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Investigating the Design of an Immersive Smart Home System for Supporting Seniors Living with Neurocognitive Disorders

by

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Abstract

In Canada, the low fertility rates coupled with the long-life expectancy are leading to a foreseeable increase in the number of senior citizens. The risk of developing Neurocognitive Disorders (NCDs) such as dementia and Alzheimers is more common among older adults. The concept of aging in place was suggested in the literature for seniors to continue living in the comfort of their own homes. However, this homecare model is not necessarily easy for individuals and their families.

The Internet of Things (IoT) technology allows for creating customized and accessible smart home systems for supporting aging in place. These systems are called Supportive Smart Home Systems (SSHS). Nonetheless, this approach comes with two main challenges. Firstly, customizing and interacting with IoT devices requires a certain level of technology literacy which many Seniors with Neurocognitive Disorders (SwNCDs) and caregivers may not have. Secondly, relying solely on smartphone applications is impractical for homecare purposes. Therefore, an alternative user-system interaction method that accommodates this population's needs is required.

Head-mounted Mixed Reality (MR) devices blend the physical and digital worlds to unlock natural and intuitive holographic interactions. This model makes designing tailored and seamless user experiences for SwNCDs more feasible. In addition, integrating a wearable MR device into an SSHS provides instant and effortless interactions. However, considering MR is an emerging field of study, there is a major lack of design recommendations, especially for SwNCDs users.

In this thesis, we applied a comprehensive User-Centered Design approach to introduce an immersive supportive smart home system for SwNCDs. During the investigation phase, we conducted a systematic literature review study to provide a taxonomy of the literature. After that, we investigated the special requirements of the target population by conducting a requirements elicitation study with a sample of SwNCDs, and formal and informal caregivers. Based on findings from these two studies, we introduced an initial system prototype addressing two use cases: medication reminders and cooking safety support. Finally, we leveraged video prototypes demonstrating all possible user-system interactions for both use cases to run an online Design Critique evaluation.

A total of 24 participants across Canada and the USA joined our Design Critique study: SwNCDs, formal and informal caregivers, domain experts, and immersive technologies developers. After running all Design Critique sessions, a course of Thematic Analysis was conducted on the qualitative data to extract design recommendations for immersive smart home systems design. A second round of Design Critique with developers was undertaken to elicit recommendations and best practices for implementing such systems.

At the final stage, we use the newly extracted design recommendations to reiterate our initial system design to produce a high-fidelity prototype which we implemented using the Unity engine, Microsoft Mixed Reality Toolkit, and a Hololens2 device. We conducted usability evaluations using the Cognitive Walkthrough and Heuristic Evaluation methods. According to our findings, evaluators did not identify any major usability issues in the prototype. These findings indicates that our design and evaluation process has the potential to produce highly usable supportive smart home system concepts.

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To Joseph and his father, his eleven planets, the sun and the moon. Thanks for teaching me 'beautiful patience'.

And to my eleven planets, and my sun and moon that I lost. May we meet again.

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List of Symbols, Abbreviations and Nomenclature

Symbol or abbreviation	Definition
Neurocognitive Disorders	NCDs
Senior with Neurocognitive Disorders	SwNCDs
Mild Cognitive Impairment	MCI
Activities of Daily Living	ADL
Supportive Smart Home Systems	SSHS
Internet of Things	IoT
Extended Reality	XR
Mixed Reality	MR
Augmented Reality	AR
Virtual Reality	VR
User Experiences	UX
User Interface	UI
Human-Computer Interaction	HCI
Microsoft Mixed Reality Toolkit	MRTK
Systematic literature review	SLR
User-Centered Design	UCD
Design Critique	DC

Chapter 1

Introduction

The homo sapiens-sapiens (humans) are the most known developed species on planet earth. Due to the -relatively- large size of their frontal lobe, humans are capable of higher and more complex cognitive functions such as memory, impulse control, problem-solving, social interactions and more [Har14]. It is common in human psychology to refer to the frontal lobe as the reasonable or logical mind. On the other hand, the amygdala is a much smaller part of the brain. It is associated with intense emotional processing, such as fight or flight. In evolutionary psychology, they may use the emotional mind term to refer to the amygdala [SBCK98]. While other species rely mainly on their amygdala for survival, we spend our entire lives learning to balance our logical and emotional minds.

Throughout our life journey, all the knowledge and skills we gather are stored in our brain, consisting of approximately 86 billion nerve cells (neurons). Although most of our body cells are replaceable, nerve cells are not. When a neuron dies, just like humans, it transforms from a living form to simple chemistry. After that, the brain gets busy filling the gap of dead neurons with neuroglial cells; meanwhile, humans will be left wondering why they are losing skills and memories [MH97].

Most of us will not experience a dramatic loss of nerve cells in our lifetime. However, we will experience a steady and slow loss of our cognitive abilities due to the normal aging process. Some of us may suffer a steeper loss of brain neurons, negatively affecting our functional and cognitive abilities. In geriatric medicine, the term minor or major Neurocognitive Disorders (NCDs) is used to describe these conditions [SBB+14]. Dementia is a general umbrella term for 400 of these conditions, whereas Alzheimer's disease is the most common cause of dementia, accounting for 60-80 percent of cases. In most forms of dementia, the build-up of toxic proteins is the main factor in brain degeneration. Consequentially, this leads to a loss of the contact points between neurons and, eventually, the loss of the neurons themselves [CC02].

The effects of NCDs on the individual include cognitive changes, memory problems, language and self-expression issues, poor decision-making abilities, changes in mood and higher levels of stress and anxiety. Furthermore, these effects negatively extend to the quality of life for seniors and their abilities to complete activities of daily living [CLML12].

While there are a few treatment options to slow down the cognitive and functional decline, we still do not have a cure for NCDs [KNO86]. Furthermore, NCDs are progressive in nature; thus, many seniors living with NCDs (SwNCDs) find themselves in a place where more caregiving is required. While neuroscientists continue to work on finding better treatments and hopefully a cure for NCDs, this PhD research humbly attempts to investigate the process of designing, prototyping, evaluating and developing immersive smart home system concepts to support aging in place for SwNCDs.

1.1 Motivations

According to the United Nations Population Division, in 2050, the total number of people over 65 will be greater than the number of youth for the first time in human history [LSS08]. This rapid increase in the aging population comes with a higher demand for personal healthcare, particularly for seniors who require additional support. Furthermore, aging is the number one factor for developing disabling conditions such as NCDs [LMB09]. Therefore, shifting the healthcare model for non-critical conditions from formal care (hospitals and nursing homes) to informal care (personal residence and senior communities) is a suggested solution [PLR+16].

The concept of aging in place - seniors staying in their own homes - aligns well with this informal healthcare model [VSLP12]. Studies revealed that seniors, including those who suffer from NCDs, prefer to continue living in the comfort of their own homes compared to living in assisted living facilities [TLBL+18a]. In fact, according to some studies, aging in place for SwNCDs improves overall cognitive decline management indicators [BPW+04, MPP+05]. This indicts that aging in place can benefit seniors first and the healthcare system second. However, informal healthcare is not always accessible, easier, or affordable for all aging groups [WWJ07]. Therefore, a potential solution was suggested using Supportive Smart Home Systems (SSHS) in the context of facilitating aging in place for SwNCDs.

The Internet of Things (IoT) provides a basis for more accessible, and customized supportive smart home systems for senior citizens' homecare [NPP+19]. A major benefit of this approach is that users can simply introduce new devices to the smart home as needed [FSA+17]. An IoT-based smart home system could assist senior users by sending notifications, and reminders [AB18a] to complete daily tasks. Most commercial IoT devices are managed via smartphone applications. While this interaction method appears appropriate for most users, it stands as a challenge for seniors and, sometimes, their caregivers [MA14]. For instance, missing a notification regarding taking medication could be crucial for the health and well-being of the individual. From a User Experience (UX) perspective, a single type of notification is insufficient because SwNCDs may dismiss phone notifications due to attention or comprehending challenges, or simply for not carrying the mobile phone [MA14]. Ultimately, commercial IoT services do not account for SwNCDs special requirements as they are not intended for homecare purposes [FSA+17]. Therefore, a better user-system interaction method tailored for this user category is required.

Mixed Reality (MR) technology blends the physical and digital worlds to unlock natural and intuitive human-holographic (virtual augmentation) interactions [SHN19]. In this model, designing effortless and seamless UX tailored for SwNCDs is more feasible [BA20]. A major benefit of using a head-mounted MR device is that it allows users to interact with the home system instantly and effortlessly [BVS+21]. Additionally, it offers hands-free interactions without isolating users from their environment [RDMG20a]. The possibility to display virtual augmentations everywhere around users enables free movement while ensuring that users still see prompts or information on the head-mounted device [GBJMACU15]. The majority of existing MR applications are limited to video games and some immersive applications with inherited User Interface design (UI) elements such as windows, menus, buttons, etc. It is worth noting that MR is not bound by any of these traditional elements, which allows for more design liberty opening more possibilities for designing tailored experiences for SwNCDs. However, there is a lack of design guidelines and recommendations for MR applications for senior users.

In this PhD thesis, we investigate designing IoT-based supportive smart home systems for SwNCDs. For the reasons mentioned above, we suggest integrating MR technology as a primary method for user-system interactions. The combination of IoT devices and MR promises more tailored and immersive smart home experiences for SwNCDs while assuring higher system usability.

1.2 Research questions

1. What are the different types of supportive smart home system concepts in the literature? From an HCI perspective, what are common design approaches? What are the different prototyping evaluation methods? What are the techniques for collecting smart home data, and what are the benefits and limitations of these techniques?

2. What are the special requirements for designing supportive smart home systems for SwNCDs? What are the common aging in place homecare scenarios among SwNCDs

which could be addressed using a smart home system? What are the system features that seniors and caregivers desire?

3. What are the considerations for designing MR applications for SwNCDs? How can the immersive user interface and user experience design accommodate the special requirements of SwNCDs users?

4. When evaluating supportive system prototypes with different stakeholders, what are the main concerns of each category? What are the relationships between participant categories and the design recommendations?

1.3 Research objectives

This research aims to achieve the following objectives:

1. This research aims to follow a User-Centered Design (UCD) approach with a focus on the users and their needs in each phase of the design process. In the first phase of the UCD, this thesis aims to provide a comprehensive understanding of the different types of supportive smart home systems for SwNCDs. This objective is achieved through conducting a systematic review of the literature to provide clear taxonomy and identify different smart home concepts, design approaches, prototype fidelity and evaluation methods. In addition, to discuss the benefits and limitations of different approaches.

2. In order to better understand the user needs, this research aims to elicit design requirements from primary sources by conducting a requirements elicitation study with a sample of stakeholders. Based on findings from these investigations, an initial system prototype is developed for user evaluation at a later stage of this study.

3. As it was mentioned earlier, evaluating MR applications for SwNCDs is challenging. Therefore, this research utilizes a systematic design review method called The Design

Critique. This method has two main benefits; firstly, it allows for an online remote system design evaluation, which is crucial during the COVID-19 pandemic. Secondly, Design Critique studies are based on collecting feedback from various participant categories, which is essential in evaluating supportive systems for SwNCDs. This Design Critique study includes various participant categories: SwNCDs, formal and informal caregivers, domain experts and MR developers. The goal of this study is to extract feedback and design recommendations. Furthermore, the different relationships between participant categories and design recommendations/concerns are explored.

4. By including MR developers in the second round of Design Critique, this study introduces recommendations and best practices for developing such systems using the Unity[1] game engine and Microsoft Mixed Reality Toolkit (MRTK)[2] for HoloLens2[3] devices.

5. At the final stage of the Design Critique phase, we introduce a comprehensive map of all interrelationships between NCDs-related problems, how they affect the design of a supportive smart home system, how this immersive UX and UI could respond to these problems, and finally how to implement these solutions using the Microsoft Mixed Reality Toolkit which is the most versatile development kit currently.

6. We use the newly extracted design recommendation to reiterate the system design and implement it on a Microsoft Hololens2 device and a set of IoT devices. As of the present, this study is the first to introduce an immersive smart home systems concept targeting SwNCDs.

7. The last objective is to evaluate the usability of the final high-fidelity system prototype through a two-stage process; Cognitive walkthrough and Heuristic Evaluation. This

[1] https://www.unity.com
[2] https://www.docs.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk2
[3] https://www.microsoft.com/en-us/hololens

evaluation is carried out with a group of domain experts who mainly work on developing MR applications for people's cognitive challenges.

1.4 Challenges

The previous section briefly presented SwNCDs and supportive smart home systems topics. It is clear that there are several challenges in designing supportive smart homes for SwNCDs. In this section of the thesis, these challenges are categorized and presented as follows:

- **Research-related challenges:** Following a UCD approach when targeting SwNCDs users was recommended several times in the literature [HIR+05, AB16, RB16]. The first phase of any UCD study is conducting an investigation before design and development. Typically, this requires reviewing previous research work to explore different concepts in the literature and develop a better understanding of research field. However, the field of supportive smart homes has attracted researchers from various fields of study, including computer science, software engineering, design, health science, social sciences, nursing, and medicine. While this variety of research backgrounds enriched this research area, understanding its state of art became difficult. There have been a few attempts to provide a systematic overview of the literature. However, these attempts didn't lead to the development of clear taxonomy and categorization of SSHS for Human-Computer Interaction researchers. It is fair to say that there is a lack of a starting point for current and future researchers.

- **User-related challenges:** It is commonly known that NCDs are usually associated with short-term memory loss; however, many NCDs manifest themselves as behaviour, personality, cognitive, and functional changes as well. This, in turn, creates a variety of individualized needs and care preferences [TLBL+18b]. Furthermore, NCDs are progressive in nature, which means the needs of an SwNCD can change over time as the condition progresses [SBB+14]. Therefore, it is crucial for a supportive system to account for all of these special requirements of this illness [AB18b].

Previous work suggested that using common testing approaches such as the System Usability Scale, TLX, and Player Experience Inventory are not suitable for SwNCDs [GMM+16, KRK+21, RB16]. Therefore, an additional evaluation method of a qualitative nature, such as the Design Critique, is required to elicit design recommendations before development and user testing.

- **Technology-related challenges:** Typically, interacting with an IoT-based smart home system requires the users to utilize smartphone applications. This method of interaction can be challenging for seniors and their caregivers as well due to technology literacy and learning difficulty factors [MDAZY20]. Furthermore, carrying a smartphone at home to receive notifications or interact with the SSHS is not practical for effective homecare purposes.

  From a UX perspective, and as it was explained earlier, a single type of smart home notifications is not sufficient as SwNCDs [MA14]. Furthermore, commercial IoT services do not account for any of these users' needs as they are not explicitly intended for homecare purposes [FSA+17]. However, for a family to rely on an IoT-based supportive smart home system, this system should accommodate these needs and provide users with different types of accessible and tailored memory prompts. Therefore, a better user-system interaction that assures delivering support for the user at all times and everywhere is required.

- **Design-related challenges:** There are two main challenges in the field of MR applications for the aging populations. Firstly, there is a lack of UX and UI design guidelines targeting SwNCDs [dBB19]. While there are a few attempts in the literature to design tailored MR applications for SwNCDS, the amount of published work is relatively sparse. Secondly, the current methods of testing and evaluating MR applications are primarily inherited from other fields such as web systems and mobile apps [BS04, RSNC20]. Evaluating MR applications with seniors is relatively difficult because the technology is not yet mainstream, and the cost of owning MR devices is still high. Furthermore, the role of the caregiver is essential when designing and testing technologies for SwNCDs; including more than multiple of stakeholders category (seniors, formal and informal caregivers) increase the difficulty running user research and user studies [AB16, AB18a]. Due to the COVID-19 pandemic, evaluating MR applications in-person with senior citizens and caregivers became even more challenging and, in some cases, not possible. A search for relevant papers published between 2019 and 2022 revealed a significant drop in studies that conducted system evaluations with senior participants. Seven relevant papers were published in 2019, and only four relevant papers were published between 2020 and 2021. Three of these studies were conducted in Scandinavian and European contexts, while only one study was published as a part of a long-term project in Canada. In addition, one relevant paper was published in 2022, where researchers used a mobile lab truck to conduct prototype evaluations with senior users in Germany (these studies are reviewed in Chapter 2). This further empathizes the importance of findings, alternative design evaluation methods and the need for more design recommendations studies.

1.5 Scope of the study

This study focuses on designing systems targeting seniors at an early-mid stage of NCDs. All prototypes in this study address two use cases extracted from the requirements elicitation study. First, evaluating system prototypes are conducted over multiple Design Critique sessions over two rounds and with samples of potential end-users, caregivers, domain experts and XR developers. All these sessions are video recorded for qualitative data analysis purposes. The Thematic Analysis method analyzes qualitative data to identify critics' feedback

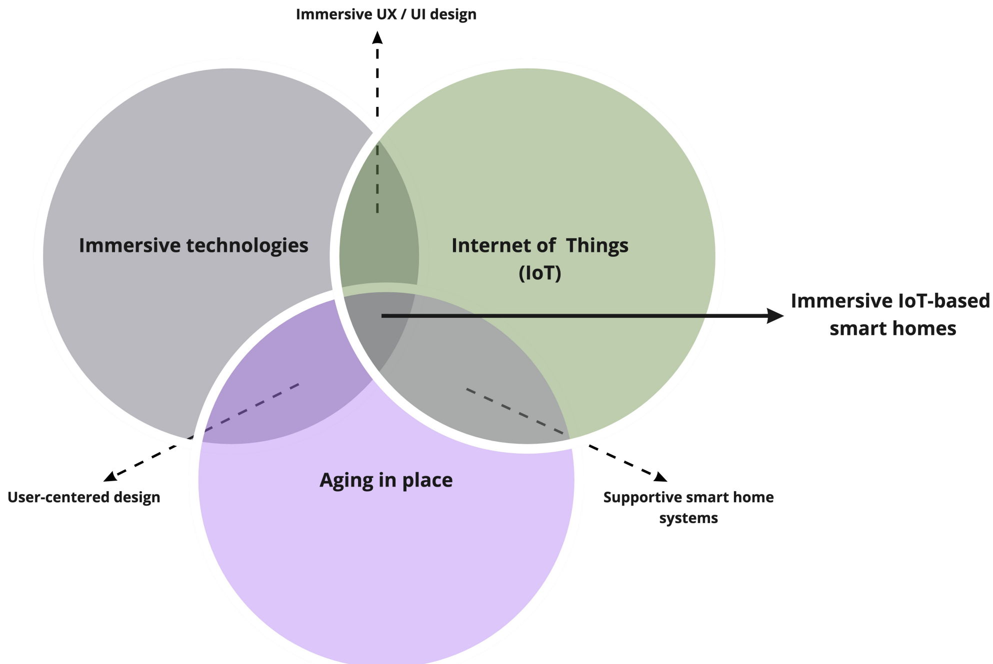

Figure 1.1: The scope of immersive IoT-based smart home systems to support aging in place for SwNCDs

patterns and elicit design recommendations. This method allows for identifying patterns in the data and introduce themes of these patterns. Having that the coding process was completed by one researcher, a reflexive approach of inductive and deductive coding was carried out as per Braun and Clarke's recommendations [BC06]. Later in this study, the design of the suggested system prototype is reiterated based on the newly extracted recommendations. This research is concluded by introducing a high-fidelity system prototype running on a HoloLens2 device and a set of IoT devices.

As illustrated in figure 1.1, the scope of the study is driven by three main research areas: immersive technologies, IoT, and aging in place. This study focuses on mixed reality technology in the context of immersive technologies. The intersection between IoT and the immersive technologies area discusses design-related topics, including UX and UI design. Approaching the field of aging in place research area from an immersive technologies perspective reveals an emphasis on following the user-centred design when targeting SwNCD users. Finally, by intersecting aging in place with IoT, we explore different supportive smart home systems concepts. The specific scope of this research study is immersive IoT- based smart home systems for SwNCDs' support which emerge at the intersection of immersive UX and UI design, UCD and supportive smart home systems.

1.6 Overview of the thesis

- Due to the multidisciplinary nature of this research, it is important to introduce textbook-knowledge style topics. Therefore, in Chapter 2, related topics such as NCDs, aging in place, IoT systems, MR technology, and Design Critique studies are presented.

- Chapter 3, the research methodology is thoroughly presented. The remaining chapters report primary, secondary and empirical research studies.

- Chapter 4 presents a systematic review of the SSHS literature where different types of smart home concepts are categorized. Data analysis is conducted on selected papers to identify several attributes in each paper, such as design approach, target users, prototype fidelity, evaluation methods, benefits and limitations.

- Chapter 5 discusses a requirement elicitation study with a sample of seniors, caregivers and experts. This chapter aims to elicit the special requirements of the end user category and to present a set of use case scenarios that can be addressed in a supportive smart home system along with system desired features.

- Chapter 6 presents the initial system prototype, the two use cases, UX task flow, UI design and the prototyping process.

- Chapter 7 introduces the Design Critique study and the study participants.

- Chapter 8 presents the thematic analysis process of the Design Critique data and the final thematic framework that presents design recommendations and critics' feedback.

