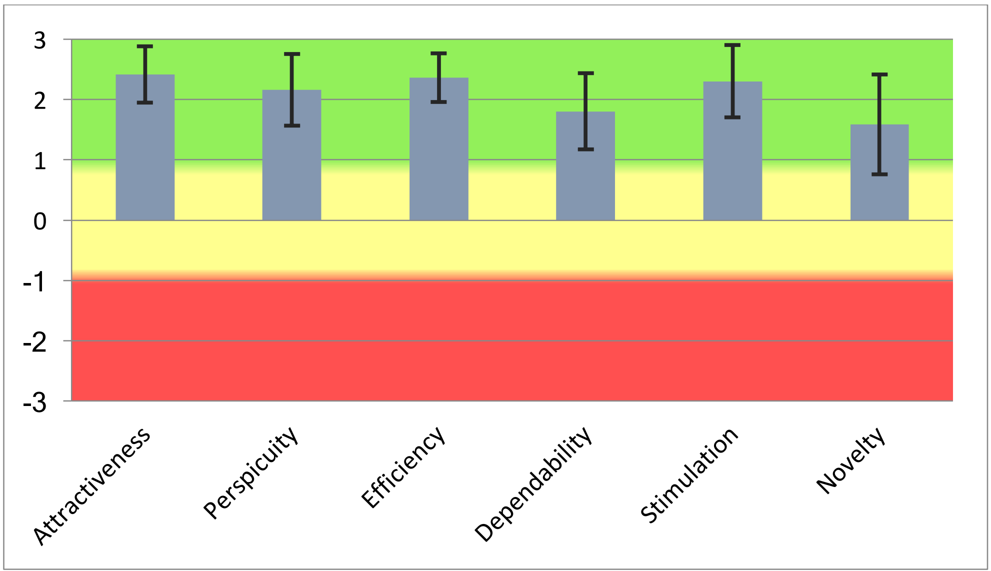

Figure 7-13: UEQ for using a computer (n =15).

Table 7-8 shows the UEQ scales associated with using a computer. The participants found the AAL service to be attractive. The scores for perspicuity, efficiency, dependability, simulation, and novelty were also positive. This signifies that the AAL service was well received by the participants. Novelty has the lowest score, which may be attributed to the fact that computers are ubiquitous, and participants had been exposed to interacting with them. For example, by using a mouth stick to tap on a keyboard.

Table 7-8: UEQ scales for using a computer.

UEQ Scales	Mean
Attractiveness	2.417
Perspicuity	2.161
Efficiency	2.363
Dependability	1.804
Stimulation	2.304
Novelty	1.589

7.6. Reflection

Section 5.2 defined the concept of interaction techniques. Interaction techniques facilitate communication between humans and computing devices/systems. The choice of interaction techniques used by the prototype were evaluated in this chapter (Chapter 7) was motivated by experimental evaluation of various interaction techniques (Section 5.5). This section compares results of the interaction techniques with literature and discusses potential improvements to the interaction techniques used in the prototype.

7.6.1. Voice Interaction

Voice was used as an interaction technique, and the evaluation results discussed in Section 7.3 were generally good. However, a few participants experienced issues with voice recognition, which can be addressed. This section focusses on how voice recognition as used in this study can be improved upon.

Section 5.2.2.1 discussed the main components of an ASR system. One of these components is training data, which is used to improve the accuracy of speech recognition. The IBM speech to text API services used in the prototype are built using a corpus of general, everyday words and pronunciations (Bhavik, 2016). While using the default corpus works well for common conversation, it can fall short when it comes to accurately transcribing unique accents, industry specific words, or uncommon dialect. Only three of the 15 participants were native English speakers, this explains the issues with voice recognition that were experienced by some of the participants. Voice recognition can be improved upon by training custom models for each user.

The IBM speech to text API allows for language model customisation (IBM, 2017b) . The speech to text service can be trained using audio input from the intended users. This way, custom models that align more closely with unique dialects of users can be created in order to accurately convert unique accents, topics, and words to text. Below is an outline of the process for creating a custom model (IBM, 2017a):

1. Create a new custom language model: Creating a custom model involves sending an Http POST request to an IBM API endpoint. The POST parameters are *name (uniquely identifies a language model in a given system), base_model_name (The name of the language model that is to be customised e.g. US English).* Other optional parameters are *dialect (parameter is currently meaningful for Spanish models), and*

description (can be used to capture detailed information about the purpose of the model).

2. Add a corpus to the custom language model: A corpus is a plain text file that ideally contains sample sentences from your domain. The IBM speech-to-text service parses the file's contents and extracts any words that are not in its base vocabulary.
3. Add words to the custom language model: An alternative to adding a corpora is adding individual custom words to the model directly. This is ideal if there are a few words or sentences that need to be added to the custom model. Multiple pronunciations of each word can be added. This feature becomes important especially when developing a solution for non-native English speakers.
4. Train the custom language model: The model must be trained on the custom words. The model is only able to use custom or new words after being trained.

Future work can improve the speech recognition by adding functionality of creating and using custom language models to the prototype. The custom models can be trained using the voice commands (Appendix C).

7.6.2. Facial Feature Tracking

Section 5.4 motivated the need for the use of head movements and or facial feature tracking as interaction techniques to assist individuals with limited hand use. The Camera Mouse software (Section 5.4.1) was used to interact with a computer. The participants generally had a positive experience when using Camera Mouse as evidenced by the qualitative interview results (Section 7.3.3). When Camera Mouse is started, a small square appears on the screen, a user is required to position a facial feature to be tracked such as a nose inside the square. The square appears for a specific time duration, default being 5 seconds; the facial feature within the square after 5 seconds is tracked and is used for navigation. Some participants complained that the initialisation period of 5 seconds was not enough for them to comfortably position a facial feature within the square window. It is recommended that this duration is customized per user.

7.6.3. Discussion

The interaction techniques chosen for this research, namely voice and facial feature tracking can be used to the control of other household electronic devices. The electronic devices need to have the ability to either connect to a local network or receive infra-red signals (Šenk, Tarjan, Ostojić, & Stankovski, 2010) such as controlling a thermostat, and controlling a radio.

7.7. Conclusion

The objective of this chapter was to meet Research Objective 7 (RO7), which was *"To evaluate the effectiveness and usefulness of the prototype"*.

An evaluation study was conducted to determine the effectiveness of the developed prototype. The prototype enabled a user to *use a phone, control electronic devices in a home environment,* and *interact with a computer*. Each participant spent about an hour interacting with the prototype multimodally. The evaluation study was conducted over a period of a month with fifteen participants from the Nelson Mandela University and Cheshire Home. The evaluation period took a long time, because the researchers had to work according to the participants' schedules. Questionnaires were used to measure effectiveness and satisfaction. Qualitative comments were also captured using questionnaires. The results of the evaluation study were highly positive. The results were slightly higher using a mobile phone and controlling the environment, as compared to using a computer. The satisfaction results also showed that the prototype was easy to use and useful.

The fifth phase of the DSR process is concerned with the evaluation of an artefact. This chapter has completed this phase. Useful feedback that can be used to extend the functionality of the prototype was also received. The next chapter will provide an overview of the contribution of this research to the existing knowledge base of the research field, i.e. designing for disability.

Chapter 8: Proposed Framework

8.1. Introduction

This research started off with a need to empower disabled individuals to be more independent in their daily lives. The DSR methodology was used to guide the research process. This chapter aims to highlight the knowledge obtained from this research study.

8.2. Theoretical Contributions

A framework may be defined as a system of concepts, assumptions, expectations, beliefs and theories that support and inform a research study (Maxwell, 2013). In multidisciplinary research, multiple bodies of knowledge belonging to different disciplines are explored. A conceptual framework can help with a better understanding of the phenomenon being investigated. The main features of a conceptual framework are (Jabareen, 2009):

1. A construct in which each concept plays an integral role
2. Provides an interpretive approach to social reality
3. Rather than offering a theoretical explanation, as do quantitative models, conceptual frameworks provide understanding
4. A conceptual framework does not provide knowledge of hard facts, but rather, "soft interpretation of intentions"
5. Conceptual frameworks are indeterminist in nature and therefore do not enable us to predict an outcome
6. Conceptual frameworks can be developed and constructed through a process of qualitative analysis
7. The sources of data consist of many discipline-oriented theories that become the empirical data of the conceptual framework analysis.

The Design Science Research methodology involves three cycles, which are discussed in Chapter 1, and illustrated in Figure 1-3. One of the cycles is the rigor cycle, which emphasises the need to ground research in existing theory, and to contribute to the existing body of knowledge. Sections 8.2.1, 8.2.2, and 8.2.3 discuss the various rigour cycles of this research.

8.2.1. Framework: 1st Iteration

Figure 8-1 illustrates the first iteration of a framework for designing AAL services for disabled individuals. Chapter 2 identified the ICF as a suitable conceptual framework for understanding the capabilities and limitations of individuals with a given disability.