The study results and discussed thoroughly where relationships between different participant categories and newly extracted design recommendations are discussed. In addition, this chapter discusses the interrelationships between NCD-related problems, aging in place, system response to these problems, and design and implementation recommendations.

- Chapter 9 presents the design of the final high-fidelity system prototype along with a usability evaluation consisting of two phases: cognitive walkthrough and heuristic evaluation. Results of the usability evaluation are presented and discussed in the same chapter.

- Finally, Chapter 10 concludes this research by providing an overview of the thesis contributions, answering the research questions, and suggesting future work.

Chapter 2

Background and Related work

2.1 Chapter overview

As was discussed in chapter one, the scope of this study lies in three areas: supportive smart home systems, immersive technology design and aging in place for SwNCDs. Therefore, Exploring related topics from these three areas is essential for understanding the full context of this thesis. Although one of this PhD research objectives is to review the SSH literature systematically, this type of study focuses only on answering specific research questions related to a specific body of the literature. Topics outside the scope of the systematic literature review are typically not covered despite their relevance to the overall PhD research. Therefore, writing this chapter to introduce related topics and review relevant studies beyond the systematic literature review is crucial. This chapter starts with a brief overview of the different types of NCDs and discusses dementia and Alzheimer's numbers in Canada and worldwide. After that, the concept of aging in place and supportive smart home systems are discussed. In the last two sections, an overview of different types of Extended Reality (XR) technologies is presented, followed by a review of related studies in the field of XR and older adults.

2.2 Neurocognitive disorders

As it was mentioned in Chapter one, the term NCDs refers a variety of illness including Dementia, Alzheimer's and MCI. In this sub-section, we discuss the differences between some of the most common forms of NCDs. In addition, we provide an brief overview of related statistics.

2.2.1 Different types of NCDs

Nine main medical conditions affect cognitive abilities, including Alzheimer's disease, frontotemporal degeneration, Huntington's disease, Lewy body dementia, traumatic brain injury, Parkinson's disease, Prion disease, neurocognitive issues due to HIV, and dementias. In geriatric medicine, NCDs are usually categorized and diagnosed as either minor, mild or major, depending on the severity of the symptoms. Alzheimer's disease is the most common cause of major NCDs, as it accounts for 60-80 percent of dementia cases [PWG+15]. A common form of minor NCDs is called slight cognitive impairment or Mild Cognitive Impairment (MCI). Other forms of major neurocognitive disorders are generally considered full-out dementia [Sim14]. This section briefly presents the three most common forms of major and minor cognitive disorders.

1. **Mild Cognitive impairment (MCI):** Usually, people living with MCI would suffer short-term memory, thinking and judgement problems that are more severe than normal aging-associated cognitive changes. Typically, these changes are notable by family members and close friends. A geriatrician would measure the changes to diagnose the case using clinical and take-home tests. Generally, changes associated with MCI are not severe enough to interfere with the person's daily life activities and independence. Nevertheless, MCI might increase the person's chances of developing Alzheimer's disease or a dementia. However, many people with MCI remain stable, while others may show cognitive improvement over time [GRZ+06].

2. **Dementia:**

   Dementia is a general medical term for several symptoms caused by neurocognitive disorders where brain cells are damaged. These symptoms include memory loss, task completion difficulties, thinking difficulties, problem-solving, reasoning challenges, neuro signal delay, and potentially language difficulties [CLML12]. To diagnose a person with dementia, these symptoms should be severe enough to reduce the person's ability to perform daily life activities. On top of that, a person with dementia might also experience mood and behaviour changes. Most dementias are progressive conditions, meaning the symptoms can worsen over time as more brain cells get damaged. Dementia itself is not a specific disease; instead, it is an umbrella term for 400 conditions that can be caused by different illnesses such as Alzheimer's disease, vascular dementia (due to strokes), Lewy Body disease, head trauma, front-temporal dementia, Creutzfeldt-Jakob disease, Parkinson's disease, and Huntington's disease [MKC+11]. People in an early to mild stage of dementia can live independent lives with limited support. In contrast, people in advanced stages would require additional support, which could significantly affect the potential for aging in place [TLBL+18a].

3. **Alzheimer's disease:**

   Dr. Alois Alzheimer first identified the disease in 1906. *"He described the two hallmarks of the disease: "plaques," which are numerous tiny, dense deposits scattered throughout the brain that become toxic to brain cells at excessive levels, and "tangles," which interfere with vital processes, eventually choking off the living cells"* [KNO86]. Alzheimer's is a brain disease where nerve cells get damaged and die, leading to a reduction in size for some brain regions. Furthermore, Alzheimer's accounts for 60-80 percent of dementia cases. It is essential to understand that Alzheimer's affects each individual differently. The symptoms, the order in which they appear, and the duration of each stage vary from one person to another. Therefore, the needs of a person with Alzheimer's may vary and change over time [PWG+15]. The following changes are the most common as the condition progresses:

- Cognitive and functional ability changes: thinking, understanding, communicating, making decisions, performing daily life tasks, engaging in conversations, short-term memory loss and eventually long-term memory loss.
- Behavioural changes: developing new reactions, repeating speech, actions and a tendency to hide personal belongings.
- Mood and emotions: losing interest in hobbies, feeling isolated and becoming less expressive and withdrawn, higher levels of stress and anxiety.
- Physical abilities: affecting mobility and muscle coordination to intervene with daily activities such as bathing, dressing and eating.

Currently, several medications (Psychotropic drugs) can help manage or ease some of the symptoms but they may increase the risk for fall and mortality. Up to this time, there is no current cure for any NCDs [PWG+15]. Therefore, learning to adapt and manage the case is the priority for any caregiving team (formal and informal caregivers) [TLBL+18a]. In countries where health care is universal, we notice more emphasis on educating SwNCDs and their caregivers about the various ways of managing the case. The efforts and the costs to provide care for SwNCDs are related to the proportion of older adults to the general population. In Canada, the older adult population is increasing rapidly and thus, reported cases of dementia are significantly increased. To better understand the scope of this issue, the following section discusses dementia numbers in Canada and worldwide.

2.2.2 Dementia numbers in Canada and Worldwide

In 2010, The Public Health Agency of Canada[1] reported that 400,000 senior citizens were living with dementia. This number was considered relatively high as the entire Canadian

[1]https://www.canada.ca/en/public-health.html

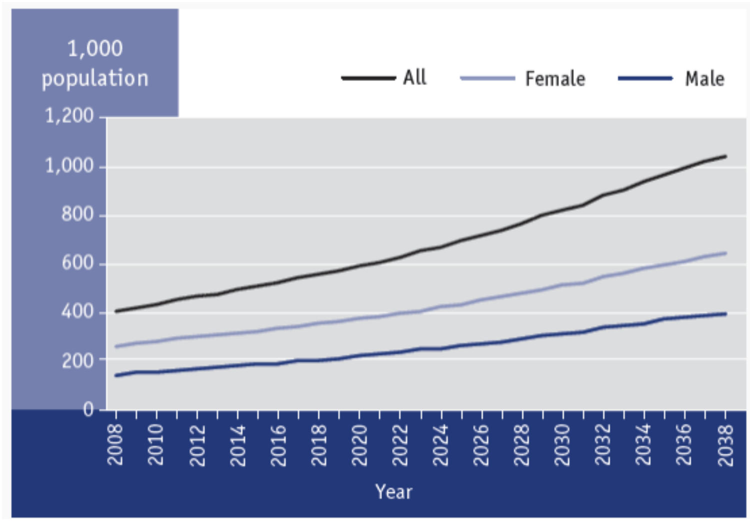

Figure 2.1: The Impact of Dementia in Canada 2008 to 2038. (Source: Public Health Agency of Canada, 2010)

population was 34 million. Furthermore, the same source estimated that the population of people with dementia will double over the next 30 years (only 18 years from now). Figure 2.1 presents the current and projected number of Canadian seniors with dementia. The estimated prevalence of dementia is higher among those aged 80 years and older, with a rate of 55 percent of all Canadians with dementia. Meanwhile, seniors aged 65 to 79 years have an incidence rate of 4.3 percent. The data suggest that senior women are more likely than senior men to develop a dementia (10.3 percent vs 7.2 percent, respectively) [oC10]. In 2016, the Alzheimer's Society of Canada revealed that 564,000 Canadians are living with dementia, and about 25,000 new cases are diagnosed yearly. The source expected the number of cases to increase to 937,000 by 2031. The reported cost of dementia care in Canada is estimated at CAD 10,4 billion per year, and this number is expected to increase to CAD 16.6 billion by 2031. According to the Alzheimer's society, approximately 65,000 Canadians with dementia are being cared for in hospitals, while this is not the ideal place for care for these particular cases [oC18].

Worldwide, there are 43 million persons living with dementia, which is projected to increase to nearly 70 million by 2030. As shown in Figure 2.2, by 2050, the number of dementia cases is estimated to reach 118 million. There are nearly 9.9 million cases of

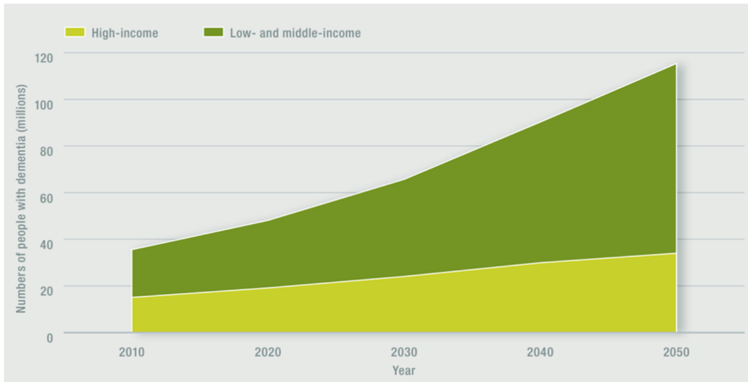

Figure 2.2: Dementia numbers worldwide. (Source: World Health Organization, 2012)

dementia diagnosed every year. Currently, the global estimated cost for dementia care is USD 818 billion per year [O+12].

These numbers indicate that the healthcare system will face severe challenges in the near future as the demand on healthcare services will increase. In developed counties like Canada, the number of senior facilities will not be enough to accommodate future aging populations. Furthermore, the cost of such programs is considered high due to the required large number of staff with professional training. In other words, social and financial pressures will be on our national healthcare system, which is facing multiple challenges already. Alternative healthcare modes like aging in place could reduce the impact of the increased aging population challenges by providing essential support for families in the comfort of their own place. However, it is vital to highlight the challenges that SwNCDs and their caregivers face at home when aging in place. In the next section of this chapter, we will provide an overview of how NCDs affect aging in place.

2.3 Aging in place for SwNCDs

Aging in place in place is an old concept that has been practised across the globe for centuries [WLG+12]. In our modern world, aging in place has become a personal or a family choice in some cultures. In some other cultures, it is considered a social or religious obligation. In China, caring for older adults is a legal obligation [ZCR20]. Despite this verity of perspectives, NCDs effects aging in place for all people in similar ways regardless of their geographical location, cultures, legal obligations and personal beliefs. To better explore these effects, we need to discuss aging in place and NCDs from the perspective of all involved parties, including the senior, informal and formal caregivers.

1. **The effect from the Senior's perspective:**

   The types and stages of NCDs determine the effect on the individual's life in various ways. According to Theresa Thoma-Lurken et al. (2018), NCDs challenge aging in place by negatively affecting the senior's ability for self-reliance. One of the main challenges is the lack of ability to complete activities of daily living; forgetting to eat and drink, missing medications, and in some cases, hygiene-related issues start to appear. Lack of structure and meaningful activities are common as well. In addition, disrupted sleeping rhythms negatively affect almost all daily activities and could lead to disorientation problems [TLBL+18b].

   The other set of effects is related to the safety of the senior resident. Forgetting the gas on when cooking and falling are considered the most dangerous situations. Using electronic devices such as irons and block heaters is another safety hazard. Indoor and outdoor wandering episodes are other effects of NCDs, especially for people who suffer disrupted sleeping and disorientation problems. Finally, poor judgment can lead to safety issues at home, such as consuming too much medication, inedible food, or wearing clothes that are not suitable for the temperature (e.g., wearing think outdoor Winter clothes at home) [TLBL+18b].

2. **The effect from the informal caregiver's perspective:**

   In most cases, informal caregivers are non-professional individuals who volunteer to care for people with NCDs living at home. Spouses and children represent the majority of caregivers. In some cultures, friends and neighbours would also volunteer for the task. Common among all informal caregivers is the struggle of -suddenly- becoming responsible for providing care. Accepting these new responsibilities and accepting a senior's personality and behavioural changes is usually the first significant challenge most families face [DVV13]. Studies that explored the effect on the informal caregiver suggest that caregiver describes their experience as a "burden" and a life-changing experience [ZCR20]. Mental, physical and financial challenges are common as well. However, families who adopt aging in place argue that providing home care -as long as possible- is better than moving to a nursing home. Interestingly, this statement is joint among both parties indicating that aging in place is preferred by the seniors and caregivers as well.

3. **The effect from the formal caregiver's perspective:**

   In developed counties like Canada, providing professional care for SwNCDs is available. There are different types of caregivers, depending on the individual's heath and medical needs including homecare assistants, nurses, occupational therapists, etc. The involvement of these caregivers varies depending on the individual's needs. Usually, the home care assistant would spend time with the senior at home, making the house, preparing meals and engaging in daily activities. Understandably, nurses would be more concerned about medical tasks such as medication management and home tests (e.g., blood pressure tests, etc.). Finally, occupational therapists are essential in aging in place as they help clients develop and improve skills needed to execute daily activities [KYJ+12].

Facilitating Aging in place requires supporting the seniors and their caregivers at the same time. Gaining more self-reliance to reduce the burden on the caregiver is a common thought among SwNCDs. Some seniors would take it as far as asking to be admitted to an assisted living facility, only to reduce the burden on their families. On the other hand, from the informal caregiver perspective, reducing the number of home care tasks to a manageable amount is crucial. Supportive smart homes can support both parties by using software and hardware components to automate many homecare tasks. However, this type of systems faces user-system interaction challenges. In the next section, we will explore this topic in detail.

2.4 Supportive Smart home systems

2.4.1 Smart home systems and aging in place

In their discussion of Alzheimer's in the context of aging, Frisardi and Imbimbo viewed supportive smart homes as *"a residence equipped with technology that facilitates monitoring of residents to improve quality of life and promote physical independence, as well as to reduce the pressure on caregiver burden"* [FI11a]. The literature presents various supportive smart home concepts for dementia homecare such as memory support, social networking applications, daily life activities support, safety and security, tracking personal belongings, behavioural and mood monitoring [RM12]. Typically, these systems are equipped with software and hardware components that collect and analyze data to notify the users, adjust or control smart home devices and notify caregivers [AMMW07]. Augusto et al. in [AMMW07] categorize the advantages of smart home systems as follows:

- Monitoring: by monitoring the daily life activities of the inhabitants, dangerous situations can be predicted and prevented. Daily life activities monitoring includes, but is not limited to, environment or body temperature, movement, sleeping, cooking, bathing, walking, using house appliances, taking medication and vital signs monitoring.
- Safety and security: including access control, automatic lock system, smoke alarm, automatic lighting at night and intruder alarms.
- Comfort: one application for smart home system comfort is Light Therapy. The home

system can take full control of the lighting system to simulate a natural light environment which is believed to reduce disorientation episodes.

- Care: this aspect of the smart home system targets seniors and their caregivers. By informing caregivers about abnormal situations and providing remote access to the home system, the system allows for remote interventions.

As discussed above, and unlike many other technologies, SSHS targets more than one end-user category. Therefore, one key factor in introducing usable SSHS is understanding the full context of both user categories; the senior and caregiver. The next section of this chapter discusses this point in detail.

2.4.2 Smart homes systems and end-users

In the literature, it is established that SSHS is expected to support the seniors primarily and the caregiver secondarily [AB18a, AB16]. Recognizing the importance of the caregiver's role was discussed in many studies in the literature [LAW+10, SHWG17]. The literature suggests that a smart home system designed to support SwNCD should address the requirements of more than one category of users [IWJ+18]. The system users were identified as the seniors themselves, their informal caregivers (usually a family member), formal caregiver (social workers, occupational therapists, nurses) and medical caregivers (doctors, geriatrics) [HIR+05]. What determines the number of end-user categories is the place of residence. For seniors living in assisted living facilities or older adult communities, we expect multiple user categories. Whereas, for those who age at their own place, the number would be less (the senior, informal and formal caregiver) [TNM17].

2.4.3 Requirements gathering for SSHS design

Following the User Center Design method (UCD) is recommended in this research area [AB16]. In this framework, eliciting the system requirements is considered the first phase

[JS05]. Typically, requirements elicitation studies include potential end-users and stakeholders. However, due to the particularity of NCDs, involving seniors in the requirements elicitation phase might be challenging. Therefore, many elicitation studies focused on gathering requirements from caregivers only [AB16]. For instance, [OGA+05] attempted to gather the most common special requirements for SwNCD using qualitative data collected through focus groups and interviews. In their study, they proposed several valuable special requirements for SwNCD. The results of their study suggested that; A) SwNCD finds it very difficult to learn how to use new technologies. B) it is essential to consider embodying any SHS component with a similar or previously familiar object. C) SwNCD prefer to maintain a certain level of control over their surrounding environment. Therefore, any SHSS should not lead to a sense of losing control. D) formal caregivers should be the first to test and evaluate any new technology. E) finally, the study emphasizes having a strategy for emergency responses pertaining to the safety of the senior user, or in case of system failure.

Other studies suggested that seniors with mild to moderate dementia can be involved in gathering design requirements. For example, researchers in [WM08] interviewed nine seniors with dementia and their caregivers. In addition, they conducted one focus group with seniors and caregivers. A Grounded theory approach was used to analyze qualitative data from the interviews and the focus group. The results of their study suggested that SwNCD requires support for taking medication, personal hygiene, making food, dressing and bathing. In addition, the study found that caregivers face frustration, confrontation, tiredness and worry, constant supervision and anxiety while caring for a SwNCD. Finally, the studies proved that gathering requirements from senior participants could lead to meaningful and accurate results.

Despite the different methods of gathering system requirements, most studies agree that system usability is a key factor in adopting new supportive systems [AB18a, GMM+16, QSA+01]. From an HCI perspective, this means a supportive smart home system should accommodate the special requirements of NCDs in the User Experience and User Interface design. Most supportive smart homes are managed via smartphone applications or web-based systems, which is not practical for homecare purposes. Exploring modern technologies such as immersive technologies can solve this user-system interaction problem by providing users with a tailored and hands-free immersive experience. The next section of this chapter discusses the different types of immersive technologies.

2.5 What are immersive technologies?

The term immersive technologies is adopted as an umbrella term for several technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [LTLL22]. Other sources may use the term Extended Reality (XR) to describe the same set of technologies [BVS+21]. The ability to produce interactive spatial interfaces is the key feature of all these technologies. In the past eight years, the excitement for producing lighter and more powerful XR devices met with more supply from technology leading companies such as HTC, Google, Microsoft, Amazon, Meta and more. Using Head-Mounted Devices (HMD) is the most common method of experiencing XR [SMO20]. Currently, there are three types of HMD; stand-alone devices, PC-connected devices, and smartphone cases. Typically, HMDs are mainly used for VR and MR applications, whereas smartphones and tablets are used for AR applications. In the following section, we will briefly discuss the differences between all these technologies and the benefits and challenges of each type. After that, a review of related research work is presented.

2.5.1 Virtual Reality

It is perhaps the most common type of XR application. The main feature of VR is that it fully immerses the user in a virtual computer-generated world. Previously, most VR headsets required a wired connection to a PC with powerful processing capabilities. To track the user's movement, built-in gyroscope and speedometer sensors constantly measure rotation and spatial movements. Hand-held controllers are often used for user-system interactions [Jer15]. Typically, that requires 2-3 external IR sensors to locate the users and their controllers in the space. This ecosystem provides various interaction methods such as gazing, teleporting, pointing, pressing buttons and free movements. These VR systems are mainly used for training, games, painting, modelling, virtual conferencing and remote collaboration. The HTC Vive series and the Oculus Rift were good examples of these types of VR systems [NLL17].

Mobile VR cases, however, are much simpler and more limited in their functionality and capabilities. This type of VR solely relies on the smartphone's ability to render 3D objects on two zones of the screen (left eye and right eye). Gazing and Bluetooth clicking buttons are the only methods of user interaction [SGHJ19]. There are many commercial VR cases in the market; however, Google Cardboard seems to be the most common as it comes with its own mobile application.

In the past two years, stand-alone VR systems have become more popular and -certainly- more affordable. For instance, the Oculus Quest series offers a wireless stand-alone VR experience. More interestingly, external sensors are not required thanks to the built-in IR sensors capable of tracking hand-held controllers and detecting hand gestures. This means the HMD is the only required device to experience VR. Controllers can be optionally used for tasks that require more precision, such as painting. It is essential to highlight those stand-alone devices with limited processing power [HGHK21].