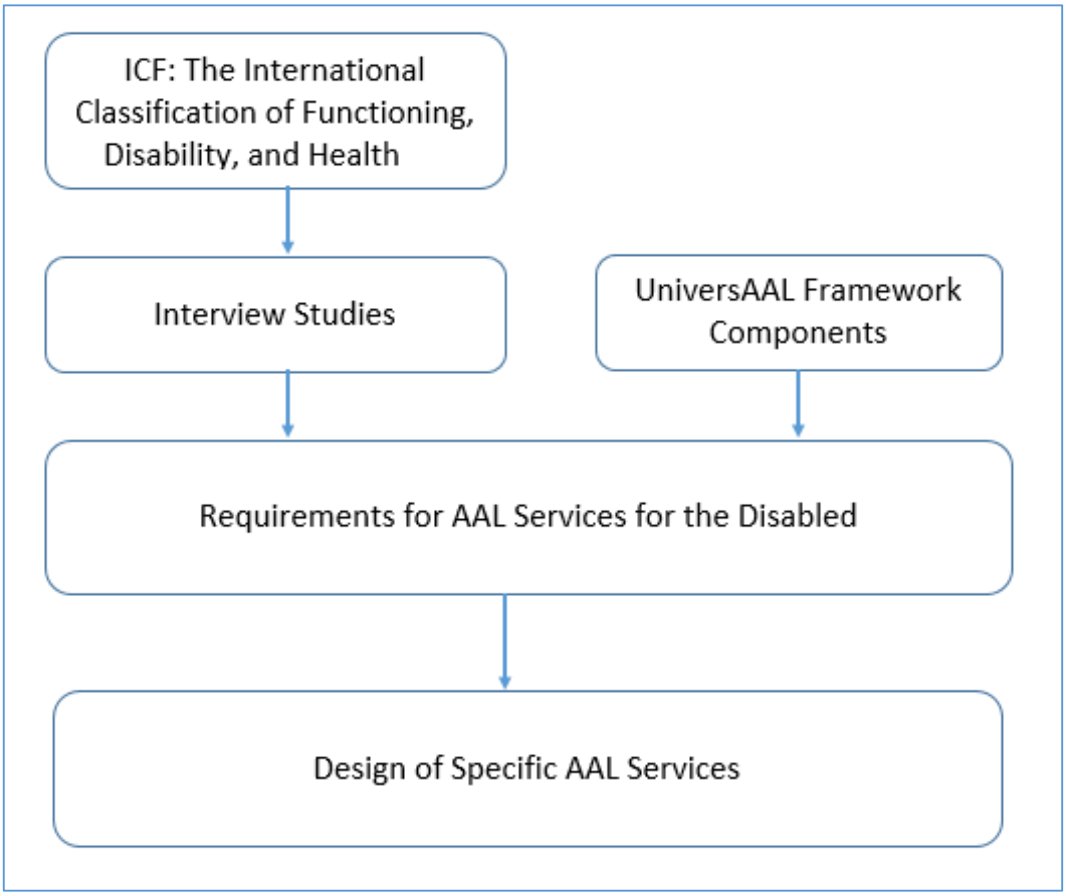

Figure 8-1: First Iteration: Framework for Designing AAL Software Services for Disabled Individuals.

The requirements for AAL services are identified by first using the ICF framework to carry out a literature review aimed at identifying the general needs of individuals with a given disability. The identified needs are then used as input for designing and carrying out interview studies with disabled individuals. A small set of open-ended interview questions is important, as the goal is to have interview participants freely share their thoughts under a given theme. The specific challenges identified from the specialization of the ICF and literature are used as probes during the interview studies. Probes are essential in situations when interview participants give brief responses to questions.

8.2.2. Framework: 2nd Iteration

Chapter 5 (Section 5.1) motivated the need to select appropriate user interaction techniques for a given disability type. Figure 8-2 illustrates a modified framework that includes a section on interaction techniques.

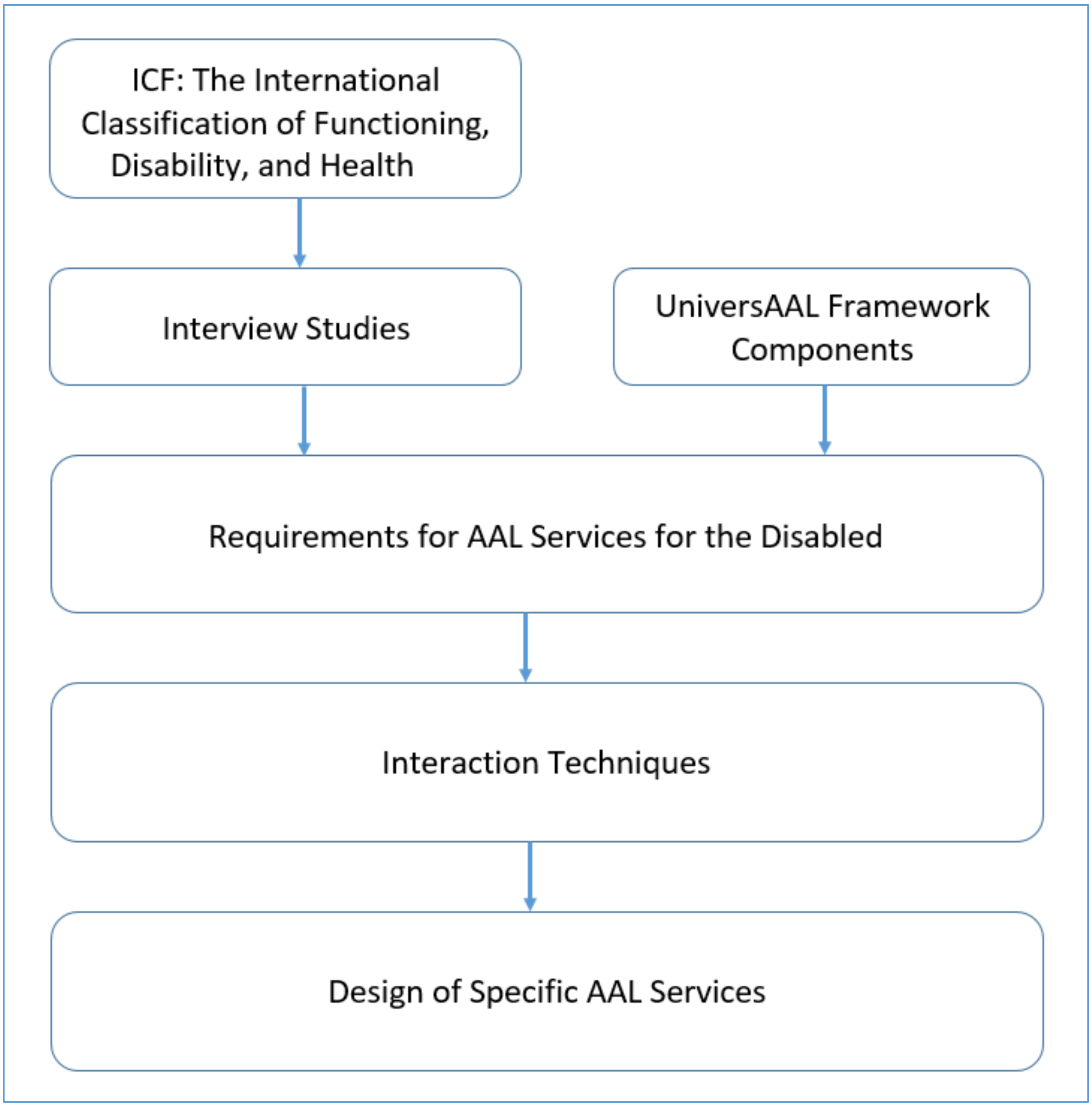

Figure 8-2: Second Iteration: Framework for Designing AAL Software Services for Disabled Individuals.

8.2.3. Framework: Final Iteration

Figure 8-3 illustrates the proposed framework for Designing AAL services for Disabled individuals. Chapter 5 (Section 5.5) highlights the importance of evaluating interactions techniques with disabled individuals in order to identify the most suitable interaction techniques for a given task. Chapter 7 also highlighted the importance of carrying out one or more usability evaluations depending on the feedback from participants.

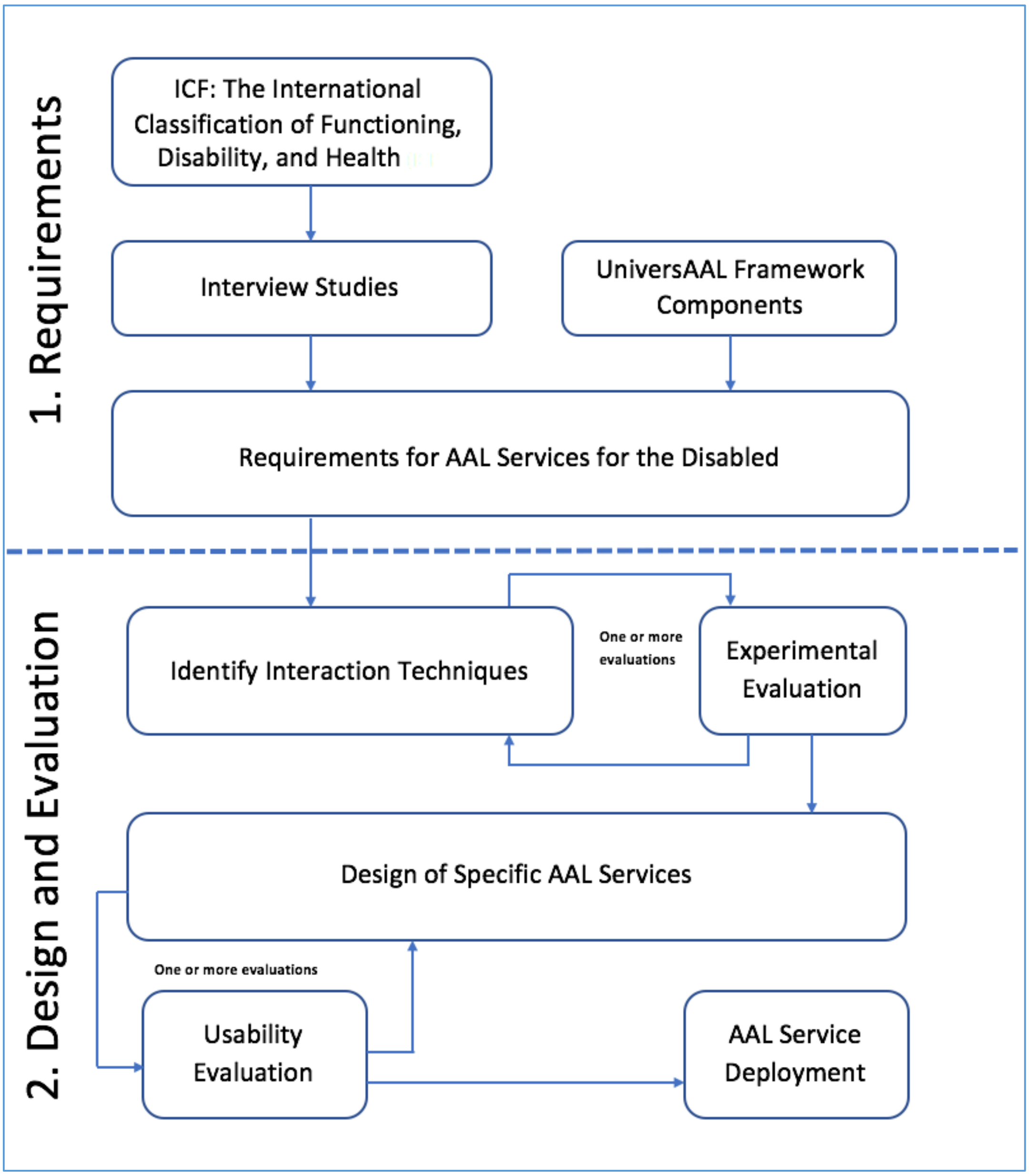

Figure 8-3: Final Iteration: Framework for Designing AAL Software Services for Disabled Individuals.