Despite the type of VR devices, one main limitation of VR is that it completely isolates users from their surrounding environment, which could cause a safety hazard. In addition, some studies report that VR users often experience disorientation and dizziness. Therefore, VR is unsuitable for tasks requiring interaction with the surrounding environment [CKY20]. Nonetheless, the literature presents some successful attempts of VR applications for seniors such as exergames in [SZCS+19, Kor12], cognitive and memory exercise in [KRK+21], and group physical exercise in VR in [ACS+19].

Figure 2.3: The difference in displaying digital content in VR, AR and MR. Source: Magic Leap's website

2.5.2 Augmented Reality

It is another form of immersive technology where 3D computer-generated objects reside in the real world via smartphone or tablet. These devices are usually equipped with Depth Cameras that scan the environment to deduct surfaces. Once the scan is completed (it takes a few seconds on newer devices), users can pick a surface to display a 3D object which is often referred to as augmentation. Other sources may uses the term 'hologram' to describe to these 3D objects, however, in this thesis we will continue to use the term augmentation. Using built-in gyroscopes and speedometers, the device movement and rotation are tracked, and augmentation display is adjusted in real-time accordingly [ZYX+20]. However, AR augmentations do not integrate with the real world. In other words, if a an augmentation collides with a real-world object, it will continue to be fully displayed. Furthermore, AR applications do not allow unrestricted movement as the user must carry the displaying device all the time while pointing at the augmentation location [VKP10]. Figure 2.3 shows the differences in displaying virtual content in VR, AR, and MR.

2.5.3 Mixed Reality

Some of the earliest sources in this field such as Paul Milgram et al (1995) uses the term Mixed Reality to describe the spectrum of immersive technologies; from completely virtual reality to augmented reality [MTUK95]. However, immersive technologies have came a long way since then. In this thesis we adopt a new definition of MR that has been introduced by multiple organizations including the Interactive Design foundation[2]; "*MR is a technology that allows not only the superposition of digital elements into the real-world environment but also their interaction. In the MR experience, the user can see and interact with both the digital elements and the physical ones. Therefore, MR experiences get input from the environment and will change according to it*"

A significant benefit of MR is that it blends virtual objects into the real world, creating a truly immersive experience [SHN19]. Unlike AR applications, MR integrates virtual augmentations with the real world. Another benefit of the MR device is that users can interact with augmentations instantly and effortlessly [BVS+21]. Additionally, it offers hands-free interactions without isolating the users from their environment [RDMG20a]. The possibility of displaying augmentations everywhere around the user enables user free movement, which is essential for tasks requiring interaction with the real-world [GBJMACU15].

There are a few commercial MR devices, such as Microsoft HoloLens 2, Magic Leap and Neal, see Figure 2.4. The HoloLens 2 is one of the market's most advanced and robust device. It is a stand-alone device with a built-in Microsoft Windows system. The devices offer several methods of interaction: hand and finger tracking, gazing, voice commands and eye tracking. Another powerful feature is the integration with MS Azure which unlocks unique possibilities such as spatial anchoring an object's detecting [SBSPM21]. From a software development perspective, HoloLens 2 has a -relativity- big online community and consistent support from Microsoft. Currently, the Microsoft Mixed Reality Toolkit (MRTK) is the most advanced development kit which supports development for HoloLens and Magic Leap devices using the Unity and Unreal Game engines. Notably, the size of the HoloLens2 makes it unsuitable for daylong use. Nonetheless, it is an excellent device for prototyping and testing purposes [UBG+20]. Alternative MR devices such as the Magic Leap light and Neal

[2] https://www.interaction-design.org

Figure 2.4: Commercially available MR devices

light are considerably smaller and lighter; however, they are not as commercially available. Another issue is that these devices require a wired connection to a portable processing device carried in the user's pocket [FLP+22].

MR is an emerging field of study in both worlds: industry and academia. It is common knowledge now that the near future holds MR devices that are more usable and user-friendly. Many major companies entered the race to produce user-friendly glasses. For instance, Facebook (aka Meta) has teamed up with Ray-Ban to produce smart glasses that can pair with the user's smartphone [KSSI21]. Some media articles reported that Apple is in the process of producing light MR glasses. Some ongoing research work went beyond MR glasses. For instance, Intel smart glasses can display visual objects directly onto the eye pupil. More optimistic research attempts to develop wearable MR contact lenses called Mojo Visio [Wie21]. After exploring the different types of XR technology, the remaining part of this section provides an overview of research work related to MR applications for senior care.

2.6 Mixed reality applications for seniors

Although MR is still an emerging field, the literature presents a small number of MR concepts for seniors' homecare. Researchers in [HBHN21] introduced a supportive system using a website and a HoloLens application to display customized memory prompts and reminders. Caregivers use the website to create customized reminders using text, images and short

Figure 2.5: Screenshot of cARe system prototype. Source: [WBS+18]

videos. The HoloLens application benefits from the Spatial Mapping feature and the MS World Locking Tool to provide indoor navigation functionality. Conducting a form of user testing can validate the claims of this study however, the paper did not report any evaluation. The conclusion was to modify the UX design to make it more suitable for people with Dementia and then evaluate the application. A more minimal application was presented in [RDMG20b] to display memory prompts on a smart glasses device.

Supporting independent life for SwNCDs can take many forms depending on the person and their needs. For example, cooking and taking medications on time are often the first two tasks to require caregiver attention. The cARe system prototype was aimed to assist SwNCDs in cooking more independently by displaying holographic directional prompts and playing audio cues [WBS+18]. Based on a requirements elicitation study, the prototype design consisted of two user interfaces; senior and caregiver users. In order to set up the system, the caregiver would use HoloLens "air tap" to place virtual cooking items into the real world. A controlled experiment was conducted to evaluate the prototype where users were tasked to cook using a paper recipe and then using the cARe. The system displayed directional arrows toward cooking items and pictures and provided audio feedback. The quantitative data showed higher success rates with shorter completion time when using cARe [WBS+19]. See Figure 2.5 for a UI screenshot.

MR can improve physical and cognitive exercises by incorporating virtual components into the physical world. The HoloLearn application was developed to assist SwNCDs in engaging in simple cognitive tasks. The current version of the application supports two activities; garbage collection and laying the table. In the first activity, users perform the

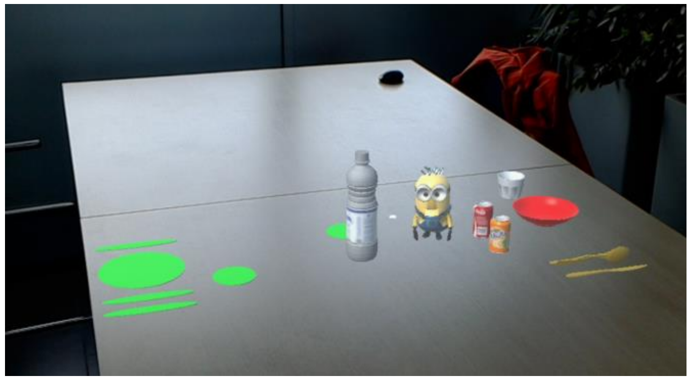

Figure 2.6: Screenshot of HoloLearn application showing the table laying exercise. Source: [GTVA18]

"Air Tap" gesture to interact with augmentations to separate waste. Similarly, in the second task, users lay virtual table elements, see Figure 2.6 for the application screenshot. Based on a therapist's recommendation to use a familiar virtual assistant, the application displays a Minion character to provide users with memory prompts. While SwNCD is the main target category for this application, researchers did not report any form of evaluation with users or stakeholders [AGTV18, GTVA18]. Researchers in [VSMW20] proposed MR exergame for seniors with a hypertension health condition. Videos for an initial system prototype were demoed to 11 seniors and health professionals to gather design requirements. Participants suggested integrating wearable sensors to monitor and evaluate user performance. The MemHolo is a cognitive training application for seniors living with Alzheimer's. The system's main objective was to explore translating standard cognitive exercises into MR-based applications. Based on feedback from stakeholders and occupational therapists, seniors at an early stage of Alzheimer's were selected as target users. The final application included three exercises revolving around finding hidden objects inside boxes. Researchers conducted three user evaluations and highlighted the benefits of MR applications in engaging users without the risk of being isolated in a virtual environment [AG19].

Interacting with augmentations is a new concept, especially for SwNCDs. Therefore, investigating different types of interaction methods to identify best practices is essential. In [DBFA20] researchers recruited ten senior participants to play Osmo games and Yong Conker

Table 2.1: Summary of related studies

Study	Device used	Target end-user	Objective(s)	Limitations
[RDMG20b]	Epson Moverio	Senior users	Display reminders	Minimal approach User evaluation not reported
[HBHN21]	HoloLens 1	SwNCDs	Customized prompts and reminder	User evaluation not reported
[WBS+18, WBS+19]			Find cooking items	UI design and usability challenges for SwNCDs
[AGTV18, GTVA18]			Cognitive training	Not age appropriate User evaluation not reported
[AG19]			Cognitive training	Doesn't properly account for NCD's special requirements
[RGA+19]			Tea preparing support	Study reported low effectiveness
[KBBP+20]			Shared eating experience	Limited utilization
[DSKBN21]	iPad	SwNCDs	Holographic calls	Hardware limitations Ease of use challenges
[VSMW20]	Unspecified	Seniors with hypertension	Exergame	User evaluation not reported

on HoloLens. The study revealed that participants used gesture actions more correctly than speech. In addition, the same participants responded to audio prompts better than visuals. The study concluded that future MR applications should use appropriate prompts to direct user attention to virtual augmentations. Similar recommendations were proposed in [dBFB19] where the study explored various prompting methods in an MR environment with a sample of seniors and caregivers. Finally, researchers in [RGA+19] used a HoloLens application to give tea-making cues to seniors with mild Alzheimer's. However, the study concluded that seniors continued to make mistakes despite visual prompts.

The COVID-19 pandemic increased the demand for online video conferencing solutions, especially between family members and senior loved ones [SLRSPR+20]. MR can facilitate holographic communications to improve social connections. While using webcams is enough to join to start a video call, a holographic call requires an external depth camera and an MR device. An alternative solution is to use a tablet with an external depth camera. Using a tripod to fix a tablet device directed towards empty space, users can see augmentations of their loved ones through the screen. This concept was evaluated with ten seniors living in nursing homes. Most of the ten study participants expressed interest in using the holographic calls system [DSKBN21]. Addressing the same problem, researchers in [KBBP+20] introduced an MR application to improve the overall eating experience for seniors living alone. Users can invite friends and family members to join and create avatars joining them for a meal. Evaluating the application with senior participants reported positive feedback and a lower sense of loneliness with a better overall mood. Table 2.1 provides a brief overview of the studies presented in this section.

2.7 Mixed reality and smart home systems

The benefits of blending virtual components into the real world and linking them to smart home appliances can change the way a senior perceives and interacts with their environment. Another potential utilization of MR is to create a smart immersive user experience where users interact with augmentations to control or interact with IoT devices. However, designing this type of application for SwNCDs requires a deeper understanding of the special requirements of NCDs in general and the aging in place challenges in particular. According to our searches, there is an evident lack of this type of study in the literature. Researchers in [dBB19] highlighted the absence of supportive smart immersive systems design guidelines. Hence, the study attempted to extract 10 UI designing principles from previous literature studies. These principles were implemented on a HoloLens 1 device connected to a set of IoT sensors. The prototype supported four main functionalities: spatial anchoring, temperature and humidity sensor data reading, indoor navigation and a directional arrow. However, the study did not report any evaluation or testing with senior users. In addition, it is unclear how integrating the humidity and temperature IoT sensor is helpful for senior users.

As mentioned before, using IoT devices requires certain smartphone literacy which can be challenging to seniors and caregivers. Using MR applications to interact with IoT devices could reduce the effect such challenges. Furthermore, every IoT product line uses its own mobile app; thus, exchanging data between different IoT devices might sometimes be impossible. For that reason, researchers in [SFS18] use Eclipse smart home platform to connect

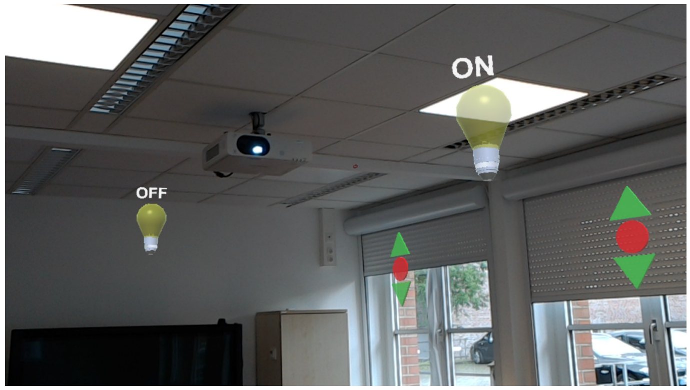

Figure 2.7: Screenshot of ARGI system prototype showing user gazing at lights and curtains. Source: [SFS18]

different IoT devices such as light bulbs and motorized curtains. The system prototype was built on a HoloLens 1 device to control smart lights and curtains; Figure 2.7 shows a screenshot of the UI. Although the study claimed that the system could be assistive for seniors, the usability of such is system remains questionable with the absence of any form of user evaluation.

To our knowledge, these are the most relevant papers in immersive, supportive smart systems. There is an apparent lack of research work in this area and a complete absence of MR design guidelines for SwNCDs users. In this thesis, we will attempt to address this gap by introducing an initial system concept. We will then conduct Design Critique evaluations with multiple stakeholder categories to extract design guidelines and recommendations. After that, we will use these guidelines to reiterate our suggested system design and conduct a further evaluation of the final high-fidelity prototype. The next chapter presents our research method in detail.

2.8 Conclusion

This chapter discussed several topics related to immersive technology, smart home systems, aging in place and SwNCDs homecare. First, to better highlight our intended populations' needs, we explored the various types of NCDs and their effects on seniors at different stages of illness. We also presented the current and projected numbers of NCD cases in Canada and worldwide. The numbers are increasing rapidly, which will negatively affect healthcare systems globally, especially in counties with a universal healthcare system like Canada. Alternative care models such as aging in place can reduce the pressure on healthcare systems by providing support for families in the comfort of their own homes. However, NCDs come with additional challenges for people who choose to age in place. In this regard, we discussed the different effects and perspectives from all involved parties, including the seniors and informal and formal caregivers. We suggested using smart home system technology to accommodate some of these challenges, which can directly benefit the senior, the caregiver and eventually the healthcare system. Since most smart home systems require interacting with smartphone applications, which is not practical for homecare uses, we suggested integrating mixed reality technology to create an immersive smart home experience. We discussed the various types of extended reality and highlighted the difference between these emerging technologies. Finally, we presented relevant research work in immersive applications for aging populations. There is an apparent lack of studies targeting SwNCDs. More importantly, there is a complete absence of design guidelines and recommendations for such applications.

Chapter 3

Research Methodology

3.1 Chapter overview

This chapter of the thesis discusses the methods applied in this PhD research. The chapter starts by introducing the User-Centered Design (UCD) process applied in this research. In the following section, the research strategy is presented where five main methods are discussed; requirements elicitation, systematic literature review, Design Critique, heuristic evaluation, and cognitive walkthroughs. Thereafter, all data collection methods are discussed including online databases, semi-structured interviews, fly-on-the-wall observations, questionnaires, and web-forms. In the last section, the three data analysis methods are presented; reflexive thematic analysis, data synthesis, and questionnaires and feedback forms analysis.

3.2 User-centered design

There are a few variations of the UCD process; however, they all revolve around investigating the user needs before implementation and evaluation. According to the Interaction Design Foundation, the UCD is defined as *"an iterative design process in which designers focus on the users and their needs in each phase of the design process. In UCD, design teams involve*

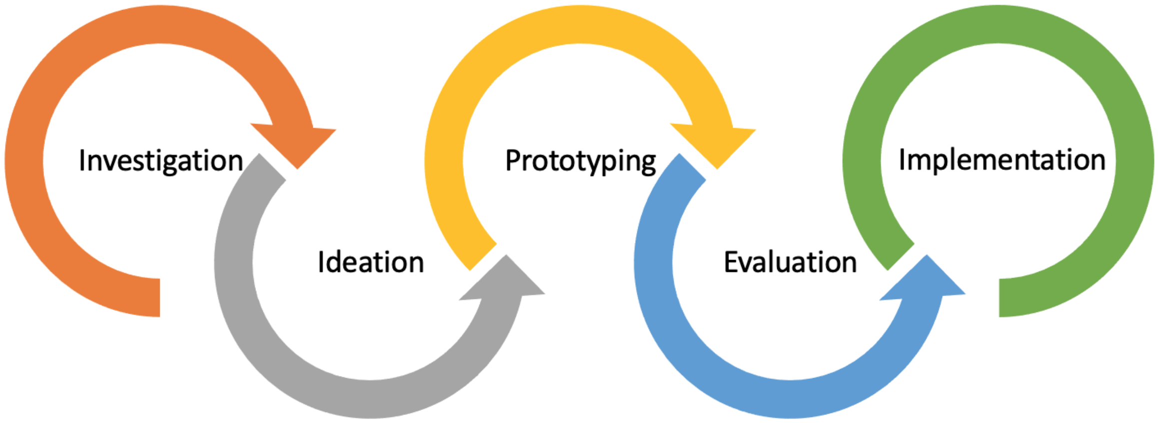

Figure 3.1: The User-Centered Design process applied in this research

users throughout the design process via various research and design techniques to create highly usable and accessible products for them" [df20]. The UCD process in this study is adopted mainly from the Interaction Design Foundation[1] and the Design of Everyday Things by Don Norman [Nor13]. As shown in Figure 3.1, the process follows these steps:

- **Investigation:** The purpose of this phase is to investigate the user needs and gather design requirements. In this thesis, two major investigation activities were conducted. Firstly, a systematic literature review to investigate the assistive smart home systems for SwNCDs' state of the art. Secondly, a requirements elicitation study with a sample of stakeholders, more on these studies in Sections 3.3.1 and 3.3.2.

- **Ideation:** In this phase, designers gather all information from the 'investigation' phase to generate design ideas and sketches. Our study explored different design ideas and system prototype concepts in preparation for the next phase.

- **Prototyping:** Usually, this phase starts with a low-fidelity system prototype to evaluate functional aspects of the design. In most cases, design teams would visit this phase more than once in an reiterative process. In this PhD project, we started with a

[1] https://www.interaction-design.org

low-fidelity system prototype (wireframe) and then reiterated the design to introduce medium-fidelity video prototypes suitable for online user evaluation which we used to run a Design Critique study (more on this in the following section). At a later stage, we reiterated the design one more time to introduce a high-fidelity prototype.

- **Evaluation:** There are many prototype evaluation methods that are common in academia and industry, such as Usability Scale Testing, Unified Theory of Acceptance and Use of Technology and the NASA task Load Index. As it was stated earlier in Chapter 1, Some studies argue that these conventional methods are not suitable for our intended end-users [GMM+16] [KRK+21] [RB16]. In this thesis, we implemented a comprehensive process conducting Design Critique including multiple stakeholder category, More on this in the following sections.

- **Implementation:** In an industrial setup, this phase involves implementing the system for demo or beta versions. In academia, this phase revolves around finalizing the system design. In our study, after reflecting on the evaluation findings, the design was iterated accordingly to produce a fully functional high-fidelity system prototype.

3.3 Research strategy

A few different research methods were used in this study, depending on the stage and desired outcome. We gathered information from primary and secondary sources of data. Some of the research methods were used in more than one phase, Table 3.1 shows every research method along with the stage of research and chapter used in. Figure E.7 shows an overview of the research activities based on the five UCD phases.

Figure 3.2: Overview of the research activities based on the UCD process. Activities are colour coded based on UCD phase

Table 3.1: Research methods and the chapter used in

Method	Chapter
Systematic literature review	Chapter 4
Requirements elicitation study	Chapter 5
Design Critique	Chapter 7 and 8
Cognitive walkthrough	Chapter 9
Heuristic evaluation	Chapter 9

3.3.1 Systematic literature review (SLR)

This type of secondary data studies uses systematic and repetitive analytical processes to collect data from primary sources [AP14]. The goal of any SLR is to identify relevant publications and critically discuss existing literature. Typically, an SLR study would identify target publications and research questions. Then, develop a search strategy and inclusion and exclusion criteria to identify relevant work.

In this dissertation, our SLR research methodology is entirely driven by the 'Guidelines for Performing SLRs in Software Engineering' by Kitchenham and Stuart, 2007 [KC07]. Our preliminary searches via Google Scholar aimed to identify existing SLR papers and assess the volume of potentially relevant studies. Afterward, we conducted trial searches using different combinations of keywords extracted from different papers. Consequently, our search strings were developed iteratively in a snowballing fashion, where the search strings were modified every time we identified a new keyword. Further searches were performed using relevant databases search tools. These searches were performed repeatedly until we could not retrieve new results. At this point, a systematic screening process using inclusion and exclusion criteria was carried out to filter search results in three stages: title screening, abstract screening and full-script screening. The analysis and discussions included only papers that passed all the screening processes.