The framework is divided into two sections, namely, Requirements, and Design and Evaluation. Requirements is concerned with identifying and contextualizing software requirements, while Design and Evaluation is concerned with delivering usable software for the target users.

The various components of the framework are:

1. **ICF:** The ICF helps to clearly define the characteristics of the target participants. The characteristics include Body functioning and structure (Chapter 2, Section 2.4). This information was then used to narrow down the scope of a literature study on disability challenges.
2. **Interview Studies:** Challenges identified from literature may lack contextual information about the intended target audience. The challenges can be used to design open-ended and non-leading questions. A number of probes can also be created from the challenges identified from literature. The probes are necessary in situations when participants give short answers to questions. Probes can help reveal more information (Chapter 4).
3. **UniversAAL Framework Components:** The synthesis of challenges identified from literature and interview studies informed the decision on which UniversAAL components should form part of the technological requirements (Chapter 3). The UniversAAL components are not exclusive; rather they provide a starting point to think about a solution.
4. **Requirements:** A set of tasks that the intended AAL services aims to support.
5. **Identify Interaction Techniques:** Interaction is the manner in which disabled individuals are able to use the AAL services. The requirements and body limitations of the disability target group, were considered when deciding on the initial set of proposed interaction techniques (Chapter 5).
6. **Experimental Evaluation:** Helps identify practical and usable interaction techniques, and also excludes the impractical techniques. Low-level prototypes, or basic software prototypes that make use of the proposed interaction techniques, are designed and implemented. The intended users (disabled) are involved in the evaluation of the interaction techniques to identify the most suitable for a given task. One or more evaluations may be carried out (Chapter 5).
7. **Design and Implementation of Specific AAL services:** The selected interaction techniques are used to design and implement the AAL requirements (Chapter 6).
8. **Usability Evaluation:** A usability evaluation study is carried out with a target set of participants. The feedback received may be used to improve the artefact. More

evaluation studies can then be carried out to the satisfaction of the solution developers (Chapter 7).

9. **AAL Service Release:** The developed AAL service may be released to the public, or for private use.

The proposed conceptual framework for designing Ambient Assisted Living Services for disabled individuals, satisfies all the main components of a conceptual framework discussed earlier in Section 8.2.3. The iteration cycles illustrated in Figure 8-3 mirror the specification by the DSR design cycle discussed in Chapter 1 (Section 1.7), and illustrated in Figure 1- 3, that emphasises the need to have one or more iterations during the design phase.

8.3. Guideline for the use of the proposed Framework

Figure 8-3 illustrates a Framework for Designing AAL Software Services for Disabled Individuals. A description of the various components of the framework is provided in Section 8.2. Whereas the descriptions of the components may suffice for some technical users, a guideline on how to use the framework can make it easier to apply. A guideline is presented below, and it is grouped into two sections namely:

8.3.1. Requirements

The upper section of the framework is called **"Requirements"**. This is because it is concerned with gaining a deep understating of the problem that is being addressed and how the target group of users currently experience and cope with the problem (phenomenon under investigation). Identifying requirements involves the following steps:

1. **Describing disabled persons in terms of the ICF framework**: This helps a researcher/solution developer to have a uniform and scientific way of describing the intended users of an artefact.
2. **Literature review**: A description of the intended users is used to narrow down literature on the types of challenges faced by a group of disabled individuals.
3. **Interview Protocol**: Using the knowledge obtained from the literature study, interview questions are formulated. The interview questions should be designed in such a way that a researcher can gain a better understanding of the phenomenon under investigation.
4. **Interviewing target users**: The protocol is used to interview disabled persons of interest and an analysis of the interview results is used to come up with system requirements of an artefact.

5. **Technical Requirements**: The UniversAAL framework is used to identify key AAL components that can address requirements identified from the interview studies.

8.3.2. Design and Evaluation

The lower section of the framework is called **“Design”**. This is because it is concerned with designing an artefact that fulfils the identified requirements. Design involves the following steps:

1. **Identification of interaction mechanisms:** Low level prototypes can be used to understand the practicality of interaction mechanisms that are envisioned by a researcher. Less practical interaction mechanisms can be eliminated during this stage.
2. **Experimental evaluation of interaction mechanisms:** A prototype of the various interaction mechanisms can be developed and evaluated with a small set of intended users. This can help a researcher understand how the interaction mechanisms are likely to be received by users. The researcher can make changes as needed.
3. **Development of artefact and usability evaluation:** Once the interaction mechanisms are confirmed, all the features of the artefact can be developed. A usability evaluation is then carried out. The feedback from the evaluation can determine if improvements to the design are necessary if not, the artefact can then be used by the target users.

The guidelines presented in this section are another practical contribution of this study and are envisioned to make the framework easier to implement by its users.

8.4. Conclusions

Chapter 2 explored disability, and identified some of the challenges that are experienced by disabled individuals. Chapter 4 identified the software requirements that were implemented in this study. The various interactions with disabled individuals, and a review of technologies, showed that technology innovations for disabled individuals are as ubiquitous as compared to innovations for able-bodied individuals.

The proposed theoretical framework can assist designers and developers to better understand the needs of disabled individuals and design appropriate solutions. The next chapter concludes this research by highlighting the various contributions made.

Chapter 9: Conclusions

9.1. Introduction

The main aim and focus of the research was to improve the design process of assisted living technologies for disabled individuals. This was achieved by proposing a conceptual framework in Chapter 8. This research followed the DSR methodology, and each step of this methodology was discussed in different chapters (2-8). Chapter 2 defined disability together with some of the challenges that are experienced by disabled individuals. Chapter 3 reviewed and discussed various technologies that can assist disabled individuals in being more independent. Interviews were held to obtain primary data on how disabled individuals experience disability, and their thoughts on assisted technology. The interview design and results are discussed in Chapter 4.

A key issue that was observed from interview studies, and also backed up by literature, is the various ways in which disabled individuals interact with technology. Chapter 5 provides a review of various interaction techniques, and also reports on experimental evaluations that were carried out to identify the most suitable interaction techniques.

Chapter 6 reports on the design of a prototype that was informed by the software requirements from Chapter 4. The evaluation of the prototype was discussed in Chapter 7. Chapter 8 discusses and emphasised the theoretical contributions of this research which is a Framework for designing AAL services for disabled individuals.

9.2. Review of Research Questions

The proposed framework (Chapter 8) was validated by using it to design three AAL services to assist disabled individuals with some of their challenges. The challenges were identified through interview studies with a representative sample of disabled individuals. Evaluation studies were carried out in order to evaluate the efficacy of the developed AAL services.

The main research question that was addressed by this research was the following:

How can AAL services be designed to assist disabled individuals in a home environment?

The above research question was answered by addressing the following sub-questions identified in Chapter 1:

RQ 1. What are the challenges faced by disabled individuals? (Chapter 2)

RQ 2. How can ICT be used to address some of the challenges faced by disabled individuals in a home environment? (Chapter 3)

RQ 3. What are the requirements for enabling independence of disabled individuals in a home environment? (Chapter 4)

RQ 4. What interaction techniques can be used to implement the identified requirements? (Chapter 5)

RQ 5. How can ICT solutions be designed to support the identified challenges? (Chapter 5 and 6)

RQ 6. How effective are the designed solutions in addressing the identified challenges? (Chapter 7)

RQ 7. What are the design recommendations resulting from this research? (Chapters 8 and 9)

9.3. Research Achievements

This research has shown that AAL services can be used effectively to enable disabled individuals to be more independent in their home environments. The aim of this research was addressed by following the DSR methodology described in Chapter 1.

The first research question (RQ1) was addressed in Chapter 2 by conducting the *Explicate Problem* and *Outline Artefact and Define Requirements* DSR activities. The concept of disability was defined, and various theoretical models of disability reviewed. This chapter narrowed down the focus of this research to individuals with physical disability. A review of challenges experienced by physically disabled individuals was carried out. Support aids that can be used by disabled individuals were also discussed.

Chapter 2 helped narrow down the research scope of this study. It also showed that even within physical disabilities, a further breakdown is necessary when deciding on support aids for disabled individuals. This is because individuals with the same disability may have slightly different body functioning.

Chapter 3 addressed the second research question (RQ2) of this research. RQ2 was also addressed using the *Explicate Problem* and *Outline Artefact and Define Requirements* DSR activities. The concept of assisted living was introduced and defined in this chapter. Various technologies exist that may help disabled individuals. It was deemed necessary to first identify existing assisted living frameworks, and the identified frameworks were then used to guide the technology review process. The UniversAAL framework was chosen as the most suitable framework to be used for understanding the various technology components that make up an assisted living environment, and defining technology requirements for a given problem.

The third research question (RQ3) was addressed in Chapter 4 using a combination of the *Explicate Problem* and *Outline Artefact and Define Requirements* DSR activities. Chapter 4 described the method and results of an interview study to determine the challenges faced by physically disabled individuals. Interview studies were carried out in Port Elizabeth, South Africa and Kampala, Uganda. This chapter identified the requirements for this research study. It was noted that the social-economic factors of disabled people impacts their view of assistive technology. The persons interviewed in Port Elizabeth had access to better disability support aids and government funding, compared to their counter parts in Uganda. This directly affected their view of assistive technology. Whereas individuals in Uganda agreed that assistive technologies may improve their lives, their most important needs are basic support aids such as wheel chairs and walking sticks. AAL technology is viewed as being out of reach for their pockets. This is in contrast to the South African participants who have access to basic support aids, and hence are eager to learn more about the possibilities of AAL technologies.

Chapter 5 partially addressed the fourth research question (RQ4) by identifying suitable interaction techniques for the requirements specified in Chapter 4. The third phase of the DSR process is concerned with the design and development of an artefact. Chapter 5 fulfilled this phase by identifying suitable interaction techniques that may be used by physically disabled individuals with limited hand use. A review of various interaction techniques that may be used by disabled individuals to interact with technology, was carried out. Experimental evaluations with five disabled individuals were conducted with the aim of identifying the most suitable interaction techniques to be used in a summative evaluation study. The experimental evaluations were deemed necessary because disabled individuals need to interact with technology in creative ways. Identifying practical interaction techniques is important, and may improve the usability of a product, and also save costs that may have been invested in building interaction techniques, which disabled individuals may find impractical.

Chapter 6 addressed the fifth Research Question (RQ5), by discussing the design and implementation of the prototype that fulfil the requirements identified from the interview studies in Chapter 4. Similar to Chapter 5, Chapter 6 also fulfilled the third phase of the DSR methodology.

Chapter 7 addressed the sixth research question (RQ6), which involved the second iteration of the *Design and Develop Artefact, Demonstrate Artefact* and *Evaluate Artefact* DSR activities. A prototype system was implemented, and 15 physically disabled individuals were involved in the usability evaluation of the system. The tasks were categorised into three sections, namely, using a computer, using a mobile phone, and controlling an electronic environment. Overall, the participants had a positive view of the prototype, and they agreed that it could bring some independence to their lives.

Chapters 8 and 9 addressed the seventh research question (RQ7) of the research, which assisted in adding knowledge to the existing knowledge base on designing for disabled individuals. This knowledge was represented in terms of a framework for designing AAL services for the physically disabled.

9.4. Summary

The DSR methodology was followed successfully for this research. The iterative process, supported by the DSR methodology, was successfully used in the requirements identification, as well as the design and evaluation phases within this research.

Section 1.7.3 discussed a fourth cycle of DSR known as Change and Impact that is mainly concerned with factors that are external to the design artefact and how those factors may impact the artefact design over time. The framework proposed as part of this research (Chapter 8) may be used to better understand the external environment. Table 1-2 described the guidelines for the DSR methodology that were identified by (Hevner & Chatterjee, 2010). The extent to which these guidelines were supported by this research are summarised in Table 9-1.

Table 9-1: Support for the Guidelines of the DSR Methodology.

	Guideline	Support
1.	Design as an Artefact	The prototype was designed to enable independence for physically disabled users in a home environment.
2.	Problem Relevance	The problem addressed in this research is the need to be more independent in a home environment. Interview studies with disabled individuals confirmed the problem.
3.	Design Evaluation	An expert evaluation was carried out followed by an experimental evaluation with disabled individuals. The experimental evaluation aimed to determine the most suitable interaction techniques for disabled users was conducted. A summative evaluation of the prototype system with 15 disabled individuals was also carried out.
4.	Research Contributions	A framework was proposed to inform the future design of assisted living smart home technologies. This contribution represents the knowledge added to the existing knowledge base on disability design.
5.	Research Rigor	Suitable interaction techniques were selected to address the requirements of this study. An experimental evaluation was used to determine the suitability of these interaction techniques.
6.	Design as a Search Process	A literature study was used to determine the challenges faced by disabled individuals. An interview study was used to determine how disabled individuals experience the identified challenges, and also identify functional requirements for this research, to be supported by the prototype.
7.	Communication of Research	A conference short paper was presented and two journal articles were submitted.

9.5. Requirements Supported

At the end of Chapter 4 (Section 4.6), functional requirements were identified from the challenges experienced by physically disabled individuals. Table 9-2 describes the extent to which these requirements were supported by the prototype.

Table 9-2: Extent of Support for Functional Requirements.

#	Requirements	Functionality	Supported?
1	Using a mobile phone	- Making phone calls - Cancelling phone calls - Ending phone calls - Adding phone contacts - Sending text messages - Playing music - Pausing music - Answering phone calls - Rejecting phone calls	Yes
4	Using a computer	- Desktop navigation - Opening a specific web site e.g. www.news24.com - Web page navigation - Playing music - Pausing music	Yes
6	Controlling an electronic environment	- Turning on lights - Turning off lights - Increasing a TV's volume - Decreasing a TV's volume - Navigating one channel upwards - Navigating one channel downwards - Navigating to a specific channel number	Yes

The way individuals use mobile phones, computers, and electronic devices is motivated by their interests. The prototype is limited to supporting the functionality listed in Table 9-2 because they are commonly used in daily life, for example; making phone calls (using a mobile phone), navigating and opening a program (using a computer), and operating a TV (controlling an electronic environment). The prototype provides more functionality support for using a mobile phone, and controlling an electronic environment as compared to using a computer. Future work can expand on the functionality of using a computer.

9.6. Theoretical Contributions

The main theoretical contribution of this research is a framework for designing AAL services for disabled individuals. The framework was discussed in detail in Chapter 8. The framework was developed from the knowledge obtained during the course of the research, and is envisioned to be a valuable tool for guiding researchers who are interested in designing innovative solutions for disabled individuals.

Chapter 5 discusses various interaction techniques. Experimental evaluations were carried out in order to determine the practicality of the envisioned interaction techniques. It was found that whereas an interaction technique can be used by a disabled person to accomplish a task in a controlled setting, it does not make the interaction technique ideal for use in a real word setting. For example, the head gesture navigation (Section 5.5) was found to be tiresome and error prone. Chapter 5 also motivated the need for multi modal interaction as ideal for enabling disabled individuals to interact with technology.

9.7. Practical Contributions

Chapter 6 discussed the design and implementation of a prototype system that fulfils the needs of the intended users. The design and prototype can be extended to support the control of different objects, such as the opening and closing of curtains, and controlling a thermostat.
This research has also proposed an interface of transmitting signals from a computer through a phone to control electronic devices in a home environment (Chapter 6, Section 6.2). This interaction technique could help individuals with limited hand use to be more independent.

9.8. Recommendations for Future Work

From this research, a number of recommendations are proposed for future work. The proposed framework could be used to identify the needs of disabled individuals and develop artefacts to address them. Examples of needs that arose from the qualitative feedback, include the need to automate the process of closing and opening curtains, and also windows, for disabled individuals. Whereas accomplishing such tasks comes naturally for able bodied individuals, disabled individuals may experience some difficulty.

Section 9.5 discusses the extent to which the identified requirements are supported. Future work can focus on extending the functionality of the using a computer requirement. For example, support can be added for document creation and editing. The proposed framework (Chapter 8) can guide researchers in discovering new interaction techniques that can complement the ones proposed by this research (Chapter 5).

References

AAL. (2013). Ambient Assisted Living Joint Programme. Retrieved April 22, 2015, from http://www.aal-europe.eu/about/

AAL-Europe. (2013a). *AAL Project Success Stories*. Brussels.

AAL-Europe. (2013b). Ambient Assisted Living (AAL) for the Ageing Society. Retrieved May 21, 2015, from http://cordis.europa.eu/ist/so/aal/home.html

Abbas, U., Shaikh, M., Panhwer, A., Turk, S., & Kumar, N. (2016). Design and Implementation of Advanced Wireless Tongue Drive/ Operated System for Paralyzed, Disabled and Quadriplegic Patients. *Journal of Bioengineering & Biomedical Science*, *6*(2), 1–5. http://doi.org/10.4172/2155-9538.1000185

Abimanyi-Ochom, J., & Mannan, H. (2014). Uganda's disability journey: Progress and challenges. *African Journal of Disability*, *3*(1), 1–6. http://doi.org/10.4102/ajod.v3i1.108

Alam, M. R., Reaz, M. B. I., & Ali, M. A. M. (2012). A Review of Smart Homes---Past, Present, and Future. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, *42*(6), 1190–1203. http://doi.org/10.1109/TSMCC.2012.2189204

Betke, M., Gips, J., & Fleming, P. (2002). The Camera Mouse: Visual tracking of body features to provide computer access for people with severe disabilities. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *10*(1), 1–10. http://doi.org/10.1109/TNSRE.2002.1021581

Bhavik, S. (2016). Build your own Custom Language Model to convert unique Speech to Text. Retrieved December 4, 2017, from https://www.ibm.com/blogs/watson/2016/09/build-custom-language-model-convert-unique-speech-text/

Bian, Z.-P., Hou, J., Chau, L.-P., & Magnenat, N. (2014). Human computer interface for quadriplegic people based on face position/gesture detection. *2014 ACM Conference on Multimedia, MM 2014, November 3, 2014 - November 7, 2014*, 1221–1224. http://doi.org/10.1145/2647868.2655063

Blattner, M. M., & Glinert, E. P. (1996). Multimodal integration. *IEEE Multimedia*, *3*(4), 14–24. http://doi.org/10.1109/93.556457

Boman, T., Kjellberg, A., Danermark, B., & Boman, E. (2015). Employment opportunities for persons with different types of disability. *ALTER - European Journal of Disability Research / Revue Européenne de Recherche Sur Le Handicap*, *9*(2), 116–129. http://doi.org/10.1016/j.alter.2014.11.003

Brady, E., Morris, M. R., Zhong, Y., White, S., & Bigham, J. P. (2013). Visual challenges in the everyday lives of blind people. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (i), 2117–2126. http://doi.org/10.1145/2470654.2481291

Brodwin, M., Siu, F. W., & Cardoso, E. (2012). Users of Assistive Technology: The Human Component. In S. Sheri & C. Lindsay (Eds.), *The Phychological and Social Impact of Illness and Disability* (pp. 331–339). New York: Springer Publishing Company, LLC.

Bryman, A. (2008). Interviewing in qaulitative research. In *Social Research Methods* (3rd ed., pp. 469–480). Oxford: Oxford University Press Inc, New York.

BuckinghamHealthCare. (2012). Important Reachers And Grabbers Breakthroughs For Disabled People. Retrieved April 19, 2015, from http://bry79vktb2.jimdo.com/2012/08/18/important-reachers-and-grabbers-breakthroughs-for-disabled-people/

Burney, A. (2008). Inductive and Deductive Research Approach. *Research Approach*, (March), 22. http://doi.org/10.1177/0266666903192004

Carpenter, D., Sheridan, S., Haenlein, K., & Dean, D. (2006). *Environmental Scan of Instruments to Inform Consumer Choice in Assisted Living Facilities*. Westat, Inc. Rockville, MD 20850.

CDC. (2010). Types of Disabilities. Retrieved April 8, 2015, from http://www.cdc.gov/ncbddd/disabilityandhealth/types.html

Cook, D. J., Augusto, J. C., & Jakkula, V. R. (2009). Ambient intelligence: Technologies, applications, and opportunities. *Pervasive and Mobile Computing*, *5*(4), 277–298. http://doi.org/10.1016/j.pmcj.2009.04.001

Dafny, N. (1997). Anatomy of the Spinal Cord. Retrieved August 7, 2017, from http://nba.uth.tmc.edu/neuroscience/s2/chapter03.html

Davis, J. W., & Vaks, S. (2001). A perceptual user interface for recognizing head gesture acknowledgements. *Proceedings of the 2001 Workshop on Percetive User Interfaces - PUI '01*, 1. http://doi.org/10.1145/971478.971504

DeafWebsites. (2012). Telecommunications Devices for the Deaf. Retrieved May 3, 2015, from http://www.deafwebsites.com/technology/telecommunication-devices.html

De Groot Kim, S. (2005). Kevin: "i gotta get to the market": The development of peer relationships in inclusive early childhood settings. *Early Childhood Education Journal*, *33*(3), 163–169. http://doi.org/10.1007/s10643-005-0041-3

Denaro, G., & Pezz, M. (2003). Lectures on Concurrency and Petri Nets. In *Petri Nets and Software Engineering* (pp. 439–466). Berlin: Springer, Berlin, Heidelberg.