The goals of this study were to categorize research work in this area and discuss several attributes in each study such as design methods, user category, privacy approach, prototype fidelity and evaluation methods. In addition, the benefits and limitations of each paper were discussed. Chapter 4 presents this entire study. Please refer to Appendix B for additional materials from this study such as raw data and tables.

3.3.2 Requirements elicitation

Requirements elicitation studies are defined as: *"Requirements elicitation is the process of seeking, uncovering, acquiring, and elaborating requirements for computer based systems. It is generally understood that requirements are elicited rather than just captured or collected. This implies there are discovery, emergence, and development elements to the elicitation process"*, Page 19 in [ZC05]. In Human-Compute Interaction (HCI), and specifically in the UCD, it is common to perform this type of study at an early stage to understanding the user needs and system requirements. In this PhD research, we conducted a qualitative study with a sample of seniors and formal and informal caregivers. In addition, one site visit to a senior's home was facilitated. The goal of this study was to accomplish the following:

- identify homecare issues that can be addressed using a smart home
- extract system design requirements
- elicit desired system features
- identify user scenarios for prototyping

Chapter 5 describes this study's procedures, data collection, data analysis, result, and discussions of the findings.

3.3.3 Design Critique (DC)

The DC is defined as an approach of 'constructive criticism' to elicit feedback and analyze a design to determine whether the design meets its objectives or not [CI15, BLRS07]. This approach is believed to reduce costs and efforts by reducing design issues before implementation, which is crucial in fields such as architecture and engineering [BLRS07]. Furthermore,

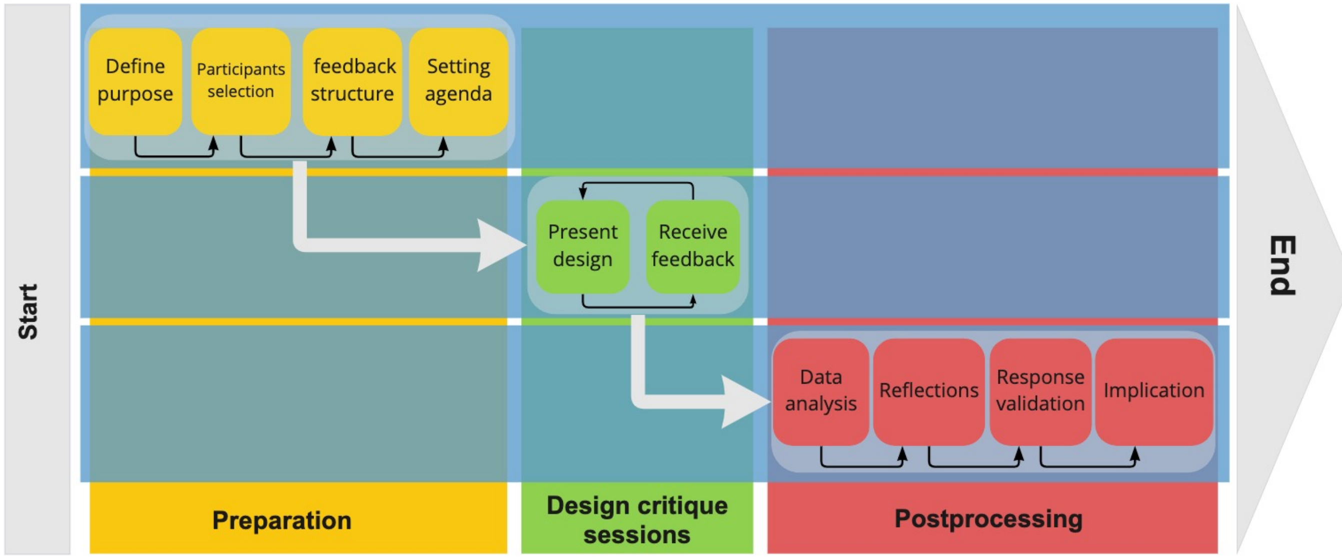

Figure 3.3: The Design Critique evaluation process implemented in this thesis. The three phases are colour coded

integrating DC into the UCD workflow introduces new design knowledge and practices from a computational design perspective. This could reduce the time, effort and cost spent during prototyping and testing. However, there are no clear guidelines for running DC studies in the context of HCI research [BLRS07]. To follow a systematic DC process, we conducted a separate SLR study to extract and analyze the different DC processes in HCI papers and, based on that, introduced a generic process.

In this SLR study, we searched for scholarly papers utilizing the Design Critique method in HCI and UX. This was a joint effort with other researchers, and I served as the main researcher and first author. We presented different contexts of using DC. In addition, we discussed essential attributes of conducting DC studies: participant category, data collection method, and data analysis method. Finally, we analyzed how the DC was conducted in each paper to introduce a novel generic DC process for HCI and UX researchers. This process is later used to evaluate our initial smart home system concept. Chapter 7 describes this process in detail. Please refer to Appendix A for the abstract and highlights of this study. We will not include the entire study in this thesis as it is currently going through a second round of review with the Information and Software Technology journal.

One significant benefit our adopted DC is that participants do not have to use the system to provide feedback. This became even more important during the COVID-19 pandemic when conducting in-person user studies with senior citizens became very challenging. This thesis used medium-fidelity video prototypes to conduct the online DC study with five participant categories (stakeholders): seniors, informal caregivers, formal caregivers and domain experts. As can be seen in Figure 3.3, our DC process consists of three phases and ten steps. The reason for labeling our initial prototype as 'medium-fidelity' is that, it features elements from both Lo-Fi and Hi-Fi prototypes. Furthermore, the goal of using our prototype is to elicit user feedback and design recommendations, rather than conducing functional or usability testings.

We conducted two rounds of DC; in the first round, we collected feedback from all participant categories on our initial prototype design. The goal was to extract design recommendations for immersive smart home systems. The second DC round was conducted with mixed reality developers to extract best implementation practices using Unity engine and Microsoft Mixed Reality Tool kit (MRTK). Chapter 7 discusses this in more detail. Finally, we use these newly extracted design recommendations to reiterate the initial system prototype and implement the system on a Hololens 2 device.

3.3.4 Usability evaluation

We used a combination of cognitive walkthroughs and heuristic evaluations to assess the usability of the final high-fidelity system prototype. These types of evaluations are conducted with a small group of experts (3-5) rather than end-users. In the following two sub-sections we dive deeper into the background of these methods and provide a brief overview of their steps.

Cognitive walkthrough

The cognitive walkthrough is a usability engineering tool that gives design teams the chance to evaluate user interface designs in a systematic fashion that simulates the end user's perspective [RFR95]. This model is grounded in Lewis and Polosn's CE+ theory of exploratory learning [PL90] which describes the user interaction from a human cognition perspective following four steps:

1. The user sets a goal to be accomplished with the system.
2. The user searches the interface for currently available actions (menu items, buttons, command-line inputs, etc.).
3. The user selects the action that seems likely to progress toward the goal.
4. The user performs the selected action and evaluates the system's feedback for evidence that progress is being made toward the current goal

This model argues that for the most realistic tasks a user would attempt with a system, these four steps would be repeated several times to achieve a series of events that eventually define the complete task. The cognitive walkthrough examines each action needed to accomplish a task and evaluates whether the four cognitive steps will accurately lead to those actions. In order to complete a cognitive walkthrough, the design team would identify every user-system interaction event. The next step is to develop a list of analysis questions that the evaluators would use to examine these event. Chapter 9 describes our detailed cognitive walkthrough process, questions and results.

Heuristic evaluation

The heuristic evaluation is a method of measuring the usability of a user interface with the help of field experts only. Evaluators review the user task flow and report usability issues based on established criteria [df19]. In 1990, Jakob Nielsen and Rolf Molich analyzed 249 usability problems and introduced their ten main usability heuristics that are believed to be indicative of user interface effectiveness [NM90] [df19]. Please refer to Table 3.2 for a detailed description of these heuristics. With the help of 4 expert evaluators, we used the cognitive walkthrough findings to identify usability issues and report them using Nielsen and Molich ten usability heuristics. Each reported issue was rated on the following scale of severity:

- 0- Does not require any actions at this stage
- 1- Cosmetic only: can be fixed if extra time is available
- 2- Minor usability problem: fixing this should be given a priority
- 3- Considerable usability problem: fixing this problem should be given high priority
- 4- Usability catastrophe: it is imperative to fix this before releasing

3.4 Data collection methods

Data were collected using one of these three methods depending on the study phase:

1. **Online sources:** in both systematic literature review papers, data was collected from online sources. A university-owned computer was used to conduct online searches via Google Scholar and the university library. Google Scholar retrieves search results from almost all online databases and university libraries, providing a variety of publications; conference papers, open source and closed source papers, and thesis and dissertations. Secondly, using a university-owned computer provides direct access via Google Scholar to all subscribed databases such as ACM Digital Library, IEEE Xplore, Elsevier Scopus, Springer, MDPI, SAGE and Taylor Francis.

   Instead of directly using the search engine user interface, the Publish or Perish (PP) software was used to preform search queries. One benefit of using this software is

Table 3.2: Jakob and Molich 10 usability heuristics, source: [df19]

No.	Usability heuristic	Description
1	Visibility of system status	The design should always keep users informed about what is going on, through appropriate feedback within a reasonable amount of time.
2	Match between system and the real world	The design should speak the users' language. Use words, phrases, and concepts familiar to the user, rather than internal jargon. Follow real-world conventions, making information appear in a natural and logical order.
3	User control and freedom	Users often perform actions by mistake. They need a clearly marked "emergency exit" to leave the unwanted action without having to go through an extended process.
4	Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform and industry conventions.
5	Error prevention	Good error messages are important, but the best designs carefully prevent problems from occurring in the first place. Either eliminate error-prone conditions, or check for them and present users with a confirmation option before they commit to the action.
6	Recognition rather than recall	Minimize the user's memory load by making elements, actions, and options visible. The user should not have to remember information from one part of the interface to another. Information required to use the design (e.g. field labels or menu items) should be visible or easily retrievable when needed.
7	Flexibility and efficiency of use	Shortcuts — hidden from novice users — may speed up the interaction for the expert user such that the design can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
8	Aesthetic and minimalist design	Interfaces should not contain information that is irrelevant or rarely needed. Every extra unit of information in an interface competes with the relevant units of information and diminishes their relative visibility.
9	Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no error codes), precisely indicate the problem, and constructively suggest a solution.
10	Help and documentation	It's best if the system doesn't need any additional explanation. However, it may be necessary to provide documentation to help users understand how to complete their tasks.

that it can record all search results in a spreadsheet, and removing duplicates is done efficiently.

To further supplement our searches, we also conducted separate searches on three of the most relevant database search tools, including ACM Digital Library, IEEE Xplore and

Elsevier Scopus. Findings from these searches were added to the master spreadsheet in both studies for screening purposes.

2. **Semi-structured interviews:** This method was used in the requirements elicitation study and the design critique study. In the first study, all interviews were conducted in person and were audio recorded. In the design critique study, all sessions were video recorded via Zoom and stored in an encrypted folder on the university-secured cloud, please refer to Appendix C and Appendix E for research ethics protocols.

3. **Fly on the wall observations:** One site visit was facilitated to a senior couple who live alone. Both residents were living with an early onset of NCDs. I spent the day with the couple and recorded audio and written notes observations.

4. **Questioners and web forms:** The process of running a cognitive walkthrough requires reviewing every single step of user-system interactions and answering a set of standard questions [RFR95]. We used Qualtrics to create two questionnaires that our evaluators used to complete the walkthrough. In addition, we created a web form on Qualtrics to report found usability issues and rate their severity. Chapter 9 describes these procedures in detail.

3.5 Data analysis methods

Data analysis took place throughout most stages of this study. The choice of analysis method was relevant to the data type and the objectives of that phase. There are three main data analysis methods in this thesis:

- **Thematic Analysis:** is one of the most common methods of analyzing qualitative research data. It emphasizes identifying, analyzing and interpreting patterns of meaning, commonly called "themes" within qualitative data [BC06]. We followed a reflexive thematic analysis approach, which does not require multiple coders as this approach requires the researcher's deep engagement and interpretations of the data [COD+21, BC21b]. Furthermore, this reflexivity allows the coder to identify personal beliefs that may have incidentally affected the analysis. In order to streamline the coding and theme creation processes, we follow the steps introduced by Braun and Clarke in [BC19, BC21a, COD+21]: familiarization of data, coding of data, creation of initial themes, iteratively reviewing and shaping the themes, and final theme generation.

All video or audio data were transcribed verbatim and imported into a qualitative data analysis software called INvivo[2]. The first step was to reflect on the script by playing the recorded audio or videos to capture any additional participants' reactions. Researcher notes were used to review specific parts of a recording. The initial coding process resulted in a higher number of codes where many codes refereed to similar points causing a certain level of redundancy. The next step was to merge redundant codes and choose appropriate descriptions. At that point, we started looking for themes. After several rounds of processing, we arrived at our final thematic framework, which consisted of main themes, sub-themes, and sub-sub-themes in some cases. This method was used to analyze the qualitative data from the requirements elicitation and site visit. The exact process was used again to analyze the Design Critique study data.

- **Data synthesis:** This method was used to analysis the SLR study data. After completing the papers screening process, all selected papers went through extensive examination and review to extract several attributes (design approach, prototype evaluation, etc.). Data was tabulated to show the paper title, authors, year, publisher, objectives, design approach, used devices, user research, privacy approach, prototype fidelity, prototype evaluation, benefits and limitations. According to Kitchenham (2004), SLR extract data should be synthesized in proper manner to address the research questions [Kit04]. Therefore, selected studies and the extracted attributes were clustered in grouped based on the similarities and trends (more on this in Chapter 4). Similar

[2] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

to [ABB15] and [ANG+17], content summaries and data tables were used to present and discusses findings .

- **Questionnaires and feedback forms analysis:**

  As it was mentioned earlier in this chapter, we use a combination of questionnaires and web-forms during the cognitive walkthrough and heuristic evaluations. Responses to the questionnaires were limited to three choices only; yes, no and maybe. If and evaluator responded with a 'no', that meant they identified a usability issue and it would be reported using the heuristic evaluation web-form. Our analysis for the questionnaire data was aimed to identify the number of negative, neutral, and positive responses. We use stretch-chords visualizations to illustrate responses, more on this in Chapter 9. For the heuristic evaluation, we extract reported issues from the web-form and cluster them based on the usability heuristic they violate.

3.6 Conclusion

In this chapter, we presented the research methodology of this PhD thesis. The user-centred design method is used throughout the entire study to produce evidence-based designs. To accomplish the goals of this research and align with the UCD method, this thesis starts with a requirements elicitation study followed by a systematic literature review. A comprehensive process of design critiquing is used to evaluate the initial system prototype and extract design recommendations, which are used later to implement a high-fidelity prototype. Then, a course of cognitive walkthroughs with domain experts is conducted to perform a heuristic evaluation on the final high-fidelity prototype. Data were collected at different stages and in various ways, including online sources, fly-on-the-wall, recorded semi-structured interviews, recorded design critique sessions, questionnaires and web-forms. Finally, three methods of data analysis were used in this thesis: thematic analysis, data synthesis, and questionnaires and feedback forms analysis.

Chapter 4

A taxonomy of supportive smart home systems

4.1 Chapter overview

Investigating the user needs prior to prototyping and development is the first phase of the User-Centred Design method. In this PhD thesis, we conducted two studies in the investigation phase: a Systematic Literature Review (SLR) and a requirements elicitation study. This chapter will discuss the SLR study, its objectives, methodology, results, and findings.

Previous SLR papers focused on identifying research work pertaining to smart homes [DH08a, QDSR17], or assistive technologies [CSCB18] for supporting aging in place for all senior populations without focusing on SwNCDs in Particular. However, as stated in earlier chapters, supportive smart homes for SwNCDs have accounted for the special requirements of this population [AB18a, AB16].

Moreover, this field of study has been growing over the last ten years, and thus, the number of publications has been steadily increasing. As we approach this field of study from an HCI perspective, we must highlight two fundamental points that tend to be mixed in some literature papers; assistive technology and smart home systems.

- Assistive technologies are defined as advanced devices used for assisting people in rehabilitation programs or people who suffer from a disability to complete activities of daily living [FLMK04].
- A smart home in the context of supporting aging in place for seniors with Alzheimer's is defined as "a residence equipped with technology that facilitates monitoring of residents to improve quality of life and promote physical independence, as well as to reduce the pressure and burden on caregivers (family members, social workers and nurses)" [FI11b].

The term 'assistive technology' is more generic as it could refer to either a stand-alone device or an entire smart home system. Designing a stand-alone device comes with different challenges and requirements, which is out of the scope of our study. Therefore, it was essential to conduct this SLR study to identify relevant work and learn about the benefits and limitations of different approaches. In this SLR study, we limit our scope to publications that:

1. Introduced supportive smart home system concepts for SwNCDs
2. And, developed a system prototype
3. And, conducted a form of evaluation on system prototypes

4.2 Methods

Our research method is driven by the 'Guidelines for Performing SLRs' by Kitchenham and Stuart, 2007 [KC07]. The first step was to set the objectives of this study and develop a search strategy to look for relevant work. Thereafter, introduce a set of inclusion and exclusion criteria to filter search results in three stages; title, abstract and full script screening. This approach is widely used in the literature such as [LSN+16, RML+13, DH08b, KYTM18].

4.2.1 Objectives

The main objective of this study is to provide an overview and a categorization of relevant work. In addition, we aim to extract several variables in every paper. Furthermore, we discuss the benefits and limitations of each approach. To fulfill these objectives, we aim to accomplish the following goals:

1. Provide a taxonomy of the supportive smart home systems for SwNCD literature and discuss the benefits and the limitations of each paper
2. Explore the different design approaches
3. Investigate the different methods of collecting smart home sensor data
4. Identify prototype fidelity and evaluation methods based on reported data
5. Discuss the different system data privacy approaches

4.2.2 Search strategy

Our preliminary searches aimed to identify existing SLR papers and assess the volume of potentially relevant studies. While we found many SLR papers related to smart homes and seniors' homecare, there was a lack of papers focusing on SwNCDs populations, as we stated earlier [DH08a, QDSR17]. On the other hand, we found papers focusing on a single aspect of smart homes, such as used devices in [CSCB18], or the usability and accessibility aspects in [QSA+01]. It is important to report that we found one paper which appeared to be very similar to our proposed work, the paper titled *"A literature review on the design of Smart Homes for people with dementia using a user-centred design approach"*. This paper discussed the importance of following the user-centred design method to improve system usability. In addition, the paper presented the various ways a smart home system can support homecare for dementia.

In conclusion, the paper argued that conventional usability testing (measuring task completion, success and failure rates) is insufficient for people with dementia due to their unique illness characteristics. Thus, early evaluations during the ideation and design stages are recommended [RB16]. The paper provided a helpful overview of the topic and did not present any systematic search and selection process for relevant work. In addition, the paper mainly focused on the applications of user-centred design and the ethical and pragmatics issues that may arise.

There is an absence of a comprehensive SLR paper focusing mainly on designing, developing and evaluating smart home systems for SwNCDs. Therefore, after the preliminary searches, we conducted trial searches using different combinations of search terms extracted from previous papers. The search terms were developed and refined iteratively, where the search strings were modified every time we identified a new keyword. Below, we present the search terms used in our final queries.

> ”smart home” ”aging in place” ”ambient intelligence” ”smart architecture” ”Ambient assisted living” (”alzheimer” OR ”Dementia” OR ”MCI” ”OR ”NCD” OR ”neurocognitive disorders” OR ”cognitive impairment”) ”empirical” ”prototype” ”pilot” ”evaluation” ”testing”.

4.2.3 Search process

We used the Publish or Perish[1] software to run queries via the Google Scholar search engine. A significant benefit of this approach is recording all search results in a spreadsheet automatically. The search for relevant papers was performed three times between 2019-2021. First, we combined all search results in one master spreadsheet consisting of study titles, year of publication, and authors. We used more than one search string and accumulated many duplicate results. We used Excel's 'delete duplicates' feature to keep unique entries only. The final spreadsheet was used for screening.

[1] https://harzing.com/resources/publish-or-perish

Table 4.1: Screening inclusion and exclusion criteria

Phase	Inclusion criteria	Exclusion criteria
Title screening	Titles indicating to using smart homes to support aging in place, lead to the development of system prototypes, conducted any form of evaluation with relevant end-users	All robotic studies, theoretical studies, survey and systematic literature review papers, non-English language studies
Abstract screening	Papers that didn't meet the exclusion criteria were passed on for full-script screening	All requirements elicitation, user research and needs assessment studies were removed if they didn't lead to smart home system design. Papers that suggested a smart home system concept but did not develop any system prototypes. Technical studies that focused on developing, training and testing machine learning algorithms using data sets to make sense of smart home system raw data
Full-script screening	Smart home system prototype that was developed to support aging in place with a focus on SwNCDs. System prototype was deployed in a lab setup or in a senior housing unit. Evaluation or a pilot study was conducted with relevant end-users; seniors, formal caregivers, informal caregivers, domain experts	Papers that did not meet inclusion criteria were removed

We consulted with a librarian who advised that when relying on Google Scholar alone, there would be a chance to miss some results due to search engine functional limitations. Therefore, we picked the top two databases in our field and ran another round of searches separately on each database search tool. We picked ACM Digital Library and IEEE Xplore. Our search for new relevant papers on these databases revealed a small number of publications that did not appear via Google Scholar. These new results were added to the screening list. Please refer to Appendix B for additional materials from this study such as raw data, tables and data analysis screenshots.

4.2.4 Screening Process

We developed three screening stages using a set of inclusion and exclusion criteria, see Table 4.1 . First, we performed screening on the studies' title, abstract and full text. Papers selection was based on the author's interpretation and the inclusion criteria.

4.2.5 Screening results

After conducting all searches, we retrieved 1749 hits. Further data filtering and data cleaning techniques were applied to exclude duplicate results, non-English language studies, google books and other literature review papers. The final number of unique studies was 963 papers. Among these, only 209 were selected for abstract screening. After applying additional

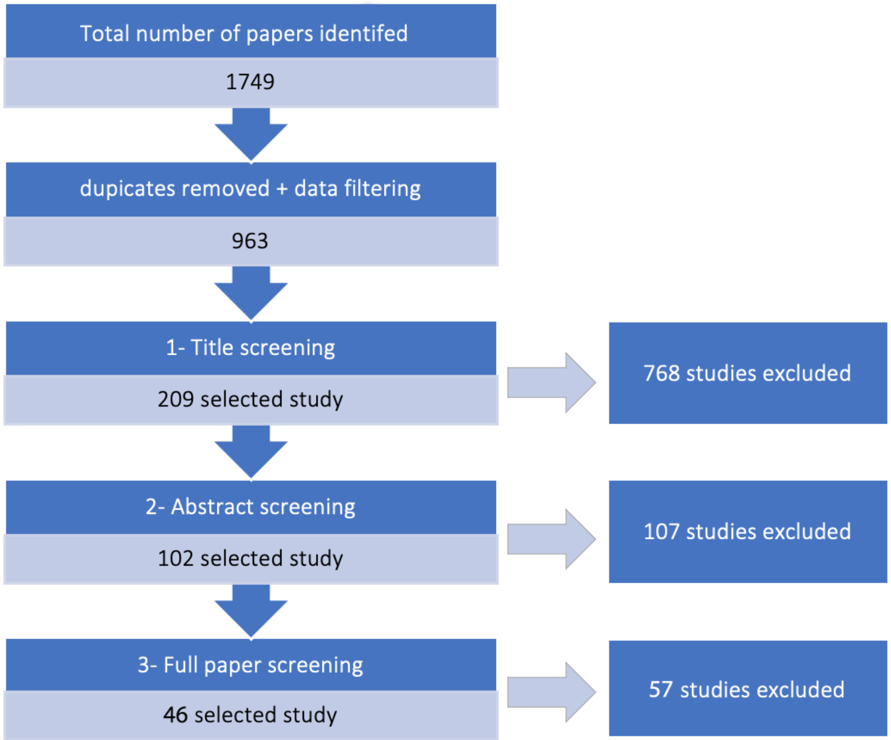

Figure 4.1: Paper selection results

exclusion criteria, 102 studies were selected for full-text screening. Among the 102 papers, 57 were excluded as they did not meet the inclusion criteria. The final number of included papers was only 46. Figure 4.1 presents the online search results and the paper selection process.

4.3 Findings

Our online search yielded 46 relevant papers. Based on the goals of each study, we identified three main types of concepts; SSHS for monitoring, assisting and emergency response, see Figure 4.2. The majority of studies fall under the monitoring category. Further analysis of the monitoring category revealed three subcategories; monitoring and detection of Activities of Daily Living (ADL), cognitive health monitoring, and physiological health monitoring. Similarly, we identified three subcategories in the SSHS for supporting category; memory

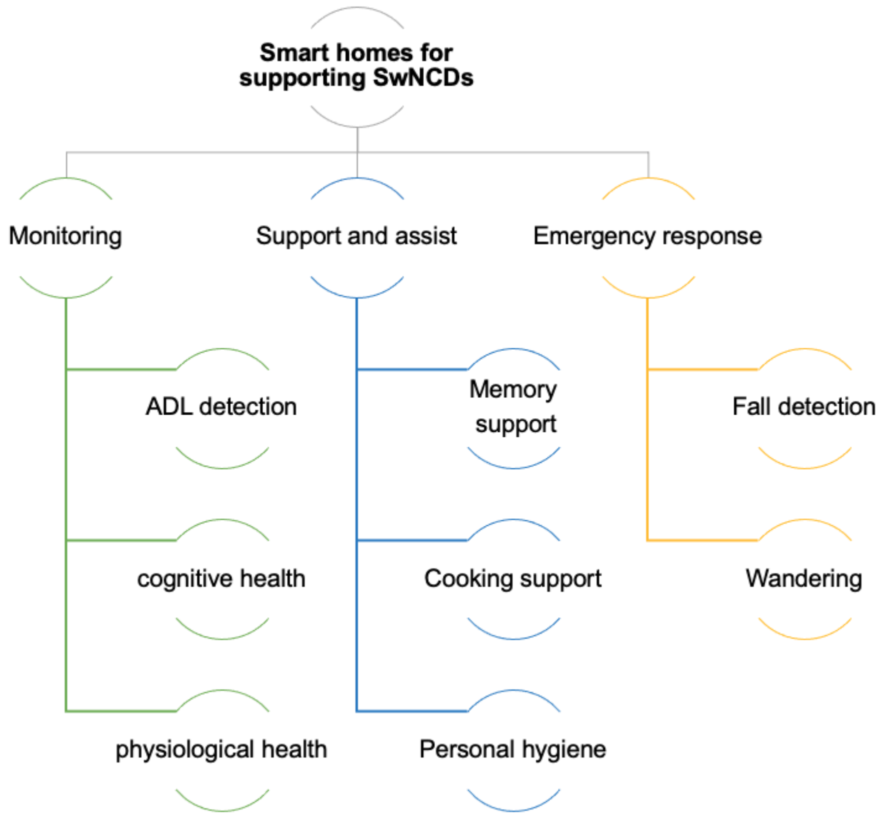

Figure 4.2: Breakdown of the three main SSHS categories and their subcategories

prompts, cooking and hygiene support. Finally, in the emergency response category, we identified the two categories of papers; fall and wandering detection.

4.3.1 Smart homes for monitoring

Typically, cognitive impairments affect seniors' ability to perform ADL negatively [GSS+14]. While it is not. The literature classifies ADL into two main groups; basic ADL, such as eating, dressing, and bathing, and complicated high-level tasks involving instruments such as cooking, hair trimming and managing finances [Kat63, LB69]. One way for SSHS to support aging in place is to reduce the burden on caregivers; this can be done by monitoring senior users, identifying their activities, and notifying caregivers in the case of abnormality. The following subsections discuss various concepts of ADL and health monitoring.

Monitoring activities of daily living

Table 4.2 presents all studies identified in this sub-category along with the sensing approach, used devices, prototype fidelity, user research and evaluation method. Using surveillance cameras is perhaps the first solution that comes to mind when monitoring a person is needed. However, conventional video surveillance requires a second person to watch the video constantly. With machine learning and artificial intelligence advancement, it is possible to identify and monitor certain activities automatically. Researchers in [AHW11] presented a low-cost SSHS to monitor the activity level of seniors living alone. The prototype used one ceiling camera and an AI algorithm capable of tracking the person's head location and identifying resting areas in the house. The system prototype was deployed in a senior's home for three days. The study reported that the system could accurately identify tasks such as resting, watching TV, and moving. While this proposed concept is very affordable and effective, there are multiple limitations to such an approach. First, the study indicated that the algorithm was re-trained six times on the first day of testing due to the change in external daylight and the levels of reflection. This problem is prevalent with computer vision-based solutions. The second major limitation is regarding the privacy and safety of the occupants [MZ13, Cou08]. Finally, a significant correlation was found between Alzheimer's and suspiciousness, paranoia, anxiety, and depression [MMSW90]. Therefore, cameras and microphones can lead to false beliefs about being targeted or bugged, increasing the frequency of wandering episodes.

Combining environmental sensors and microphones to monitor seniors at home was explored in [VBM+17]. The goal was to collect temperature, humidity and CO2 data to determine the presence of house occupants and potentially the ADL. In addition, the study explored using voice commands to control certain appliances. Finally, researchers evaluated the system's ADL detection reliability after being deployed in a house in Moravin-Sillesian, Czech Republic. The study stated that the system could only detect room occupancy using non-intrusive environmental sensors. Although detecting an occupant's location indoors is

Table 4.2: Smart home systems for activities of daily living monitoring

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[AHW11]	Ambient	Camera	Hi-Fi	Not reported	Accuracy testing
[VBM+17]		Temperature sensor, humidity sensor, CO2 sensor, microphone, speakers	Hi-Fi	Not reported	Accuracy testing
[PL20]		Door sensor	Hi-Fi	Not reported	Accuracy testing
[RCG11]		Electricity usage sensor	Lo-Fi	Not reported	Accuracy testing
[BCH+09] [SCB+09]		Motion sensor, pressure sensor, door sensor and electricity usage sensor	Hi-Fi	User research was conducted	Accuracy testing Prototype usefulness
[YAHK19]		Motion, door, electricity usage, humidity and temperature sensors	Hi-Fi	Not reported	Accuracy testing
[LLMA12]		Floor sensor, door sensor, bed sensor	Hi-Fi	Not reported	Prototype usefulness
[Coo06]		Motion sensor, door sensor, humidity sensor, temperature sensor, light sensor, smoke sensor, gas sensor	Lo-Fi	Not reported	Accuracy testing
[WA04]	Hybrid	Motion sensor, door sensor, RFID tags	Hi-Fi	Not reported	Accuracy testing
[Ian18]		Motion sensor, Bluetooth low energy, radar sensor, RFID tags, and IR sensor	Hi-Fi	Not reported	Accuracy, implementation ease and scalability
[DPS+18]		Motion sensor, wearable e-health kit, smart watch, robot sensors; depth camera, microphones, motion sensors	Hi-Fi	Not reported	Accuracy testing

valuable, it is not enough to determine their activities. In addition, environmental indicators do not change instantly, which means the system will not be able to detect occupancy in real-time.

In [PL20], an IoT-based routine analysis system was introduced using door sensors only. The system benefits from a machine learning algorithm to learn about the occupant's life routine based on an Indian Sanskrit concept called "Prahara," which divides the day into three-hour time units. Researchers installed break-beam sensors on the doors, the fridge, and the entrance sensor in a single-occupant senior apartment for 100 days. The system could identify certain life activities based on the sensor data time signature and the open and close sensor signal duration. Similarly, researchers in [RCG11] suggested using electricity usage sensor installed at the main utility service entry to identify some ADL. The system relies on the concept of electric device load signature to identify ADL. The system prototype was installed in 7 houses where home appliances turn on and off separately to train the system algorithm. The testing shows that the system could accurately identify ADL when using certain home appliances. Although these two studies introduced low-cost, the accuracy of such an approach remains questionable as the false positive is considered high.

The Smart Condo project is a multi-disciplinary research project designed, developed and deployed at the University of Alberta. The project's goal was to provide affordable and high-quality healthcare for seniors while enabling them to live independently [BCH+09]. A wireless sensor network including motion, pressure, door and electricity usage sensors was installed in a condominium unit. Sensor data were fed to a web system and then visualized in a 2D Geographic Information System (GIS) and a Second Live. Actor users followed a written script (e.g., move from room A to room B, open door, etc.). At the same time, occupational therapists used the system interface to monitor the occupant's location and activities. Video cameras were installed to record the evaluation process. The study reported that both the camera video and the visual representation matched the written script. One of the best benefits of this approach is that it relies entirely on sensor data, improving overall privacy. In addition, the study explored the problem of user-system interaction where caregivers can benefit from an easy method of monitoring seniors at home without severely breaching their privacy[SCB+09]. However, it is clear that such a monitoring approach requires a formal caregiver to watch the screen constantly. Therefore, the feasibility of using the proposed system for long-term monitoring is questionable.

Similarly, [YAHK19] introduced an SSHS concept using ambient sensors, including; motion, door, electricity usage, humidity and temperature sensors. The system prototype was deployed for three months in a single female occupant apartment in Yangtza River Delta city in China. The testing results indicated that the system was feasible and accurate in detecting ADLs such as sleeping, cooking, and opening/closed doors. In [LLMA12] researchers tested an SSHS concept using only motion, door and floor sensors. A case study with a SwNCD and their caregiver was conducted where the caregiver could monitor the ADL via a web application. However, the usability of this approach from the caregiver's perspective was not evaluated. Finally, researchers in [Coo06] suggested using computer algorithms and a set of ambient sensors, including; motion, door, humidity, temperature, light, smoke, and gas. The main goal of this study was for the SSHS to monitor the occupant's ADL and provide assistance when needed. Only a low-Fi prototype was tested in a lab setup where the system's database was populated with 1400 events per day by students and researchers in the lab. The system successfully identified some basic ADL and assisted the MavPad volunteers.

[WA04] introduced an SSHS using only motion and door sensors along with RFID tags. The study used machine learning algorithms to identify multiple occupants, their ADL, and their location inside the house. Prototype testing was carried out in multiple senior occupant houses over five days. Relying on individual motion models for the three occupants, the prototype testing achieved 84 percent indoor localization accuracy. However, the study reported a decrease in the accuracy when occupants are asleep, indicating that further improvement to the system's tracking algorithm is required.

Similarly, researchers in [Ian18] suggested equipping the doorway of a house with motion, Bluetooth, IR sensors, and a RFID reader while providing senior users with small sticky RFID tags. The accuracy of the system in identifying the position of the senior user, among others, was evaluated in the housing unit of two occupants. The study reported an ADL identification accuracy of 97 percent. Closing room doors affected the system's accuracy negatively.

The concept of RiSH was introduced in the literature as an integration of a hybrid sensing SSHS and a robot for elderly home care. A Hi-Fi system prototype was implemented in a lab equipped with motion sensors. Users wore a smartwatch while the robot was equipped with a depth camera, microphones and motion sensors. A total of ten graduate students participated in the prototype evaluation to test multiple features, including; auditory perception service, body activity recognition, indoor positioning, sound-based human activity monitoring, and fall detection and rescue. The final testing results indicated that occupant trajectories were estimated with a root mean square error of less than 20 cm. Furthermore, the study reported that the robot could recognize 37 human activities based on sound events with an average accuracy of 88 percent [DPS+18]. It is worth noting that 20 percent of the time, the robot could not detect humans due to occlusion, making it a potential hazard.

Summary:

This sub-section reviewed how smart homes can detect and monitor the resident's daily activities. These types of functions are considered valuable for caregivers for remote monitoring purposes. Sensing technology is the most important aspect of this type of smart home system. We reviewed various studies ranging from using electricity consumption patterns to a set of ambient sensors and ending with the most intrusive way on the spectrum; using a surveillance camera.

Cognitive health monitoring

In [RFH15] a SSHS concept is developed using a machine learning algorithm to detect the location of the senior resident and analyze their movement patterns using cameras only. The study claims that such data can be valuable in assessing the cognitive health of the senior resident. System prototype testing took place in an apartment. Only one person participated in the study by entering the apartment and moving around multiple times. Testing results indicated that the system could determine the occupant's location when moving. Instead of using audio/visual data only, researchers in [UNCH10] utilized a combination of video analysis techniques and binary motion sensor data to detect repetitive actions, which in turn may indicate a cognitive decline. A Hi-Fi system prototype was implemented in a lab that consists of a living room and a kitchen. One participant was asked to enter the lab, perform multiple repetitive actions, walk around randomly, and then leave. The study reported that the system could identify six types of trajectory patterns with an average accuracy of 96.67 percent. Refer to Table 4.3 for all studies identified in this sub-category.

Avoiding using audio/visual data, in [FDVV10] a SSHS concept relying on binary motion sensor data only is presented to detect and quantify possible nycthemeral shifts in daily life routine, which may be an indicator of pathological behaviour. The logic behind this approach is to measure the dissimilarity between sequences of ADL using a variant of the

Hamming distance, typically used in information theory. The Hi-Fi system prototype was implemented in an apartment of a single 80-year-old lady. Prototype testing demonstrated the system's ability to learn about the occupant's life routine. However, since the system relies only on motion sensor data and machine learning, the positive false is expected to be high as the system will not differentiate between different occupants. Using only one IR sensor in the bathroom, researchers in [CLBG19] endeavoured to develop a SSHS system to recognize bathroom activities such as using the toilet, washing hands or showering. The study argues that activities related to corporal hygiene are a strong indicator of the development of cognitive impairment. A total of 8 young people aged 22 to 29 were recruited to evaluate the Hi-Fi system prototype. Participants were asked to use a paper sheet to record their bathroom activities for 59 days. The system recorded participants' activities with an accuracy of 95.26 percent compared to the manually entered data.

In [KIAI18] an ambient sensing SSHS concept was introduced to detect "typical dementia" behaviours. This system benefits from a Machine Learning (ML) algorithm and several ambient sensors, including motion, door, light and pressure sensors. Low-Fi prototype testing revealed this approach to detect 'dementia-related' behaviours. A more advanced concept was introduced in [DCSE13] to assess the quality of the occupant's ADL. A Hi-Fi system prototype was developed at Washington State University in a smart home testing lab consisting of a living area, dining area, a bedroom and a kitchen. Item trackers and an ambient sensor network were installed in the testing lab. A total of 179 participants were recruited to perform a complex interweaving set of activities in the lab including seniors and young people. All participants completed standard neuropsyological tests and a small group met the DSM criteria for dementia. The prototype testing indicated that the SSHS was able to distinguish between healthy seniors, seniors with cognitive impairments, and young people based on the quality of ADL. Researchers in [GLB+17] proposed a SSHS concept using motion, door and temperature sensors only to train a Deep Conventional Neural Network Classifier to classify indoor travel patterns for elderly people living alone. A low-Fi prototype

Table 4.3: Smart home systems for cognitive health monitoring

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[RFH15]	Ambient	Camera	Lo-Fi	Not reported	Accuracy testing
[UNCH10]		Camera and motion sensor	Hi-Fi	Not reported	Accuracy testing
[FDVV10]		Motion sensors	Hi-Fi	Not reported	Accuracy testing Field deployment
[CLBG19]		Infrared sensor	Hi-Fi	Used previous user research	Accuracy testing Field deployment
[KIAI18]		Motion sensor, door sensors, pressure sensor, light sensor	Hi-Fi	Not reported	Accuracy testing
[DCSE13]		Motion sensor, door sensor, temperature sensor, light sensor, water sensor, stove sensor, item tracker.	Hi-Fi	Not reported	Accuracy testing
[GLB+17]		Motion sensor, temperature sensor, door sensor	Hi-Fi	Not reported	Accuracy testing field deployment
[TT18]	Hybrid	Motion sensor, bed sensor, door sensor, key tracker, med box, bracelet with vital signs sensors	Hi-Fi	Not reported	Accuracy testing Field deployment Usefulness
[ARH+16]		Wireless sensor tag (WST), object sensor, motion sensor, Ethernet tag manager, bracelet with vital sign sensors	Hi-Fi	Used previous user research	Accuracy testing Usability testing Field deployment
[KZY+17] [SNI+]		Wearable sensors: Pulse, SpO2, ECG, position. Motion sensor, door sensor, pressure mates.	Hi-Fi	Used previous user research	Accuracy testing

was developed and tested using a dataset collected in seniors' apartment buildings for 21 months. Testing results yielded an average classification accuracy of 96.16 percent.

A SSHS concept for early detection of Mild Cognitive Impairment (MCI) using IoT devices was introduced in [TT18]. A Hi-Fi system prototype utilizing ambient sensors, key trackers, a medication box and a vital signs monitoring bracelet was deployed in two seniors' communities for two months. A total of 17 elderly participated in the testing to determine if the system could detect different ADL patterns among the two groups. The system was able to distinguish three different patterns of forgetfulness related to personal items and medication intake. The study suggested that the system was able to identify seniors who are likely to develop MCI. While this study's results appear promising, longer monitoring for these subject humans is required to verify whether they will develop MCI or not.

Deeper integration of ambient and vital sign sensor data to assess the functional and behavioural health of SwNCD was explored in [ARH+16]. The study hypothesized that cognitive health could be measured by tracking the occupant's activities and mental arousal states. A wearable bracelet equipped with Electrodermal Activity, Photoplethysmogram and accelerometer was used to test that. A ML algorithm was developed to assess cognitive impairments and their correlation with functional health decline. A Hi-Fi system prototype was deployed in multiple retirement communities in Baltimore City, USA. Only seniors living alone and older than 65 years old were recruited. Video recording was used throughout the testing process to annotate the ground truth of activities. Results showed that seniors with MCI had the highest arousal, which was represented by increased EDA and decreased heart rate compared to cognitively intact seniors and SwNCD. A similar SSHS concept was introduced in [KZY+17, SNI+] to detect and predict incidences of agitation and aggression. A pilot study was conducted on the system prototype with a dataset collected from 17 SwNCD over 600 days of using ambient and wearable sensors. The pilot study findings suggested that the system was able to classify multiple classes of agitation and aggression. The study indicated that a Hi-Fi system prototype is currently being installed and tested at the Toronto Rehabilitation Institute in Canada.