Disabled World. (2012). Physical & Mobility Impairments: Information & News. Retrieved August 17, 2015, from http://www.disabled-world.com/disability/types/mobility/

Dpsa. (2001). *Pocket guide on disability equity*. Retrieved from http://www.dpsa.org.za/wp-content/uploads/2013/05/Pocket-Guide-on-Disability-Equity.pdf

Drechsler, A., & Hevner, A. (2016). A four-cycle model of IS design science research: capturing the dynamic nature of IS artifact design. *Breakthroughs and Emerging Insights from Ongoing Design Science: Research-in-Progress Papers and Poster Presentations from the 11th International Conference on Design Science in Information Systems and Technology (DESRIST)*, 1–8. Retrieved from https://cora.ucc.ie/handle/10468/2560

Dubberly, H., Pangaro, P., & Haque, U. (2009). What is interaction? Are there different types? *Interactions*, *16*(1), 69. http://doi.org/10.1145/1456202.1456220

DWCPD and UNICEF. (2012). *Children with Disabilities in South Africa: A Situation Analysis: 2001-2011.* Pretoria.

Furfari, F., Tazari, M.-R., & Eisemberg, V. (2011). universAAL: an Open Platform and Reference Specification for Building AAL Systems. Retrieved May 5, 2016, from https://www.sintef.no/globalassets/project/tradlospasient/091105-workshop/universaal.pdf

Furui, S. (2005). 50 Years of Progress in Speech and Speaker Recognition. *Specom*, (1), 1–9.

Ghahramani, Z. (2001). An Introduction to Hidden Markov Models and Bayesian Networks. *International Journal of Pattern Recognition and Artificial Intelligence*. http://doi.org/10.1142/S0218001401000836

Gips, J., & Margrit, B. (2007). Camera Mouse. Retrieved May 21, 2017, from

http://www.cameramouse.org/
Glass, J., & Zue, V. (2003). Automatic Speech Recognition. Retrieved September 20, 2016, from http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-345-automatic-speech-recognition-spring-2003/index.htm
Google. (2016a). Google Voice Actions. Retrieved from https://developers.google.com/voice-actions/system/#system_actions_reference
Google. (2016b). Voice Access. Retrieved from https://support.google.com/accessibility/android/answer/6151848
Grasch, P. (2011). Overview:Architecture. In *The Simon Handbook* (pp. 10–12). Retrieved from https://docs.kde.org/trunk4/en/extragear-accessibility/simon/simon.pdf
Gray, D. E. (2012). Theoretical Perspectives and Research Methodologies. *Doing Research in the Real World*, 422. http://doi.org/10.1017/CBO9781107415324.004
Guillén, S. (2014). *The universAAL Reference Architecture: Intro D1.3.E*. Retrieved from http://depot.universaal.org/Documents/D1.3-E - Reference Architecture - Release 1.0 - Part III.pdf
Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Result of Empirical and Theoretical Research. *Human Mental Workload*, *1*, 239–250.
Harvey, L. (2007). A framework for physiotherapy management. In *Management of Spinal Cord Injuries, 1st Edition* (1st ed., pp. 36–48). Churchill Livingstone.
Hevner, A. (2007). A Three Cycle View of Design Science Research A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2).
Hevner, A., & Chatterjee, S. (2010). *Design Research in Information Systems: Theory and Practice (Integrated Series in Information Systems)*. (S. Ramesh & S. VoB, Eds.). New York: Springer New York.
Hudson, R. (2011). Measuring accessibility. Retrieved March 15, 2017, from http://usability.com.au/2011/11/measuring-accessibility/
IBM. (2016). Watson Developer Cloud. Retrieved September 14, 2016, from https://www.ibm.com/watson/developercloud/speech-to-text.html
IBM. (2017a). Creating a custom language model. Retrieved December 4, 2017, from https://console.bluemix.net/docs/services/speech-to-text/language-create.html#languageCreate
IBM. (2017b). Understanding customization. Retrieved December 4, 2017, from https://console.bluemix.net/docs/services/text-to-speech/custom-intro.html#customIntro
Jabareen, Y. (2009). Building a Conceptual Framework: Philosophy, Definitions, and Procedure. *International Journal of Qualitative Methods*, *8*(4), 49–62. http://doi.org/10.1177/160940690900800406
Johannesson, P., & Perjons, E. (2012). *A Design Science Primer* (1st ed.). CreateSpace.
John Hopkins Medicine. (2000). Spinal Cord Injury. Retrieved March 29, 2016, from http://www.hopkinsmedicine.org/healthlibrary/conditions/physical_medicine_and_rehabilitation/spinal_cord_injury_85,P01180/
John Hopkins University, S. D. S. (2015). Types of Disabilities. Retrieved from http://web.jhu.edu/disabilities/faculty/types_of_disabilities/
Juang, B. H., & Furui, S. (2000). Automatic recognition and understanding of spoken language - A first step toward natural human-machine communication. *Proceedings of the IEEE*, *88*(8), 1142–1165. http://doi.org/10.1109/5.880077
Karray, F., Alemzadeh, M., Saleh, J. a, & Arab, M. N. (2008). Human-Computer Interaction: Overview on State of the Art. *International Journal on Smart Sensing and Intelligent Systems*, *1*(1), 137–159. http://doi.org/http://www.s2is.org/Issues/v1/n1/papers/paper9.pdf

Kavanagh, A. M., Krnjacki, L., Aitken, Z., LaMontagne, A. D., Beer, A., Baker, E., & Bentley, R. (2015). Intersections between disability, type of impairment, gender and socio-economic disadvantage in a nationally representative sample of 33,101 working-aged Australians. *Disability and Health Journal*, *8*(2), 191–199. http://doi.org/10.1016/j.dhjo.2014.08.008

Kjeldskov, J., & Graham, C. (2003). A Review of Mobile HCI Research Methods. *Human-Computer Interaction with Mobile Devices and Services.*, 317–335. http://doi.org/10.1007/978-3-540-45233-1_23

Lai, E. R. (2011). *Critical thinking: A literature review*. *Pearson*. Retrieved from http://images.pearsonassessments.com/images/tmrs/CriticalThinkingReviewFINAL.pdf

Langtree, I. (2010). What is Quadriplegia: Quadriplegic Facts & Definition. Retrieved from http://www.disabled-world.com/definitions/quadriplegia.php

Laugwitz, B., Held, T., & Schrepp, M. (2008). Construction and Evaluation of a User Experience Questionnaire. *HCI and Usability for Education and Work*, 63–76.

Leonardi, M., Bickenbach, J., Ustun, T. B., Kostanjsek, N., & Chatterji, S. (2006). The definition of disability: what is in a name? *The Lancet*, *368*(9543), 1219–1221. http://doi.org/http://dx.doi.org/10.1016/S0140-6736(06)69498-1

Lewis, J. (1995). IBM Computer Usability Satisfaction Questionnaire: Psychometric Evaluation and Instructions for Use. *International Journal of Human-Computer Interaction*, *7*(1), 57–78.

Li, J., Deng, L., Gong, Y., & Haeb-Umbach, R. (2014). An overview of noise-robust automatic speech recognition. *IEEE Transactions on Audio, Speech and Language Processing*, *22*(4), 745–777. http://doi.org/10.1109/TASLP.2014.2304637

MacKenzie, S. (2013). Within-subjects and between-subjects. In M. Dunkerley & H. Scherer (Eds.), *Human-Computer Interaction: An Empirical Research Perspective* (pp. 175–177). Waltham, MA 02451: Elsevier.

Maxwell, J. A. (2013). *Conceptual Framework: What do you think is going on? Qualitative Research Design: An Interactive Approach*. Thousand Oaks, California: Sage Publications. http://doi.org/10.1007/978-3-8349-6169-3_3

Memon, M., Wagner, S. R., Pedersen, C. F., Beevi, F. H., & Hansen, F. O. (2014). Ambient Assisted Living healthcare frameworks, platforms, standards, and quality attributes. *Sensors (Switzerland)*, *14*(3), 4312–4341. http://doi.org/10.3390/s140304312

MSDN. (2012). Face Tracking. Retrieved March 13, 2017, from https://msdn.microsoft.com/en-us/library/jj130970.aspx

Neville, C. (2007). Effective Learning Service: Introduction to Research and Research Methods. *Bradford University School of Management*, 1–44.

Nielsen Norman. (2014). Turn User Goals into Task Scenarios for Usability Testing. Retrieved from http://www.nngroup.com/articles/task-scenarios-usability-testing/

Olivier, M. S. (2009). Information technology research: a practical guide for computer science and informatics. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Information+Technology+Research:+A+practical+guide+for+Computer+Science+and+Informatics.#0

OneSignal. (2014). OneSignal. Retrieved June 9, 2017, from https://onesignal.com/

Paggio, P., & Navarretta, C. (2011). Feedback and gestural behaviour in a conversational corpus of Danish. *Proceedings of the 3rd Nordic Symposium on Multimodal Communication*, 33–39.

Peterson, D. B. (2012). An International Conceptualization of Disabilty: The International Classification of Functioning, Disability, and Health. In I. Marini & M. Stebnicki

(Eds.), *The Phychological and Social Impact of Illness and Disability* (pp. 405–415). New York: Springer Publishing Company, LLC.

Philips Electronics. (2014). Philips Hue. Retrieved August 14, 2017, from https://www.developers.meethue.com/

Picheny, M. (2015). IBM Watson now brings cognitive speech capabilities to developers. Retrieved October 10, 2016, from https://developer.ibm.com/watson/blog/2015/02/09/ibm-watson-now-brings-cognitive-speech-capabilities-developers/

Prat, N., Comyn-Wattiau, I., & Akoka, J. (2014). Artifact Evaluation in Information Systems Design Science Research - A Holistic View. *PACIS 2014 Proceedings*, *Paper 23*, 1–16.

Punch, K. F. (2009). Collecting Qualitative Data. In *Introduction to Research Methods in Education* (pp. 143–164).

Rajasekar, S., Philominathan, P., & Chinnathambi, V. (2006). Research Methodology, 1–53. http://doi.org/arXiv:physics/0601009v3

Regneir, J., & Hamilton, Y. (1995). Defining Assisted Living. In *Assisted Living for the Aged and Frail* (pp. 1–26).

Saleh, S., & Berns, K. (2015). Nonverbal Communication With a Humanoid Robot Via Head Gestures. In *PETRA 2016*. http://doi.org/10.1145/2769493.2769543

Samsung. (2013). Input Methods. Retrieved August 14, 2017, from http://developer.samsung.com/tv/design/input-methods

Sanchez, A., & Tercero, R. (2010). Smart home technologies: Uses and abuses. In *Proceedings of Special Session - 9th Mexican International Conference on Artificial Intelligence: Advances in Artificial Intelligence and Applications, MICAI 2010* (pp. 97–102). Pachuca: IEEE. http://doi.org/10.1109/MICAI.2010.10

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*.

Šenk, I., Tarjan, L., Ostojić, G., & Stankovski, S. (2010). Infrared Transceiver for Home Automation. *Faculty of Electrical Engineering University of Banja Luka*, *14*(2), 82.

Shotton, J., Fitzgibbon, A., Cook, M., Sharp, T., Finocchio, M., Moore, R., … Blake, A. (2013). Real-time human pose recognition in parts from single depth images. *Studies in Computational Intelligence*, *411*, 119–135. http://doi.org/10.1007/978-3-642-28661-2-5

Simeonsson, R. J., Leonardi, M., Lollar, D., Bjorck-Akesson, E., Hollenweger, J., & Martinuzzi, A. (2003). Applying the International Classification of Functioning, Disability and Health (ICF) to measure childhood disability. *Disability and Rehabilitation*, *25*(11–12), 602–610. http://doi.org/10.1080/0963828031000137117

Smart, J., & Smart, D. (2012). Models of Disability: Implications for the Counselling Profession (pp. 61–75). Wiley. http://doi.org/10.1002/j.1556-6678.2006.tb00377.x

Smart Box Assistive Technology. (2003). The GRID software. Retrieved March 27, 2018, from http://inclusivesolutions.co.za/wp-content/uploads/2014/07/catalogue_software.pdf

Souza, C. (2008). Accord-Framework. Retrieved June 9, 2017, from http://accord-framework.net/

Statistics South Africa. (2011). *Profile of persons with disability in South Africa*. (03-01-59, Ed.). Pretoria.

Stone, D., Jarrett, C., Woodroffe, M., & Minocha, S. (2005). *User Interface Design and Evaluation,*. (S. Card, J. Grudin, & J. Nielsen, Eds.). Morgan Kaufmann.

Tazari, M.-R., Furfari, F., & Valero, A. F. (2012). The universal Reference Model for AAL. *Handbook of Ambient Assisted Living*, *1*, 610–625. http://doi.org/10.3233/978-1-60750-837-3-

Trace Centre. (2010a). A Brief Introduction to Disabilities. Retrieved May 1, 2015, from http://trace.wisc.edu/docs/population/populat.htm

Trace Centre. (2010b). What Problems Do People with Disabilities Have? and Why? Retrieved August 17, 2015, from http://trace.wisc.edu/docs/software_guidelines/software.pcs/disabil.htm

Tullis, T., & Albert, B. (2008). What are usability metrics. In *Measuring the User Experience* (pp. 7–8).

Turk, M. (2014). Multimodal interaction: A review. *Pattern Recognition Letters*, *36*(1), 189–195. http://doi.org/10.1016/j.patrec.2013.07.003

UK General Medical Council. (2007). Assistive technologies for people with physical impairments. Retrieved April 15, 2015, from http://www.gmc-uk.org/accessibility/assistive_technologies/physical_impairments.asp

UniversAAL. (2010). UniversAAL open platform and reference Specification for Ambient Assisted Living. Retrieved from https://www.tsb.upv.es/proyectos/encurso/universaal/documentos/brochure-universAAL.pdf

UniversAAL. (2014). *Innovative AAL Service Specification*. Retrieved from http://universaal.sintef9013.com/images/stories/deliverables/d4.1-c_part3.pdf

UniversAAL. (2015). Understanding universAAL. Retrieved July 20, 2015, from https://github.com/universAAL/platform/wiki/Understanding-universAAL

Vaishnavi, V. K., & William, J. K. (2008). *Design Science Research Methods and Patterns: Innovating Information and Communication Technology*. http://doi.org/978-1420059328

Wang, J. (2006). Petri Nets for Dynamic Event-Driven System Modeling. *Transition*, (4), 1–17.

Wei, H., Scanlon, P., Li, Y., Monaghan, D. S., & O'Connor, N. E. (2013). Real-time head nod and shake detection for continuous human affect recognition. *International Workshop on Image Analysis for Multimedia Interactive Services*, 2–5. http://doi.org/10.1109/WIAMIS.2013.6616148

Western Cape Government. (2012). Care Dependency Grant. Retrieved May 15, 2015, from https://www.westerncape.gov.za/service/care-dependency-grant

WHO. (2002). *Towards a Common Language for Functioning , Disability and Health ICF*. *World Health Organisation* (Vol. 1149). Retrieved from http://www.who.int/classifications/icf/training/icfbeginnersguide.pdf

WHO, & World Bank. (2011). *World report on disability*. Geneva. Retrieved from http://www.who.int/disabilities/world_report/2011/report.pdf

Wilson, A., & Pham, H. (2003). Pointing in Intelligent Environments With the WorldCursor. *Proceedings of the 9th International Conference on Human-Computer Interaction (INTERACT'03)*, (c), 495–502. http://doi.org/10.1.1.88.4174

Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2014). Smart homes and their users : a systematic analysis and key challenges. *Personal and Ubiquitous Computing*, *Vol. 19*(Issue 2), 463–476. http://doi.org/10.1007/s00779-014-0813-0

Wolf, P., Schmidt, A., Otte, J. P., Klein, M., Rollwage, S., & König-Ries, B. (2010). openAAL - The Open Source Middleware for Ambient Assisted Living (AAL). *AALIANCE Conference*, (March), 1–5. http://doi.org/10.1029/2006GL026143

Appendix A-1:Ethics Clearence

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Nelson Mandela Metropolitan University

for tomorrow

Chairperson: Research Ethics Committee (Human)
Tel: +27 (0)41 504-2235

Ref: [H15-SCI-CSS-031/Approval]

Contact person: Mrs U Spies

20 January 2016

Prof J Wesson
NMMU
Faculty: Science
South Campus

Dear Prof Wesson

AN AMBIENT ASSISTED LIVING FRAMEWORK TO ASSIST PHYSICALLY DISABLED INDIVIDUALS IN A HOME ENVIRONMENT

PRP: Prof J Wesson
PI: Mr M Kyazze

Your above-entitled application served at Research Ethics Committee (Human) for approval.

The ethics clearance reference number is **H15-SCI-CSS-031** and is valid for three years. Please inform the REC-H, via your faculty representative, if any changes (particularly in the methodology) occur during this time. An annual affirmation to the effect that the protocols in use are still those for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.

We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

CB Cilliers

Prof C Cilliers
Chairperson: Research Ethics Committee (Human)

cc: Department of Research Capacity Development
Faculty Officer: Science

Appendix A-2: Ethics Clearence 2

NELSON MANDELA UNIVERSITY

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Change the World

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NMU Ref: [H15-SCI-CSS-031/ Extension]

Contact person: Mrs U Spies

25 July 2017

Prof J Wesson
Faculty: Science
South Campus

Dear Prof Wesson

A FRAMEWORK FOR DESIGNING AMBIENT ASSISTED LIVING SERVICES FOR DISABLED INDIVIDUALS

PRP: Prof J Wesson
PI: Mr M Kyazze

We take pleasure in informing you that the Research Ethics Committee (Human) approved the extension of protocol **H15-SCI-CSS-031** for another three years.

Please inform the REC-H, via your faculty representative, if any changes (particularly in the methodology) occur during this time. An annual affirmation to the effect that the protocols in use are still those for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.

We wish you well with the project.

Yours sincerely

Prof CB Cilliers
Chairperson: Research Ethics Committee (Human)

cc: Department of Research Capacity Development
Faculty Officer: Science

Appendix B: Spinal Cord Injury Levels

Level of Injury	**Limitations**
High-Cervical Nerves (C1 – C4)	• Most severe of the spinal cord injury levels • Paralysis in arms, hands, trunk and legs • Patient may not be able to breathe on his or her own, cough, or control bowel or bladder movements. • Ability to speak is sometimes impaired or reduced. • When all four limbs are affected, this is called tetraplegia or quadriplegia. • Requires complete assistance with activities of daily living, such as eating, dressing, bathing, and getting in or out of bed • May be able to use powered wheelchairs with special controls to move around on their own • Will not be able to drive a car on their own • Requires 24-hour-a-day personal care
Low-Cervical Nerves (C5 – C8)	• Corresponding nerves control arms and hands. • A person with this level of injury may be able to breathe on their own and speak normally. • *C5 injury*

	- Person can raise his or her arms and bend elbows. - Likely to have some or total paralysis of wrists, hands, trunk and legs - Can speak and use diaphragm, but breathing will be weakened - Will need assistance with most activities of daily living, but once in a power wheelchair, can move from one place to another independently *C6 injury* - Nerves affect wrist extension. - Paralysis in hands, trunk and legs, typically - Should be able to bend wrists back - Can speak and use diaphragm, but breathing will be weakened - Can move in and out of wheelchair and bed with assistive equipment - May also be able to drive an adapted vehicle

	- Little or no voluntary control of bowel or bladder, but may be able to manage on their own with special equipment *C7 injury* - Nerves control elbow extension and some finger extension. - Most can straighten their arm and have normal movement of their shoulders. - Can do most activities of daily living by themselves, but may need assistance with more difficult tasks - May also be able to drive an adapted vehicle - Little or no voluntary control of bowel or bladder, but may be able to manage on their own with special equipment *C8 injury* - Nerves control some hand movement. - Should be able to grasp and release objects - Can do most activities of daily living by themselves, but may

	need assistance with more difficult tasks • May also be able to drive an adapted vehicle • Little or no voluntary control of bowel or bladder, but may be able to manage on their own with special equipment
Thoracic Nerves (T1 – T5)	• Corresponding nerves affect muscles, upper chest, mid-back and abdominal muscles. • Arm and hand function is usually normal. • Injuries usually affect the trunk and legs(also known as paraplegia). • Most likely use a manual wheelchair • Can learn to drive a modified car • Can stand in a standing frame, while others may walk with braces Thoracic Nerves (T6 – T12) • Nerves affect muscles of the trunk (abdominal and back muscles) depending on the level of injury. • Usually results in paraplegia • Normal upper-body movement