Summary:

> In this sub-section, we reviewed the various ways of monitoring seniors' cognitive health and potentially identifying changes that require attention. Using a combination of ambient and wearable sensors was more present in this type of smart home concept. In addition, we noticed more integration of machine learning and artificial intelligence algorithms.

Physiological health monitoring

As can be seen in Table 4.4, our online search identified six SSHS concepts for physiological monitoring, all of which were part of a project between the TigerPlace seniors residence and the University of Missouri, USA. The TigerPlace is a retirement community built based on the concept of aging in place for all seniors in the age range of 64-97 years old. One of the studies in this project suggested using motion sensors and Fuzzy Logic to estimate relative energy expenditure as an indicator of health changes. The system prototype was tested using motion sensor data collected in two apartments at the TigerPlace for two weeks. Although the human subjects were not diagnosed before the testing, the SSHS suspected the first participant of having dementia and the second participant of having depression. These findings were then forwarded to the professional medical care staff for further investigation [WSZG11]. Another study proposed using motion and bed sensors to detect health changes for seniors in the end-of-life housing unit. The system benefits from a ML algorithm capable of learning about the occupant's lifestyle over an extended period. A system prototype was installed in two seniors' apartments for two years. Findings suggest that the system could passively recognize very early signs of health decline. The system findings were verified with clinical staff. The study's recommendations reported that the system might not be suitable for monitoring people with cognitive impairments due to difficulties in training the ML algorithm [SGR15].

A similar approach was introduced in [RSMK08] to investigate the potential correlation between health events such as falls, emergency room visits and hospitalization. A system prototype was installed utilizing a fuzzy logic rules engine and several sensors, including motion, bed, and stove sensors, in 15 apartments for two years. Two case studies were investigated in depth; a 96-year-old lady and a 79-year-old man under cardiac rehabilitation. In both cases, prototype testing showed that the system could detect early abnormal patterns. However, the study reported the following limitation; improving the reliability and accuracy of the sensor network was required, implementing a video sensor network that hides identifying features of the residents and the difficulty in interacting with the web-based system interface.

In a separate study, researchers attempted to use a similar ambient sensor network to early detect signs of Urinary Tract Infection (UTI) among the aging in place community at TigerPlace. 11 males and 26 females were monitored with the integrated sensor network for an average of one year and eight months per unit. Throughout the entire five years of

Table 4.4: Smart home systems for physiological health monitoring

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[WSZG11]	Ambient	Motion sensor	Hi-Fi	Not reported	Accuracy testing
[SGR15]		Motion sensor, bed sensor	Hi-Fi	User research study was conducted co-design	Accuracy testing Field deployment
[RSMK08]		Bed sensor, motion sensor, stove sensor, camera	Hi-Fi	Not reported	Usability testing Field deployment
[RSK+11]		Motion sensor, bed sensor, chair sensor, stove sensor	Hi-Fi	Not reported	Usability testing Field deployment
[EBE+14]	Hybrid	Door sensor, chest band for physiological monitoring and indoor localization	Hi-Fi	User research was conducted	Usability testing Accuracy testing Field deployment
[VAD+08a] [VAD+08b]		Wearable sensors: Pulse, SpO2, BP, Fall, ECG, Accel, Position, and Environment sensor network: temperature sensor, dust sensor, light sensor, motion sensor	Hi-Fi	Used previous user research study	Usability testing

the data collection phase, clinicians reviewed sensor data before and after events to identify initial patterns that can be used as bases for alerts. Multiple refinements were made to the alert algorithms and web-based interface using an iterative Design Critique process with the help of on-site clinicians. Then a pilot study began in June 2010 to investigate the system's ability to deduct UTIs early. The pilot study results showed that it was possible to detect UTIs early based on ambient sensor data only. Two subject cases were diagnosed with UTIs and treated after that. However, the system generated too many false positive events. Therefore, practising physicians recommended monitoring toilet usage to reduce the false positive rate [RSK+11].

The RITA project in Pisa, Italy, demonstrated the efficiency and the feasibility of using a following user-centred design to introduce SSHS to improve the sense of safety for seniors and their caregivers. A system prototype was implemented in DomoCasa Lab in Italy, utilizing a chest band for physiological sensing and several door sensors. Prototype testing was carried out in a residential care home with 17 seniors and nine formal caregivers. The testing result suggested that most senior participants found the system to provide a higher sense of safety. In addition, caregivers thought the system could increase the quality of their work. However, they also expressed concern about the effect of personal relationships between them, and the elderly person [EBE+14].

Similarly, the concept of the AlarmNet SSHS system was proposed for physiological monitoring using machine learning and a combination of wearable and ambient sensors. The Hi-Fi prototype wearable device included vital signs, fall and positioning sensor. The system prototype was implemented in an emulated environment in a lab set up in Saint Paul, USA, where an ambient sensor network and some furniture were placed in the testing environment [VAD+08a]. Multiple system evaluations were carried out on the system prototype to test its reliability and stability in monitoring activity and behavioural patterns. However, the most important evaluation was published in a separate study where a prototype was implemented in an assisted living facility and tested with 12 seniors [VAD+08b]. Findings showed that the system could detect deviations that may indicate physical illness. More importantly, the system provided accurate outcomes even in the presence of noise due to visitors and formal caregiver movement.

Summary:

> In this sub-section, we reviewed the various ways smart homes can detect and monitor the physiological health of the resident. The studies presented in this section emphasized the power of ambient sensors only to detect alarming health changes such as falling or early detection of UTIs, as we saw in the TigrePlace project. Using a combination of ambient and wearable devices was explored in the RITA and AlarmNet project creatively where both projects reported collecting accurate smart home system data

4.3.2 Smart homes for supporting and assisting

Memory support

Researchers in [AB18a] explained how accommodating the special requirements for SwNCD and their care circle is essential. The study started by eliciting initial user scenarios in the form of short stories, which were evaluated later by a sample of caregivers. Furthermore, this study highlighted the importance of different system levels of intervention. Five levels of intervention adopted from [Gol76] and [OPKKE07] were integrated into the system; inviting awareness, suggesting, prompting, urging and performing. A Hi-Fi system prototype was developed using a non-intrusive vital signs sensor kit and a number of motion and pressure sensors. The system prototype was then deployed in a doll (toy) house setup. Five geriatric specialists participated in 45-minute evaluation sessions. The goal was to answer questions related to the mentoring capability of the prototype, the potential of reducing care difficulty, seniors' safety and finally, if the system can improve the quality of dementia care. The same five geriatrics were invited again to participate in a second evaluation to test the usability of the system prototype by performing the NASA-TLX model. Participants were presented with two care case scenarios; monitoring general health and sleeping patterns. The result of the first evaluation suggests that the prototype can reduce the difficulties of dementia care for common care scenarios as it increases the caregiver's peace of mind. Individual stakeholders reported the need to accommodate the progressive nature of dementia through designing a highly personalized SSHS in a simplified fashion. Table 4.5 details all smart home concepts for memory support purposes.

Recently, many concepts started incorporating IoT devices to overcome conventional smart home problems such as system expandability, customizability and flexibility. In [FSA+17], a solution for supporting aging in place is introduced using a standard heterogeneous IoT platform and a tool to help caregivers create customized automation. Prototype evaluation was carried on with the research team only. The study reported that the system accurately tracks medication intake, assuming that medication is taken every time the pill box is removed from the base. However, further testing with senior subjects is required to evaluate the usability of such a system. Most importantly, the effectiveness of the notification and memory prompts delivery method is questionable as using mobile apps for SwNCDs comes with several usability challenges [MA14]. A similar concept was introduced in [NPP+19], but researchers proposed using voice commands and LED lights to deliver

Table 4.5: Smart home systems for memory support

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[NPP+19]	Ambient	Motion sensor, light bulbs, voice commends device	Hi-Fi	Used previous user research	Usability testing Level of acceptance
[AB18a]	Hybrid	Motion sensors, pressure sensors, and e-health sensor kit (SPO2, airflow, body temperature, blood pressure)	Hi-Fi	User research was conducted	Usability testing
[FSA+17]		NFC tag, NFC reader, smart phone, speaker, light, vibration device, rice cooker.	Hi-Fi	Used previous user research	Usability testing
[BGC+19]		wearable bluetooth ID, speaker	Hi-Fi	Not reported	Accuracy testing Usefulness
[LKS+16]		Camera, sleep sensor, wireless tag, utility usage sensor, bracelet with vital signs sensors	Hi-Fi	User research was conducted co-design	Usability testing

prompts instead of using mobile applications.

Researchers in [BGC+19] developed a non-intrusive acoustic-based SSHS concept to address the issue of forgetting names by providing audio memory prompts to SwNCD living at home. The study introduced a Hi-Fi system prototype implemented in a lab setup utilizing wearable Bluetooth IDs, Bluetooth trackers and speakers. Twelve test configurations were performed to evaluate the system's ability to locate the user based on the distance to the nearest smart speaker. Further testing was performed by adding more users (family members) with different Bluetooth IDs to the system. The study reported that the system could identify all users and provide appropriate audio memory prompts to seniors users all the time.

[LKS+16] introduced the SSHS concept with a fully customizable web application that can visualize information tailored for each user category; formal caregiver, informal caregiver, and senior users. The system prototype utilizes a number of sensors, including a camera, sleep and utility sensors, wireless tags and a bracelet to measure vital signs. The user interface was co-created with a sample of potential end-users to assure higher levels of usability. The system's main goal was to provide visual information about ADL to caregivers to create custom health and behavioural interventions to improve seniors' cognitive health. Four SwNCDs were recruited for a four-month system prototype trial; two participants were diagnosed with MCI and two others with early stages of dementia. After the four months, participants were asked to take a neuropsychological assessment, and the results described a meaningful reduction in anxiety and an improvement in the senior's cognitive performance.

Summary:

In this sub-section, we reviewed various concepts of smart home systems for memory support. In this type of study, we notice more emphasis on the role of the caregiver. Accommodating the special requirements of NCDs was manifested in the various techniques supporting the user's memory, such as using lights, audio systems, and other external stimulants. In addition, most studies conducted user evaluations with relevant participant categories (seniors, caregivers, experts).

Cooking support

Many people with disabilities, including SwNCD, encounter challenging situations in the kitchen. Assisting seniors in the kitchen was explored in a couple of studies. See Table 4.6 for all selected studies in this sub-category. Such efforts are very appreciated in the aging in place community because it helps increase the senior's sense of independence and agency. Researchers in [BMC+14] introduced a novel concept of a smart kitchen to increase the autonomy of people with disabilities, including SwNCD. The system prototype utilized a set of non-intrusive sensors network, including RFID tags, ZigBee wireless sensors (motion, light and door sensors), safety sensors (fire, smoke, flood sensors) and a TV to display the system's user interface. A caregiver can manage the system via a mobile application. The prototype was implemented in multiple locations throughout the UK and Spain and was tested by 12 SwNCD who were not involved in customizing the system. Instead, they only received memory prompts and notifications on the TV screen, such as; the washing machine is on or the milk is expiring soon. User testing reported that 90 percent of participants found the system easily accessible.

Commonly, a SwNCD would forget the location of cooking materials and kitchen items due to their non-visibility. Therefore, [ZNCP17] suggested using RFID tags and a camera

Table 4.6: Smart home systems for cooking support

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[BMC+14]	Ambient	RFID tag, RFID reader, ZigBee hub, motion sensor, door sensor, light sensor, fire, smoke, flood sensors), TV, Smart phone	Hi-Fi	Not reported	Usability testing, Accessibility evaluation
[ZNCP17]		RFID tags, RFID reader, camera, projector	Hi-Fi	Not reported	Usefulness ease of use UTAUT
[FN12]		DC motors, speakers, screen, microphone	Hi-Fi	Not reported	UTAUT

to keep track of hidden objects. A system prototype equipped with middleware, a database and a user interface was developed and deployed at the University of Oulu. A projector was installed in the kitchen to display hidden items on cabinet doors. Informal caregivers can remotely monitor the senior's kitchen activities using a web application. Audio-visual instructions can be communicated by the caregivers using the same web application. A total of 12 seniors were invited to evaluate the system using the Usability Scale Test evaluation and Unified Theory of Acceptance and Use of Technology (UTAUT). The prototype evaluation reported an average of 2 out of 5. The usability testing showed that the system scored 10.7 out of 12. Both results indicate that participants found the SSHS concept usable and acceptable to a certain extent.

Serving the same purpose, researchers in [FN12] introduced a unique automated smart kitchen cabinet for seniors with short-term memory loss. The smart kitchen concept in this study incorporates cognitive assistance such as sorting new items, finding existing items and obtaining meal recipes. The smart kitchen Hi-Fi prototype utilizes a DC motor (to operate drawers), speakers, a screen and a microphone. The prototype was built and deployed in a lab setup consisting of the user interface and the automated cabinet. The research team evaluated the functionality and the feasibility of the system. In addition, a UTAUT scale evaluation was designed to measure the acceptance and the potential of the proposed system to be used by seniors. The system performance evaluation resulted in more than a 90 percent success rate in recognizing speech input and displaying items located on shelves.

In addition, the system was deemed useful and easy to use based on the results of the UTAUT questionnaire that five seniors completed. However, some reported anxiety toward the system which could be due to the automated shelves as seniors tend to be concerned about physical hazards.

Summary:

> This sub-section discussed three different smart home concepts for cooking support. Interestingly, these studies explored providing assistance for completing cooking tasks such as finding cooking times, motorized drawers, and visual prompts. All smart home concepts utilized various ambient sensors and RFID tags. The user of the Unified Theory of Acceptance and Use of Technology was present in two studies

Hygiene support

In some cases of dementia, forgetfulness and confusion can affect basic activities of daily living such as hand washing or teeth brushing. Therefore, the COACH project aimed to examine the efficiency of using smart home technology to assist people with dementia to complete hygiene ADL [MBCH08]. A user research was conducted with a sample of end-users and caregivers early in this project. Afterwards, researchers proposed using audio-video monitoring with an artificial intelligence reasoning engine to decide when an intervention/prompt is required. A Hi-Fi system prototype was developed and deployed in a lab setup at the University of Toronto. Six seniors formally diagnosed with moderate-to-severe dementias were invited to test the prototype. Hand washing was selected as the target scenario for the testing. A camera was installed on top of the sink to monitor the hand washing process, and a screen was mounted on the wall to display instructions when needed. Participants were tasked to wash their hands twice, with and without the help of COACH. The data analysis focused on investigating the impact of COACH on the participants' independence and caregiver burden as well as COACH's overall performance. Another test was conducted on the system prototype after improving the AI algorithm. The second study explored integrating emotional intelligence with the COACH system [Lin14]. Prototype testing revealed that participants with moderate-level dementia could perform 11 percent of the hand washing steps independently. In addition, participants required 60 percent fewer instructions from their caregiver when the COACH system was in use.

Furthermore, four participants achieved complete independence. The second prototype testing with the emotional intelligence feature was added, indicating that users with high activity levels (high potency) were more likely to receive system prompts. However, the system still suffers a significant privacy concern due to the use of a camera in the washroom.

Summary:

> The COACH project was developed and tested at the University of Toronto in Canada to monitor hand washing tasks and provide assistance when needed. The system utilizes a ceiling camera and a screen to display instructions.

4.3.3 Emergency response

Despite all the benefits of aging in place, emergencies remain a significant stressor to families. It is argued that emergency concerns can be the breaking point when moving seniors from home to assisted living facilities. For instance, falling is a major cause of seniors' frailty, immobility, and chronic health impairment. Some studies suggest that falling with a long laydown period on the ground after the fall occurs is associated with increased mortality and injury severity [BC+92]. In 2008, [NRB+08] reported that receiving help after a fall reduces the risk of death or hospitalization by 26 percent and the risk of death by 80 percent. More importantly, SwNCD showed poor reactions to emergencies [JLP98]. Other major emergencies that are more common among seniors with cognitive impairment is wandering. The good news, both of these emergency cases can be captured using various types of smart home systems.

Table 4.7: Smart home systems for fall detection

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[RSA+15]	Ambient	Pulse-doppler radar, a Microsoft Kinect, camera	Hi-Fi	User research was conducted in previous study	Usability testing Accuracy testing Field deployment
[DSD08]		Camera and microphone	Lo-Fi	Not reported	Accuracy testing
[ORH+14]		Floor sensor, door sensor, bed sensor	Hi-Fi	Not reported	Accuracy testing

Fall detection

Smart home systems can alleviate falling-related concerns by detecting falling incidents and sending immediate notifications to caregivers. As seen in Table 4.7, we identified three studies addressing this issue. First, researchers in [RSA+15] developed a fall risk assessment and detection system using Pulse-Doppler radar, Microsoft Kinect and two web cameras. The idea is to train a ML algorithm to detect falls from different sources using different types of data; 3D depth maps, electronic waves and camera images. Then, the ML uses these multi-type data to reduce false positive incidents. The system prototype was deployed in 16 apartments at the TigerPlace community for two years. During that period, the ML algorithm was being trained to capture falls and send appropriate notifications to formal caregivers. The prototype testing reported high accuracy of fall detection. Furthermore, residents expressed a higher sense of confidence and security when they knew help would come if they fell. As of March 2015, many of these systems were installed in the TigerPlace unites in several locations in Missouri, USA.

In [DSD08] researchers attempt to detect multiple emergencies such as falling, shouting or running using ML and audio/visual data only. A low-fidelity prototype was implemented in a lab set up to train and evaluate the system's algorithm. Ten volunteers participated in populating a dataset of activities such as walking, sitting and sleeping. As for falling detection data, actor participants simulated falling in a lab setup. Prototype evaluation showed that the system recognized some emergency events like falling, shouting and crying.

Further investigations are required to test the system's ability to detect emergency events in real-time with actual potential end-users. For example, researchers in [ORH+14] explored using the floor, door and bed sensors to capture falls, night wandering and disturbed sleeping patterns. The study introduced a Hi-Fi system prototype consisting of commercially available devices and a smartphone application for caregivers. Sixteen volunteers participated in testing the prototype in a lab setup that simulates a small apartment. Volunteers were tasked to randomly perform a series of postures and actions such as lying down in bed, walking, standing, leaving and coming back and falling. The system achieved an average of 98 percent of true positive rate and 0.03 percent positive rate in detecting falls and night wandering. However, the promise of delivering immediate alarms to caregivers was not explored.

Summary:

> Falling is one of the most dangerous situations that seniors face at home every day. Detecting falling incidents was explored in two papers using audio/visual data. Using a combination of sensors (door, floor, and bed) and video data. In the TigerPlace, a smart home concept using Microsoft Kinect, Pulse-Doppler radar and cameras was introduced and later deployed in many housing units in Missouri, USA.

Wandering

Indoor nocturnal wandering can be dangerous as the senior gets exhausted, remains sleepless, becomes dehydrated, and potentially falls and hurts themselves [BL87]. Therefore, detecting indoor nocturnal wandering episodes can be more difficult because it requires more advanced monitoring techniques. In [KNPL+20] suggested detecting night wandering and providing seniors with cues to encourage them to return to sleep and notify the caregiver when needed. A single occupant housed was upgraded to a smart home using motion, pressure, power, light, door and water sensors to test this concept. In addition, several speakers were distributed to deliver cues to the occupant to return to sleep. The occupant was a senior lady who was diagnosed with moderate Alzheimer's. A system usability evaluation was carried out for 14 days. Results show that the system provided accurate and useful notifications to the caregiver when needed.

Furthermore, the caregiver found the notifications to be very helpful and acceptable. However, the system's effectiveness in delivering cues to the senior occupant to return to sleep remained unexplored. [KLC+16] suggested using ML-based SSHS to detect wandering indoors and outdoors. This study collected indoor navigation data using wrist-worn radio tags and wall-mounted sensors. The mobile GPS receiver was used for the outdoor data collection. Only one volunteer subject was equipped with the GPS receiver and was instructed to simulate various walking patterns for data collection. The suggested system managed to identify four patterns of walking: direct, pacing, random, and lapping. Based on these four patterns, the algorithm managed to detect wandering indoors and outdoors with an accuracy of 90 percent. Table 4.8 details all studies that addressed wandering scenarios.

A very comprehensive SSHS concept was introduced in [PCG+19] to identify ADL and provide immediate notification and immediate assistance to seniors in emergency cases. Uniquely, this study suggests using a combination of environmental sensors, RFID tags, a panic button attached to the wearable device, and a robot equipped with communication devices to facilitate a Skype video call with the caregiver when needed. The robot is also equipped with sensors and a tag reader that can be used for tasks like robot localization or to help the senior to find objects. A Hi-Fi prototype was implemented in a simulated environment in a lab using cardboard furniture models at Universidad de Málaga, Spain. A highly customizable web application was developed for caregivers to create alarms and notifications and to move the robot around remotely. Several testings were carried out with one participant who showed that the system successfully generates a warning in cases of emergency. For instance, the SSHS can open the windows when smoke is detected and switch lights on or off when the user is inactive for an extended period. Moreover, it moved the robot to the user's location to start an audio conference with a caregiver. In another testing, a participant pushed the panic button, which generated high-priority warnings in the web application and sent a notification to the caregiver.