	• Fair to good ability to control and balance trunk while in the seated position • Should be able to cough productively (if abdominal muscles are intact) • Little or no voluntary control of bowel or bladder but can manage on their own with special equipment • Most likely use a manual wheelchair • Can learn to drive a modified car • Some can stand in a standing frame, while others may walk with braces.
Lumbar Nerves (L1 – L5)	• Injuries generally result in some loss of function in the hips and legs. • Little or no voluntary control of bowel or bladder, but can manage on their own with special equipment • Depending on strength in the legs, may need a wheelchair and may also walk with braces
Sacral Nerves (S1 – S5)	• Injuries generally result in some loss of functioning the hips and legs. • Little or no voluntary control of bowel or bladder, but can manage on their own with special equipment • Most likely will be able to walk

Spinal cord injuries (John Hopkins Medicine, 2000)

Appendix C: Voice Commands

Smart TV

Voice Command	Description
Power, TV, TV ON	Turn on/off the TV
Volume up	Increase TV volume by 1
Volume Down	Decrease TV Volume by 1
Channel Next	Navigate to the next channel
Channel Previous	Navigate back one channel

Smart Lights

Voice Command	Description
Light one on	Turn light 1 on
Light one off	Turn light one off
Light two on	Turn light two on
Light two off	Turn light two off

Phone Menu

Voice Command	Description
Help, Menu	Show the available voice commands

Phone Interaction

Face Navigation Command	Description
Open App	Open the voice control phone app
Play Music	Play music on phone
Pause Music	Pause the current song
Next Song	Go to the next song
Previous Song	Go to the previous song
Answer Phone Call	Answer an incoming phone call
Reject Phone Call	Reject an incoming phone call

Computer Interaction

Face Navigation Command	Description
Open App	Navigates to a program icon and a click is triggered.
Open URL	Opens a URL in a new tab
Navigate	Navigate the desktop computer
Speech to Text	Click on the speech to text button in order to start listening for audio input to be transcribed.

Appendix D: Evaluation Study Research Protocol

1. Tasks

Subsections A,B, and C lists tasks that are to be completed by participants as part of the evaluation study. The tasks can be completed using the following interaction techniques: voice, head gestures (nod and shake), and face detection. Feel free to explore the system as you interact with it. For example, a given task may require you to first unlock the phone, carry out a search, among other sub-tasks

A. Using a mobile phone Tasks

A mobile phone is mostly used for personal communication. However, it may also be used to meet other needs of a user such as playing music among others. The tasks in this section are predominately meant to assess the communication aspect of mobile phones. A few tasks are also included to assess some of the other possible uses of mobile phones.

i) **Task 1: Make a phone call**
Call Peter.

ii) **Task 2: Cancel/End Phone call**
Call Peter. End the call after one minute

iii) **Task 3: Add Contact**
Add Joseph as a contact. His number is 0781234567.

iv) **Task 4: Send Text Message**
Send Peter a text message saying: “I will be home for dinner”

v) **Task 5: Play Music**
Play music by Taylor Swift

vi) **Task 6: Pause**
Pause music

vii) **Task 7: Answer a phone call**
Answer an incoming phone call

viii) **Task 8: Reject a phone call**
Answer an incoming phone call

B. Using a computer Tasks

A computer may be used to accomplish a wide range of activities such as creating documents, and browsing the internet among others. The evaluation tasks are limited to the ones listed below because they are representative of the common tasks that students and adults usually carry out with a computer. The tasks also require participants to navigate around the system.

i) **Task 1: Navigate to a browser icon “chrome” and open the program**
Find the chrome browser icon and open the program.

ii) **Task 2: Open The news24 website**
Using your voice, open the the news 24 web page.

iii) **Task 3: News Article Detail**
Click on a news article in order to read more detailed information.
iv) **Task 4: Play Music**
Search for and play music by Taylor Swift
v) **Task 5: Pause Music**
Pause the song that is currently playing

C. Tasks to evaluate the control of an electronic environment

Individuals spend a considerable amount of time in their homes. The tasks below evaluate some of the basic tasks that individuals may have to accomplish in their homes.

i) **Task 1: Turn on lights**
Turn the lights on
ii) **Task 2: Turn off lights**
Turn the lights off.
iii) **Task 3: Increase TV volume**
Increase the volume of the TV.
iv) **Task 4: Increase TV volume**
Dcrease the volume of the TV.
v) **Task 4: Select Next Channel**
Select the next channel.
vi) **Task 5: Select Previous Channel**
Navigate back to the previous channel.

2. Evaluation Metrics

This study uses the Design Science Research (DSR) methodology. Prat et al. (2014) propose evaluation criteria for DSR research artefacts. The criteria is grouped under 5 dimensions namely: goal, environment, structure, activity and evolution (Prat et al., 2014). Figure A-1 illustrates the various system dimensions, evaluation criteria and sub-evaluation criteria for a DSR artefact.

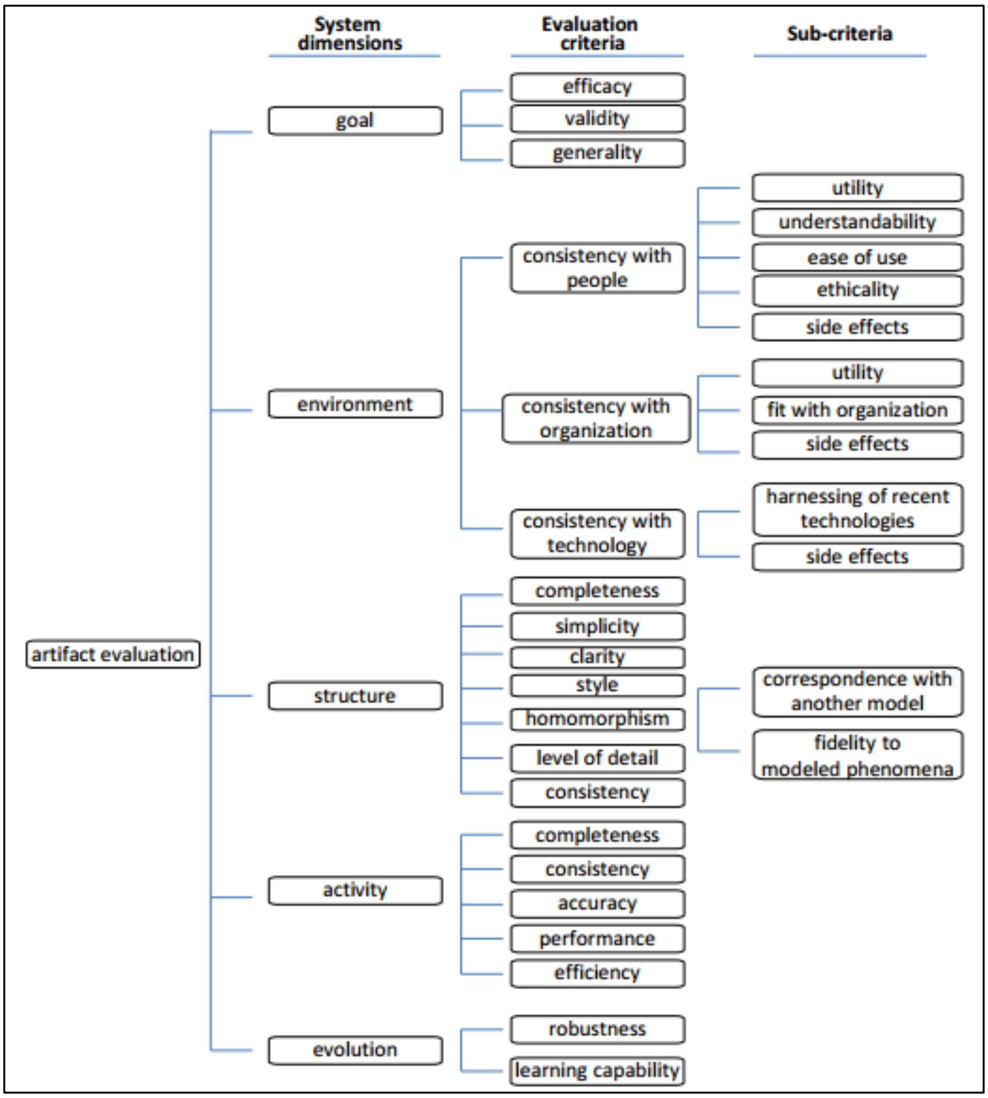

Figure A-1:Hierarchy for evaluation criteria of a DSR artefact (Prat et al., 2014)

Below is a brief discussion of the various system dimensions:

1. **Goal**: Consists of the efficacy, validity and generality of the system. Efficacy is the degree to which the artefact achieves its goal, while validity is the degree to which the artefact works correctly. The generality refers to the completeness of the system in addressing all the specified requirements.
2. **Environment:** The environment consists of the people or organization who are supposed to use the artefact. This dimension verifies the consistency of the artefact with the needs of the user and the technology used. The evaluations were carried out from ac computer lab, and the Cheshire living room. These are environments that individuals are comfortable with

3. **Structure**: The structure of the prototype is assessed by the simplicity, clarity, completeness, level of detail and consistency. The prototype should be simple, minimalistic and elegant in design with a high degree of generality to achieve completeness. The structure is a static aspect of a system and it should not change.

Expert evaluation of the prototype is to be carried out prior to user evaluations. This will help ensure the quality of the prototype.

4. **Activity**: The activity dimension is characterised by accuracy, performance, efficiency, consistency and completeness of the artefact.

5. **Evolution**: Is characterised by robustness and learning capability. Robustness refers to the ability of an artefact to respond to changes in the environment.

The evaluation metrics were instrumental in designing the tasks and the evaluation questionnaires (Post Test, and After Scenario) which are attached.

Data Analysis Methods

Microsoft Excel will be used to analyse the data captured from the questionnaires.

Equipment to be used in the Evaluation Study

Task Group	Equipment
1. Using a mobile phone tasks	- 2 mobile devices - Laptop computer
2. Using a computer tasks	- Laptop computer - USB Hands-Free microphone - Microsoft Kinect
3. Controlling an electronic environment tasks	- Smart TV - USB Hands-Free microphone - Phillips hue smart lights

NB: The equipment were used in conjunction with the software services**.**

Appendix E: Evaluation Study Questionnaire

Post Test Questionnaires

Biographical data
1. Gender: Male …………., Female…………
2. Age range: 18-20 years….., 21-29 years....., 30-39 years....., 40-49 years….., 50+…..
3. Occupation: …………………………………………………………………………….
4. Android Experience: 0-6 months………., 1-2 years………., > 2 years..........

Using a Mobile Phone Tasks

A. Cognitive load

1. Mental demand: How mentally demanding were the tasks?							
	Very Low	1	2	3	4	5	Very High
2. Physical demand: How physically demanding were the tasks?							
	Very Low	1	2	3	4	5	Very High
3. Temporal demand: How hurried or rushed was the pace of the tasks?							
	Very Low	1	2	3	4	5	Very High
4. Performance: How successful were you in accomplishing what you were asked to do?							
	Very Low	1	2	3	4	5	Very High
5. Effort: How hard did you have to work to accomplish your level of performance?							
	Very Low	1	2	3	4	5	Very High
6. Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?							
	Very Low	1	2	3	4	5	Very High

B. Overall satisfaction

1. Overall, I am satisfied with how easy it is to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. Overall, I am satisfied with the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
3. It was easy to learn to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
4. It was simple to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree

C. Usability

1. I can effectively use a mobile phone to complete the tasks without assistance							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. Overall, I am satisfied with the amount of time it took to complete the task							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
3. Overall, I am satisfied with the support information when completing the task							
	Strongly Disagree	1	2	3	4	5	Strongly Agree

Post Test Questionnaires

D. General Feedback
1. Identify the most positive aspect of the task
2. Identify the most negative aspect of the task
3. Please provide any general comments or suggestions for improvement

Post Test Questionnaires

Using a computer Tasks							
A. Cognitive load							
1. Mental demand: How mentally demanding were the tasks?							
	Very Low	1	2	3	4	5	Very High
2. Physical demand: How physically demanding were the tasks?							
	Very Low	1	2	3	4	5	Very High
3. Temporal demand: How hurried or rushed was the pace of the tasks?							
	Very Low	1	2	3	4	5	Very High
4. Performance: How successful were you in accomplishing what you were asked to do?							
	Very Low	1	2	3	4	5	Very High
5. Effort: How hard did you have to work to accomplish your level of performance?							
	Very Low	1	2	3	4	5	Very High
6. Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?							
	Very Low	1	2	3	4	5	Very High

B. Overall satisfaction							
1. Overall, I am satisfied with how easy it is to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. Overall, I am satisfied with the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
3. It was easy to learn to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
4. It was simple to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
C. Usability							
1. I can effectively use a computer to complete the tasks without assistance							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. Overall, I am satisfied with the amount of time it took to complete the task							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
3. Overall, I am satisfied with the support information when completing the task							
	Strongly Disagree	1	2	3	4	5	Strongly Agree

Post Test Questionnaires

D. General Feedback
4. Identify the most positive aspect of the task
5. Identify the most negative aspect of the task
6. Please provide any general comments or suggestions for improvement

Post Test Questionnaires

Control of an electronic environment Tasks							
A. Cognitive load							
1. Mental demand: How mentally demanding were the tasks?							
	Very Low	1	2	3	4	5	Very High
2. Physical demand: How physically demanding were the tasks?							
	Very Low	1	2	3	4	5	Very High
3. Temporal demand: How hurried or rushed was the pace of the tasks?							
	Very Low	1	2	3	4	5	Very High
4. Performance: How successful were you in accomplishing what you were asked to do?							
	Very Low	1	2	3	4	5	Very High
5. Effort: How hard did you have to work to accomplish your level of performance?							
	Very Low	1	2	3	4	5	Very High
6. Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?							
	Very Low	1	2	3	4	5	Very High

B. Overall satisfaction							
1. Overall, I am satisfied with how easy it is to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. Overall, I am satisfied with the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
3. It was easy to learn to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
4. It was simple to use the system							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
C. Usability							
1. I can effectively use a computer to complete the tasks without assistance							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. Overall, I am satisfied with the amount of time it took to complete the task							
	Strongly Disagree	1	2	3	4	5	Strongly Agree
3. Overall, I am satisfied with the support information when completing the task							
	Strongly Disagree	1	2	3	4	5	Strongly Agree

D. General Feedback
7. Identify the most positive aspect of the task
8. Identify the most negative aspect of the task

Post Test Questionnaires

9. Please provide any general comments or suggestions for improvement

Post Test Questionnaires

Usability Experience Evaluation

1. Using a mobile phone

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Post Test Questionnaires

2. Controlling an electronic environment

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
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clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Post Test Questionnaires

3. Using a computer

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
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good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
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impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Appendix F: Informed Consent Form

NELSON MANDELA METROPOLITAN UNIVERSITY

INFORMATION AND INFORMED CONSENT FORM

RESEARCHER'S DETAILS	
Title of the research project	**A Framework for Designing Ambient Assisted Living Services for Disabled Individuals**
Reference number	
Principal investigator	**Michael Kyazze**
Address	**Embizweni Building, 01E PhD Lab**
Postal Code	**6031**
Contact telephone number (private numbers not advisable)	27 41 504 2322

A. DECLARATION BY OR ON BEHALF OF PARTICIPANT		**Initial**
I, the participant and the undersigned	(full names)	
ID number		
OR		
I, in my capacity as	(parent or guardian)	
of the participant	(full names)	
ID number		
Address (of participant)		

A.1 HEREBY CONFIRM AS FOLLOWS:		**Initial**
I, the participant, was invited to participate in the above-mentioned research project		
that is being undertaken by	Michael Kyazze	
from	Department of Computing Sciences	
of the Nelson Mandela Metropolitan University.		

NELSON MANDELA METROPOLITAN UNIVERSITY

INFORMATION AND INFORMED CONSENT FORM

RESEARCHER'S DETAILS	
Title of the research project	**A Framework for Designing Ambient Assisted Living Services for Disabled Individuals**
Reference number	
Principal investigator	**Michael Kyazze**
Address	**Embizweni Building, 01E PhD Lab**
Postal Code	**6031**
Contact telephone number (private numbers not advisable)	27 41 504 2322

A. DECLARATION BY OR ON BEHALF OF PARTICIPANT		Initial
I, the participant and the undersigned	(full names)	
ID number		
OR		
I, in my capacity as	(parent or guardian)	
of the participant	(full names)	
ID number		
Address (of participant)		

A.1 HEREBY CONFIRM AS FOLLOWS:		Initial
I, the participant, was invited to participate in the above-mentioned research project		
that is being undertaken by	Michael Kyazze	
from	Department of Computing Sciences	
of the Nelson Mandela Metropolitan University.		

		THE FOLLOWING ASPECTS HAVE BEEN EXPLAINED TO ME, THE PARTICIPANT:			Initial
2.1	**Aim:**	The investigator is in the process of evaluating a software solution that may assist individuals with Quadriplegia to complete the tasks below without physical assistance in a home environment: 1. Using a mobile phone (making/receiving phone calls, texting, and playing music) 2. Controlling electronic devices (controlling TV set, and controlling lights) 3. Using a computer (using email, and browsing the internet)			
2.2	**Procedures:**	I understand that I will be asked to complete tasks that require me to use voice and head gestures.			
2.3	**Risks:**	None. However, you are free to withdraw from the study at any time.			
2.4	**Possible benefits:**	There are no benefits			
2.5	**Confidentiality:**	My identity will not be revealed in any discussion, description or scientific publications by the investigators.			
2.6	**Voluntary participation / refusal / discontinuation:**	My participation is voluntary	YES	NO	
		My decision whether or not to participate will in no way affect my present or future academic performance / development / care / employment / lifestyle	TRUE	FALSE	

3. THE INFORMATION ABOVE WAS EXPLAINED TO ME/THE PARTICIPANT BY:									Initial
(name of relevant person)									
in	**Afrikaans**		**English**		**Xhosa**		**Other**		
and I am in command of this language, **or** it was satisfactorily translated to me by									
(name of translator)									
I was given the opportunity to ask questions and all these questions were answered satisfactorily.									

4.	No pressure was exerted on me to consent to participation and I understand that I may withdraw at any stage without penalisation.	

5.	Participation in this study will not result in any additional cost to myself.	

A.2 I HEREBY VOLUNTARILY CONSENT TO PARTICIPATE IN THE ABOVE-MENTIONED PROJECT:	
Signed/confirmed at on 20	
	Signature of witness:
Signature or right thumb print of participant	Full name of witness:

B. STATEMENT BY OR ON BEHALF OF INVESTIGATOR(S)								
I,	(name of interviewer)			declare that:				
1.	I have explained the information given in this document to			(name of participant)				
	and / or his / her representative			(name of representative)				
2.	He / she was encouraged and given ample time to ask me any questions;							
3.	This conversation was conducted in	**Afrikaans**		**English**		**Xhosa**		**Other**
	And no translator was used OR this conversation was translated into							
	(language)	by		(name of translator)				
4.	I have detached Section D and handed it to the participant			YES		NO		
Signed/confirmed at		on		20				
Signature of interviewer		Signature of witness:						
		Full name of witness:						

C. DECLARATION BY TRANSLATOR *(WHEN APPLICABLE)*			
I,	(full names)		
ID number			
Qualifications and/or			
Current employment			
confirm that I:			
1.	Translated the contents of this document from English into	(language)	
2.	Also translated questions posed by	(name of participant)	as well as the answers given by the investigator/representative;
3.	Conveyed a factually correct version of what was related to me.		
Signed/confirmed at		on	20
I hereby declare that all information acquired by me for the purposes of this study will be kept confidential.			
Signature of translator		Signature of witness:	
		Full name of witness:	

D. IMPORTANT MESSAGE TO PARTICIPANT/REPRESENTATIVE OF PARTICIPANT	
Dear participant Thank you for participation in this study. Should, at any time during the study: - an emergency arise as a result of the research, or - you require any further information with regard to the study, or - want to end your participation	
Kindly contact	Michael Kyazze
at telephone number	27 41 504 2322