Table 4.8: Smart home systems for wandering detection

Paper	Sensing approach	Used devices	Prototype fidelity	User research	Prototype evaluation
[KNPL+20]	Ambient	Speakers, motion sensor, pressure sensor, power sensor, light sensor, door sensor, and water sensor	Hi-Fi	User research was conducted	Usability testing Field deployment
[PCG+19]	Hybrid	RFID tags, panic button, a robot (camera, speakers and mic)	Hi-Fi	Not reported	Accuracy testing
[KLC+16]		Wearable radio tag, ambient radio sensors, GPS receiver and Mobile phone	Hi-Fi	Not reported	Accuracy testing

Summary:

In this sub-section, we presented three different approaches to detecting and reacting to wandering episodes. In the first concept, researchers used ambient sensors only to detect wandering and deliver audio cues to the Senior via speakers. The second concept introduced a combination of ambient sensors and an assistive reboot. The last paper presented using a combination of ambient sensors and a wrist-worn device to detect indoor and outdoor wandering. The smart home would notify the caregiver when wandering is detected in all papers.

4.4 Discussions

This section discusses our findings from four perspectives: design approach, smart home system data, prototype fidelity and user testing, and privacy approach. Discussing the findings from these different perspectives provides important insights into the various concepts of designing smart home systems in this domain.

4.4.1 Design approach

One way to achieve higher system usability is to follow a UCD process, where conducting user research prior to development is typically the first step. Running these studies requires collecting primary data such as interviews, focus groups, and direct observations. In this

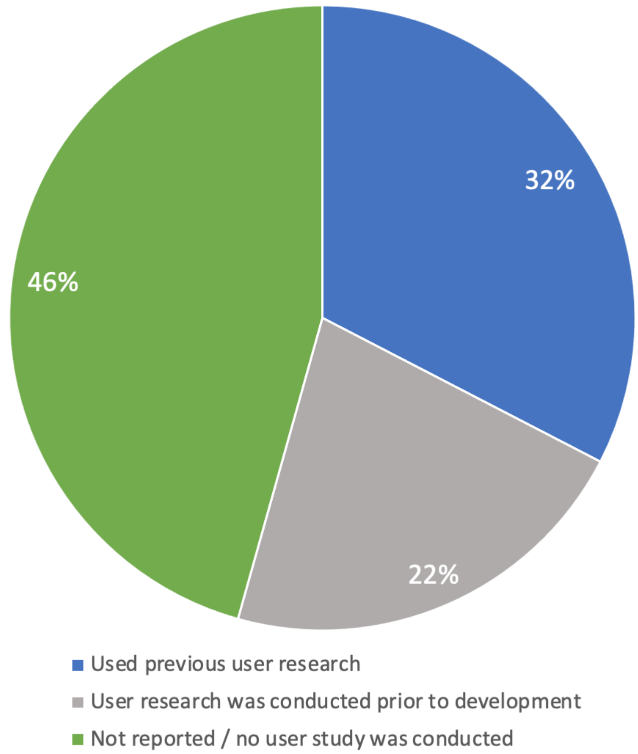

Figure 4.3: Analysis of the design approach bases

review, we identified three different approaches to design.

As shown in Figure 4.3, it is notable that only 22 percent of the total number of studies (a total of 10) reported conducting user research prior to development. All these studies shared that they highlighted the importance of involving the end-user in the design process. Most of these studies were a part of more significant projects such as the COACH, the Smart Home project by the University of Alberta, and the TigerPlace project. In addition, we identified 15 papers that relied on previously published user research to extract user scenarios, tasks, and design requirements. This approach of investigation is effective when conducting user research is difficult or is not possible.

Surprisingly, while all studies claimed to introduce system concepts tailored for SwNCDs, 46 percent of these studies did not report conducting user research or using previously published work. A possible explanation of this finding is that most studies focused on developing an SSHS for monitoring purposes. Usually, these studies are very objective in their scope where researchers would identify a prevalent problem, such as wandering, then focus on developing technology with high detection accuracy. In this case, user research is unnecessary, as the focus is purely functional.

We can conclude that only ten studies in this domain followed a formal and complete user-centred design approach that starts with a user investigation and ends with a user evaluation. This is an essential finding for multiple reasons. Firstly, studies that conducted user research introduced highly usable SSHS concepts; one study led to the development of a commercial product implemented in several aging in place communities in the USA. Thirdly, it was notable that accurate user scenarios were more present among research papers that conducted user research. It is important to state that, in some cases when the problems are relatively common (detecting wandering, monitoring ADL, etc.), conducting new user research might not be needed, which could partly explain the 46% of studies that didn't report user research.

4.4.2 Smart home data and sensing approach

Generally, any smart home consists of two main components; hardware and software. The hardware components are either sensors (gather data) or actuators (perform actions) [FI11a]. The software component is responsible for making sense of sensor data and triggering automation [CSCB18]. Conventionally, SSHS relies on ambient or environmental sensors to gather data. However, with the recent advancement of IoT, it became possible to include wearable devices in the ecosystem, creating a hybrid sensing mechanism.

As shown in Figure 4.4, the number of ambient sensing concepts is significant, especially in the SSHS for the ADL detection category. A significant benefit of using ambient sensing is collecting data without the need for wearable devices. Surprisingly, ambient sensing is more common in SSHS for health monitoring (a total of 11 papers). Most of these papers focused on monitoring and assessing the resident's cognitive health. Only a few papers introduced ambient sensing concepts for physiological health monitoring, e.g., early detection of UTIs

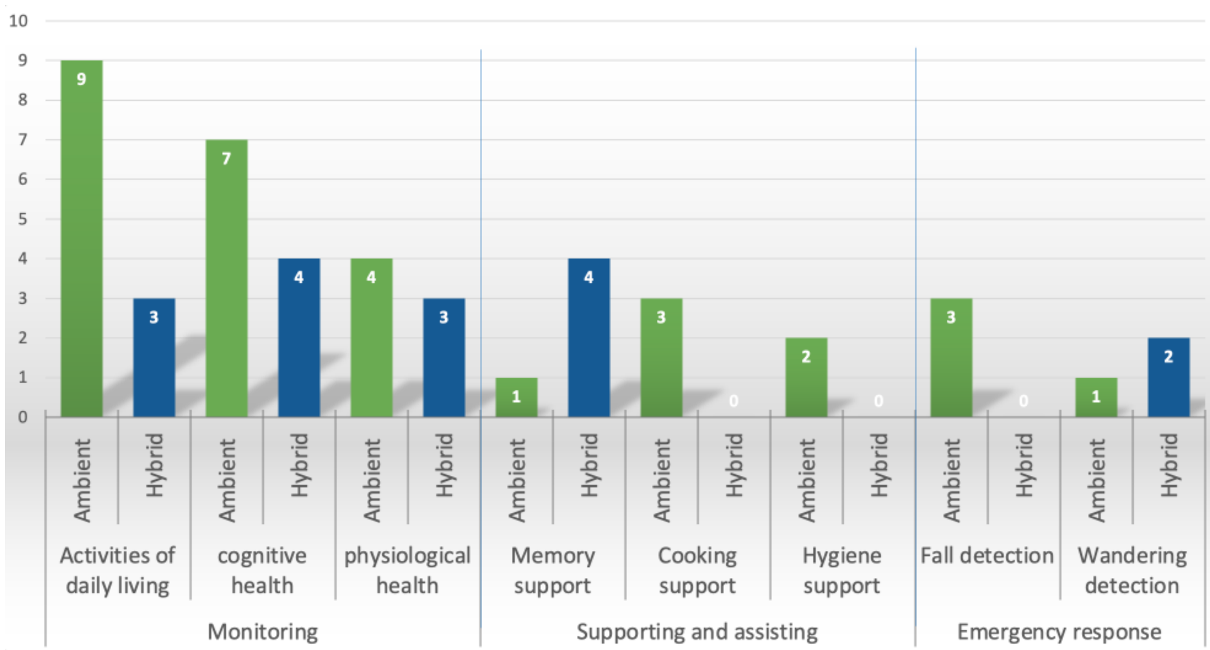

Figure 4.4: Sensing approach in each category

using passive sensing. While this type of technology can be very valuable, its accuracy is not considered high. Understandably, medical staff rely on lab tests for diagnoses. Therefore, using ambient sensor data for early detection of illness might be more appropriate for bringing awareness to the caregiver rather than using this data for medical diagnoses.

We identified 11 papers that introduced a SSHS for supporting and assisting, and both ambient and hybrid sensing approaches were present almost equally. It is worth mentioning that more usability and technology acceptability tests were performed in these papers. Furthermore, using standard IoT devices was explored in several studies. This utilization of IoT was a response to two significant issues facing the aging in place community. Firstly, seniors have various needs requiring flexible and highly customized systems. Secondly, seniors' needs can change over time, especially among SwNCD. Using standard IoT devices can accommodate these needs by allowing the introduction of new devices and new automation recipes to the system as needed.

Our systematic literature review resulted in only six relevant SSHS concepts for emergency response purposes that met the inclusion criteria. The main focus of these papers was to detect falling or wandering. Detecting three types of wandering were explored; indoor, night, and outdoor. Using wearable devices is more accurate in detecting falling and wandering. Nonetheless, the user taking off the wearable device is always a possibility. Two papers used hybrid sensing for emergency responses, and one of them introduced an assistive robot to the smart home ecosystem.

Among all studies included in this paper, only one study in the USA reported a successful fall detection emergency system using ambient sensing only. The system in this study was deployed in many TigerPlace units and several other locations in Missouri, USA. However, this system utilized cameras and MS Kinect devices, which severely breach the resident's privacy when others access the data.

4.4.3 Prototype fidelity and user testing

One of the main objectives of this study was to identify the prototype fidelity of every included study. Moreover, we wanted to explore the various methods of prototype evaluation in this domain. It is important to establish criteria for distinguishing prototype fidelity. From an HCI perspective, fidelity describes how prototypes can be distinguished from the final product [WTL02]. Generally, Lo-Fi prototypes are intended for functional testing where visual elements and UI design are not important at that stage [STG03]. Whereas, Hi-Fi are closer to final products and thus, they are more suited for usability testing [VSK96].

As presented in figure 4.5, only four papers presented Lo-Fi prototypes. Notably, all four papers fall under one of two categories; monitoring or emergency response. Prototype testing was limited to some functional aspects to evaluate the accuracy in identifying ADL or detecting emergencies. Meanwhile, Hi-Fi prototypes are more realistic and closer to an end product; therefore, they are more suited for usability testing.

In total, 42 papers conducted Hi-Fi prototype testing either in a lab setup (19 papers) or in seniors' residences (23 papers). Understandably, usability and accuracy testings represent the majority of prototype evaluation. Accuracy testings were performed in a lab setup in

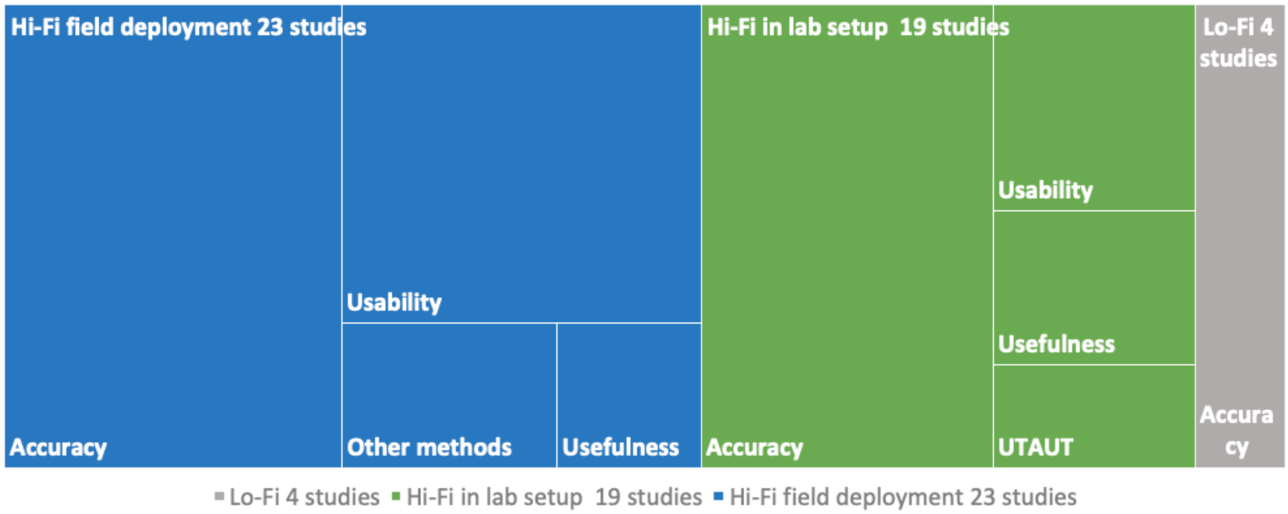

Figure 4.5: Prototype evaluation methods analysis

10 papers, where a small apartment environment was simulated in a university lab. Three more papers reported conducting accuracy testing coupled with usefulness evaluation. Only five papers presented prototype usability testing in a lab setup. The Unified Theory of Acceptance and Use of Technology (UTAUT) was explored in two studies where a small sample of seniors measured the level of acceptance; 12 participants and 5 participants [NL93].

Regarding the number of participants, most of these 19 studies recruited 5-25 participants for prototype evaluation. From a usability perspective, 5 participants can find 75 percent of usability problems according to [NM90]. However, it is crucial to highlight that many of these studies did not include SwNCD in the prototype evaluation process.

We have identified 23 papers that reported testing system prototypes in the field, either in assisted living facilities or senior homes. Studies that tested the accuracy of detecting daily activities represented the majority. Most of these studies fall under the monitoring and emergency response categories. Interestingly, the average number of participants in these studies is less than three. This could point to difficulties in implementing SSHS prototypes in seniors' homes or challenges in recruiting participants. Even studies that deployed a SSHS prototype for a short period of time did not report more than three user testings. However, this was not the case with five studies which performed usability tests. Four of these studies deployed a system prototype in seniors communities, assisted living and senior homes. The number of testing participants was much higher in these studies, between 4 - 36 participants. Only one paper presented a case study of prototype usability testing implemented in a seniors' home.

A combination of usability testing and accuracy testing was used in 4 papers. Three of them conducted a prototype evaluation in assisted living facilities. Notably, the number of participants in these studies was relatively high; 13 - 53 participants. The remaining four studies reported conducting more than one test, including accuracy, ease of use, usability, usefulness and level of acceptance. The number of participants in these studies was between 8 - 17 participants. We have noticed two new trends among studies that deployed system prototypes in the field. Firstly, many included a variety of stakeholders such as formal (nurses, occupational therapists, doctors, etc.) and informal caregivers in the evaluation. From a usability perspective, it is imperative to evaluate prototype usability with all potential user categories. Secondly, big projects that implemented SSHS prototypes in the field tended to conduct more than one type of evaluation with a more significant number of participants and for long periods. Some of these projects are; the RITA project, TigerPlace and the smart kitchen for ambient assisted living project.

4.4.4 Privacy

It is established that smart homes would require a sensing layer that could be either ambient or hybrid. Either way, the primary function of a SSHS is to make sense of the sensor data and either send notifications or take actions. That is to say; any system will eventually collect data about a resident's ADL, which in turn breaches the user's privacy to a certain extent. In this thesis, and based on recommendations from previous publications, we considered a SSHS concept that uses cameras and microphones to be highly intrusive [Cou08, RB16]. Besides the privacy concerns, there could be a safety issue where geriatric studies demonstrated a significant correlation between neurocognitive disorders and higher stress and anxiety levels.

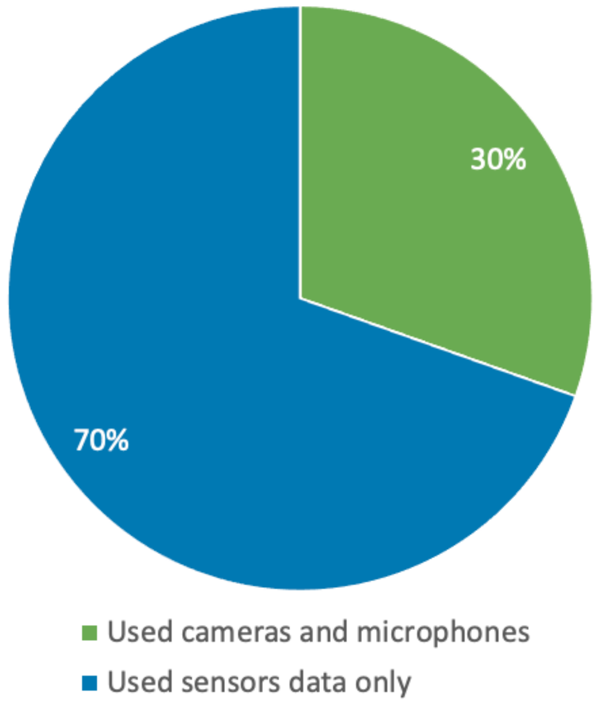

Figure 4.6: Privacy approach analysis; the percentage of studies that introduced intrusive / non-intrusive smart home concepts

Furthermore, it is common among some seniors with dementia to feel suspicious and to have false beliefs about being under surveillance or being bugged [MZ13]. Therefore, using conventional cameras and microphones can increase suspiciousness [CMN+07, MMSW90] which could increase anxiety and the chances for wandering episodes.

The less intrusive way of collecting data is to use ambient (passive) or wearable sensors. While we understand that both monitoring methods (intrusive or non-intrusive) will eventually lead to collecting personal data, there has to be a trade-off between privacy and safety in the context of aging in place. This argument was explored in multiple literature studies that are concerned about technology acceptance and privacy [BWM+13, LHBC+11, TKH+18]. However, in this thesis, we approach the literature from a design perspective, and we are more interested in identifying SSHS concepts that reduce the degree of intrusiveness to a minimum extent. According to our research, both types of data, audio-visual or binary sensors data, can help a system identify ADL. Since this goal can be achieved without using audio-visual data, we considered all studies that introduced a system prototype using ambient or wearable sensors to be non-intrusive. Figure 4.6 presents the percentage of intrusive and non-intrusive SSHS concepts in the selected literature papers. The desire to design non-intrusive systems was evident in the literature (70 percent of the studies), while only 30 percent of studies used audio or visual data. Among all intrusive concepts, 29.41 percent relied on audio-visual data only, while the rest of the studies used a combination of audio-visual and binary sensor data.

4.5 Limitations

There are three main limitations to this study. Firstly, inclusion and exclusion criteria were narrowed to studies that introduced, developed and tested SSHS. Therefore, all studies that did not meet these criteria were excluded and thus, they were not reported. Secondly, our search strategy and the selection process could threaten the validity of our findings due to search engine functional limitations. According to our librarian, online search engines perform timed queries, meaning particular results could be missed due to a query time out. Although we supplemented our search results by conducting further searches on ACM Digital Library and IEEE Xporer, we might have missed papers published on other databases. Finally, during the paper selection process, we implemented a single reviewer screening protocol, increasing selection bias due to subjective interpretation of data.

4.6 Conclusion

In this chapter, we introduced our systematic review of relevant literature work. The selection process focused on identifying studies that introduced, developed, and evaluated supportive smart home system concepts. To provide future researchers with a clear taxonomy of the literature, we categorized our findings into three main categories: smart homes for monitoring, supporting and assisting, and emergency responses.

According to our findings, there are three different methods for collecting data for smart home systems: ambient sensing, environmental sensing and wearables. Some studies used a hybrid of two methods. A significant benefit of ambient and environmental sensing is the ability to collect data passively and effortlessly. However, identifying different users in the same space challenges this sensing method. Using a camera and microphones is considered a form of ambient sensing that overcomes the false user identification problem, but collecting audio/visual data severely breaches the user's privacy. Therefore, we noticed a few studies that utilize a combination of ambient sensors and RFID tags to identify target users in the space.

While most studies claimed to introduce smart home concepts tailored for SwNCDS, reported user research was completely missing in 46% of studies which contradict recommendations for designing technologies for SwNCDs. A small number of studies relayed on previously published user research as a starting point of their design, while 32% of studies conducted their own. Most studies conducted a form of user evaluation using high-fidelity system prototypes, including Usability Scale Test, accuracy testings, and Unified Theory of Acceptance and Use of Technology.

In conclusion, there appears to be a lack of smart home concepts that directly support senior users in completing daily tasks. Memory and cooking support represented the majority of work in this area which indicates the importance of these two topics, understandably. These studies proposed various methods of user-system interactions such as audio-based systems (voice commands and speakers) and visuals (TVs, screens, and projectors). Each of these approaches comes with a set of benefits and limitations. Capturing the user's attention and assuring successful delivery of these prompts is the main challenge in these approaches. Therefore, a better user-system interaction is still required to adapt smart home technology successfully.

Chapter 5

Understanding the User's needs: Requirements elicitation study

5.1 Chapter overview

This chapter presents a field study aimed to gather requirements for designing a supportive smart home system for Seniors with Neurocognitive disorders (SwNCDs)[1]. The chapter starts by presenting the purpose of the study; then, the study participants and their categories are discussed. In the following section, the procedures of this study are presented, including pre-interview, during interview and site visit details. The thematic data analysis method is briefly discussed in the next section, followed by the study findings. The analysis resulted in a thematic framework including four main themes; common issues, desired system features, system requirements, caregiver worries and coping mechanisms. Each of these themes is broken into multiple sub-themes discussed in detail in their respective sections. Discussions of the study findings include; user scenarios that can be addressed by a supportive smart home, system requirements, user-system interaction discussion, and brief discussion about

[1]This study was fully funded by the World of 21st Century (W21C) through the summer funding program, 2018. The W21C is a research and innovation initiative based in the University of Calgary and the Calgary Zone of Alberta Health Services

safety and privacy. Finally, the chapter ends with reporting limitations and a conclusion.

5.2 Purpose of the study

Typically, following a comprehensive User-Centered Design (UCD) process starts with a requirements elicitation study prior to design and development [RB16, AB16]. As stated in Chapter 3, the primary purpose of this part of the thesis is to elicit design requirements and investigate common case scenarios and challenges that can be addressed using a Supportive Smart Home System (SSHS). To accomplish this goal, we start this study by conducting interviews with a sample of seniors, and formal and informal caregivers to investigate common homecare issues. After that, we investigate the effect of these issues on the senior's life and the caregiver. Throughout these conversations, we focus on eliciting system requirements such as desired system features, design and user considerations and more.

5.3 Study participants

All study participants were recruited with the help of the University of Calgary participants recruitment online portal, the Alzheimer's Society of Calgary[2], and the World of 21st Century[3]. Table 5.1 presents the details of all study participants. All interviews took place in the city of Calgary between March and September 2018. Six participants were interviewed, and one site visit to two seniors' homes was conducted. As mentioned in Chapter 2, it is essential to include formal and informal caregivers when gathering design requirements for SwNCDs homecare [HIR+05, AB18b]. Hence, we recruited participants from three different categories: seniors and formal and informal caregivers. Two of the participants were nurses who specialize in SwNCDs. Both nurses worked with SwNCDs at home and in nursing homes as well. Two other participants were informal caregivers; both are daughters of parents with

[2] https://www.alzheimercalgary.ca
[3] https://www.w21c.org

Table 5.1: Study participants details

Participant	Category	Age	Condition
P1	Senior	Early 70s	MCI
P2		Early 70s	Early dementia
P3	Formal caregiver	Late 20s	NA
P4		Late 50s	NA
P5	Informal caregiver	Mid 20s	Caring for person with early dementia
P6		Early 60s	Caring for a person with dementia

dementia. The last two participants were a couple aging in their place, and both were diagnosed with a form of NCDs; the husband was diagnosed with an early Mild Cognitive Impairment (MCI), while the wife had an early stage of dementia. Both seniors were in their early 70s, and they identified as the primary caregiver for the other.

5.4 Procedures

5.4.1 Pre-interview

This study was conducted pre-COVID-19 pandemic. Upon expressing interest in the study, potential participants received a study description and a consent form to review via email. When they agreed to participate, a one-on-one interview was arranged either at the ICT Building at the University of Calgary or at the participant's residence. The two formal caregivers were interviewed at the UofC, whereas senior participants were interviewed at their residences. Please refer to Appendix C for certificate of research ethics, consent form, sample of interview transcripts [4], and sample of data analysis.

[4] According to our research ethics protocol, we are required to secure the research data in a protected folder for a maximum of five years or until the research is completed (whichever comes first). Therefore, we are unable to share the data publicly. We will include screenshots of script samples and the qualitative data analysis process from NVivo

5.4.2 During-interview

All participants consented to have the interview audio recorded. As explained in Chapter 3, we used semi-structured interviews to run the study. Semi-structured interviews allow for a free flow of conversations while providing the opportunity to explore topics relevant to a particular participant spontaneously. Below is a sample of the interview questions:

- Can you please tell me about your experience with seniors with NCDs?
- Could you please tell me about some of the homecare-related issues you experienced while caring for him/her this past year?
- Now that we explored what a smart home system is, can you think of three different ways how this technology can help you or your family/client?

Based on the participant category and their answer to the opening questions, follow-up questions were asked. When a participant raises an issue, we ask them more specific questions about its effect on aging in place. We focused on investigating issues that can be addressed using supportive smart homes (for instance, we focused more on the issue of the senior forgetting the hair iron device on). We tried to address at least two issues in every interview. In the third quarter of the interview, we proposed solutions to the problems that a participant raised and then asked them more questions about our proposed solution to explore their reactions. In the last quarter of the interview, we discussed the potential for adopting such technology. In addition, we discussed two concerns that come with the technology; data privacy and user safety.

5.4.3 Fly on the wall observations

One visit to a local aging in place community in Calgary was facilitated for fly-on-the-wall observations. The family allowed us to spend the day observing their daily activities and taking notes. The two residents were senior citizens diagnosed with an early stage of

Table 5.2: The thematic framework presenting the main four themes

Theme	No. of participants	No. of references
Common issues	6	37
Desired system features	6	34
System requirements	6	35
Caregiver worries and coping mechanisms	6	30

Dementia and MCI; these are the same couple who participated in the interviews. Fly-on-the-wall researcher's observations were recorded on paper and sometimes in the form of voice notes using a voice recording device.

5.5 Data analysis

All audio and notes data were transcribed and imported into NVivo software for qualitative data analysis. Each interview was coded separately following a reflexive coding process guided by Braun and Clarke's [BC19, COD+21, BC21a] (please refer to Chapter three for details about this process). The initial coding process resulted in 81 codes. Some of these codes were referencing the same point but with different names. After reviewing and merging all these similar codes, we ended up with 54 codes. At that point, we gathered codes that shared similar trends to create initial themes. After multiple reviews, we arrived at our final four main themes described in the next section.

5.6 Findings

Table 5.2 presents the entire thematic framework with the four main themes only. The first theme presents common issues that seniors with NCDs or caregivers face at home. The second theme presents a number of system desired features. The third theme, discuss extracted system requirements.The last theme presents the caregiver's worries and coping mechanisms.

Table 5.3: The Common Issues theme and all three sub-themes with their references

Sub-theme	Code	No. of participants	No. of references
Daily living	Leaving home appliances on	5	5
	Difficulty remembering names	3	4
	Difficulty recognizing new objects	1	1
	Losing personal items at home	1	1
	Losing sense of time	1	1
	Difficulty completing daily tasks	1	1
	Potential for confusion	1	1
	Accepting illness is a key factor for accepting technology	1	1
	Orientation problem	1	1
	Risk of not comprehending	1	1
Health related	Missing important medication	4	4
	Losing appetite	1	1
	Sleeping issues	1	1
	General forgetfulness	1	1
	Lack of drinking water	1	1
	Potential hygiene issues	1	1
	Risk of fall	1	1
Personality changes	Safety paranoia	2	3
	Difficulty expressing themselves	3	3
	Hide personal items	1	1
	Higher levels of frustration	1	1
	Irritation when intervening in personal items	1	1
	Pretend to know out of being polite	1	1

5.6.1 First theme: common issues

This theme is split into three sub-themes; daily living related issues, health related issues, and personality change-related issues. Table 5.3 presents these sub-themes and their references.

Daily living related issues

NCDs affect the senior's ability to complete daily living activities negatively [GSS+14]. Our study participants discussed ten common issues they face when caring for their family members or clients (for formal caregivers). The two most reported issues were leaving home appliances on and difficulty remembering names. Some participants highlighted that these two issues were the primary sources of concern before receiving formal diagnoses. For example, one of the participants talked about his wife forgetting her hair iron tuned on and leaving the house. On the other hand, the rest of the participants reported forgetting the stove for long periods of time, seniors and caregivers. Pertaining to these two issues, P2 said the following:

"He had a problem driving, and because he loves to cook, he tends to use the stove more often. Sometimes we will be watching TV, and I will notice that the pots on the stove are burning", P2.

"Well, I know he struggles with names a lot. We have three dogs, and he struggles to remember their names. So aging is what seems to be causing him to have trouble remembering names", P2.

Losing personal items at home appeared to be a common issue. According to our conversations, it appears that there are three main reasons for such incidents. First, some participants discussed losing personal items due to short-term memory loss. Other participants reported difficulty in recognizing objects, especially new objects. However, one study participant linked these incidents to recurring episodes of paranoia and a tendency to hide personal belongings. In any scenario, our participants discussed the potential for technology to track and find personal belongings. Another issue was related to losing the sense of time and becoming disoriented.

"She also hides things because she is worried someone might steal them. She also lost things because she had hidden them. Once, she thought that her wallet was stolen because she had hidden it somewhere at home and couldn't find it later", P1.

When we asked one of our formal caregivers about the effect of NCDs on daily living activities and how SSHS can assess that, we learned that people who accept their illness are more willing to accept the changes. For example, in our interview with P3, she stated:

"As long as they've accepted this illness, then they'll probably accept everything else. Knowing that if they did [accept their illness], they kinda really depend on their own emotions and their way of dealing with it", P3.

Health related issues

Missing important medications appeared to be the most common and worrisome reported issue among all our participants; seniors and caregivers. The majority of SwNCDs suffer from other health issues, some of which are serious conditions and require strict routines such as taking blood thinners or asthma puffers [oC10]. One of our formal caregivers reported the following story:

> *"For one client, an informal caregiver forgot to give eye drops, and the client had a bad eye infection. Then she went to the hospital, then she had pneumonia, and then her eye cleared up because there was a formal regiment, unlike the informal forgetful caregiver, you had someone doing it to a schedule and just remembered. Things like that, like was the eye drop bottle picked up at 10 o clock or not. It would be awesome if that technology had been there; I could have had that infection cleared up in no time; I could just remind him to put it on his phone or tracking these eye drops or having a beep to remind him that it's medication time"*, P4.

The risk of falling was another reported issue. Unlike the majority of cognitively healthy people, some SwNCDs take a longer time to react when falling, while some others might not react at all. There are many reasons for falling, some of which are related mainly to NCDs. For instance, some seniors forget to drink enough water, which could lead to dehydration, dizziness and eventually falling.

> *"He doesn't drink enough water however, I will mention it from time to time. When we go for a drive, I will always take two bottles. And if he sees me drinking he will drink too"*, P2.

> *"As his dementia progresses and Parkinson's progresses, and this is a bit off because of the Parkinson's, he started dropping things and with his walker, I would be worried that if he dropped something that as he's trying to pick it up, and he is unsteady and tried to pick it up and there is a fall risk"*, P4.

Sleeping issues are common among SwNCDs, and they occur for different reasons such as losing a sense of time, disorientation, medication side effects and more [KNPL+20]. Our participants reported either sleeping too much or not having enough sleep. In both scenarios, this could lead to more severe problems such as increasing the likelihood of wandering or falling [KNPL+20]. Therefore, monitoring sleeping was one of the desired features for an SSHS.

Personality changes related issues

Typically, the ordinary course of aging is associated with personality changes [HM03]. However, SwNCDs, are prone to more notable personality changes due to the changes in their cognitive health [oC18]. Our study participants reported three common personality changes; difficulty expressing thoughts, higher levels of frustration, and irritation. One of the participants hypothesized that SwNCDs are aware of their illness and its effect on their abilities to express themselves, which causes frustration. In addition, difficulties in self-expression could lead to irritation and sometimes social withdrawal.

> *"because he was trying to relay something to us and we would paraphrase it back to him and we would get it wrong, and he always remained very kind he didn't get angry with us, but he would get frustrated, he would say you don't understand, you need to listen"*, P4.

> *"Mostly communications. He forgets words, he can't describe what he needs and what he wants. It is frustrating for everyone around him and to himself because he can't describe what he wants"*, P5.

Some SwNCDs exhibit a persisting feeling of being unsafe at home. When we discussed this issue with our study participants, we learned that these behaviours are different and they depend on the individual's personality and background. For instance, participant P5 discussed her father's fears of someone breaking into their house anytime. His coping mechanism was to close curtains and ensure all doors were locked; he would keep checking on the door locks periodically. Other participants talked about his wife having extensive worries about her valuable belongings, where she kept changing where she hid them.

5.6.2 Second theme: desired system features

In this theme, we present findings related to desired systems featured that we discussed with study participants. Table 5.4 presents all codes and sub-themes found in this theme. As shown in the table, each code represents a desired system feature. In addition, we divided all codes into two sub-themes, resulting in two categories of desired system features; activity monitoring and memory prompts.

Table 5.4: The Desired System Features theme and all the two sub-themes with their references

Sub-theme	Code	No. of participants	No. of references
Activity monitoring	Monitor stove usage	5	7
	Importance of real-time activity monitoring	2	5
	Sleeping	3	4
	The importance of medication monitoring	1	2
	Eating	1	1
	Physical activities	1	1
	Water intake	1	1
Prompting	Cooking safety support	5	8
	Task completion prompts	2	3
	Support communications	1	1
	Physical activities	1	1

Activity monitoring

Two of the study participants expressed their desire to have a system to monitor residents' activities of daily living. The other four participants reported desired features mainly related to a resident's safety or health. Understandably, the system feature that all our participants agreed on is monitoring stove usage and other home appliances that lead to safety concerns (clothes and hair irons, etc.). In addition, monitoring sleeping was reported by three of our study participants.

"For the stove, it would be helpful to be able to turn it off remotely if it was left on. Especially when we know that the person has the tendency to use the stove, that becomes a safety issue, and it requires attention. The alternative solution is to unplug the stove altogether, which in my opinion is not nice if the person is still at an early stage", P3.

At some point in the study, all participants discussed the importance of taking medication on time and expressed a great desire to have a system feature to track medication intake. Further discussions about health-related issues led to another desired system feature; physical activity monitoring. For example, one of our formal caregiver participants argued that it is important for caregivers to know if their client had done their exercise at home or not.

"Unlike the informal forgetful caregiver, you had someone doing it [giving medication] to a schedule and just remembered. Things like that, like was the eye drop bottle picked up at ten o clock or not?. It would be awesome! If that technology had been there, I could have had that infection cleared up in no time, and I could just remind him to put it on his phone or tracking these eye drops. Or having a beep to remind that it is medication time. That would have avoided the client the eye surgery they had a month later", P4.

"she [our client] needs to straighten her legs so she can loosen her hamstrings because she is in a position where it creates cramping, so she has to do certain exercises to loosen her hamstrings, and as her legs are straightening out, she doesn't have that pain anymore at night. I think it would be great if we can check on her remotely to make sure she is on top of her exercises", P4.

Some SwNCDs lose their appetite, which leads to body weakness, fatigue and eventually higher chances of falls. In addition, many medications should be taken after a meal. Similarly, some seniors do not drink a sufficient amount of water. This could be due to the forgetfulness that comes with NCDs or, in some cases, the misinterpretation of feeling thirsty. In any scenario, our participants expressed the desire to be able to monitor food and water intake, if possible.

> *"Yes, I think so, it would be wonderful for me to have a better understanding too, it would help me provide better care. Very useful information to have, and I think the more you know about your client, the more and better care you can provide to them. How much water the client drank, does she have an appetite, did she take her medication"*, P4.

Prompting

The second group of desired system features is related to prompting the user to complete daily living activities. The most desired prompting features were taking medication and turning off home appliances such as stove, irons, etc. Prompting the user to take medication reduced the chances of missing important pills (blood thinners, asthma medication, etc.) while reminding the user to turn off the stove could prevent a fire; both features are related to the user's safety.

> *"It would be really good if we could have events tracking in a sense that the system could track if she [the senior] has completed a task and if she did not, it might remind her. Currently, we only use a calendar to track if we completed a task or not. Especially when it comes to medication, it would be great if the technology could track and remind her to take her pills"* P3.

Another set of prompting features was related to the well-being of the senior user, such as prompting the user to move around and complete some physical activities. One of our study participants wondered if such an SSHS could assist a user in communicating and finding the correct words. While prompting the user to move around is possible using SHH, communications support appears to be more complicated, and it is unclear at this point if such a feature is possible.

Table 5.5: The System Requirements theme and the two sub-themes with their references

Sub-theme	Code	No. of participants	No. of references
User considerations	Safety is number one priority	5	8
	Consider other health issues	3	3
	Maintain sense of agency	3	3
	Account for user feelings	3	3
	Support senior user caregiver users	2	2
	Self introduction technology	1	2
	Technology can be adopted if it does the work	1	1
	Account for neurodelay	1	1
	User consent is required	1	1
	Account for culture and religious factors	1	1
	Family decision	1	1
Design requirements	Repetition is key for technology acceptance	1	2
	Simplicity is required for caregivers	2	2
	Allows for different levels of interventions	2	2
	Using audio messages	1	1
	The power of visuals	1	1
	Prompting works even for severe cases	1	1

5.6.3 Third theme: system requirements

In this section, we discuss our findings from a system requirements perspective. We use interview materials and site visit observations to elicit these requirements. We classify these requirements into user considerations and design requirements; refer to Table 5.5 for details.

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User considerations

In our case, we have two main user categories; the senior user and the caregiver. Therefore, the first and most basic requirement for an SSHS is to account for the different user experiences. Furthermore, the system should consider the variety of caregivers (formal vs informal) and the different technology literacy backgrounds. For instance, in our site visit to a senior couple's home, it was notable that one of them was more comfortable with technology than the other.

> ”It is interesting to see that despite their age, they are both comfortable using some technology at home. However, the husband is more interested in exploring newer technology. He was happy to show me how he customized GoogleHome to

remind him and his wife to take medication. However, a designer should account for the user like the wife, who likes her iPad but gets frustrated quickly if she has to learn how to use a new application". Research observation.

Keeping the user safe was discussed multiple times throughout our discussions. Missing one medication and cooking safety came up during our discussions, along with other safety-related issues such as wandering or falling. Study participants from both main categories (caregivers and seniors) agreed that an SSHS that provides a sense of safety would improve the quality of life for everyone. From the senior's perspective, they reported feeling safer if they knew that their caregiver would be notified in the case of an emergency. Similarly, caregivers complained about feeling worried about leaving their seniors alone at home; thus, having a SSHS could put their worries at ease.

Two primary considerations related to social factors were reported; accounting for the user's feelings and maintaining a certain level of user agency. It is well established that SwNCDs would require more reminders; however, the way of delivering these reminders remains unclear. Further discussions with our participants revealed that seniors would feel irritated when they receive too many direct reminders. One of our study participants talked specifically about their mother's irritation when she receives reminders from her daughter in front of people. Therefore the design of a SSHS has to account for how reminders are delivered. The study participants described a few approaches in our discussion of supporting the senior's sense of agency. For instance, one caregiver warned us against suddenly turning off the stove remotely as it would look intrusive to the user, even if that was in their best interests. Instead, we could reach out to the user, ask if they left the stove running first, and get them to turn it off before intervening.

"If I think about someone [a client] where I would turn off their stove. I would have to be careful with it; she might be upset that she is hungry and can't cook anything, and someone else decided she couldn't cook. It would be very annoying.

If it to absolutely protect their safety, then you also must show dignity and respect in other ways and give them as many possible choices in a safe manner", P4.

"Although both seniors are formally diagnosed with a form of NCDs, they both try to have some level of independent life. They are each other's caregivers but they also understand the importance of self-reliance, and they both try to support each other respectfully", Research observation.

In our discussions about system interventions, some study participants agreed that user consent is needed. However, other participants believed adopting such technology is a big decision; thus, it must be discussed with all involved parties, including the senior, family members, and primary caregivers. These discussions could determine the proper levels of system interventions and data accessibility. In this regard, it is worth mentioning that social and cultural factors such as religion should be considered whenever possible. For instance, in some cultures, caring for elderly parents at home is the natural, normal course of action. On the other hand, moving older parents to children's homes is a religious obligation in some religions. Thus, the discussion of an SSHS, in this case, should account for these differences where the main role of technology, in this case, is to support the entire family.

"It is a family matter, just like writing a will. The family should make the decision, so it all depends on the family and how they respond", P2.

"I will never leave her alone at home. We don't even leave her alone with the home assistant. There will always be a family member at home, even when the home assistant is there. And when we are all unavailable, I will call my sister to come and stay with her. This is the least I could do for my mother. After all, as a [participant states their religion], I am obligated to serve my parents when they are old", P6.

Design Considerations

The central focus of the findings in this sub-theme is related to how the senior user experiences the supportive system. For instance, our participants emphasized the importance of memory prompts and repetition. One of the formal caregivers described their experience in introducing new technologies for SwNCDs at an early stage, saying, repeating instructions daily eventually leads to successful adaptation. As for prompting, it is important to supplement the user with different types of prompts, according to our study participants. Prompting is a repetitive process; thus, new technology should provide users with more than one prompt.

> *"If I prompted her [the senior] by telling her it was time to go to the dining room, sometimes she wouldn't know where to go, so I couldn't just prompt her to go and get her food. So I would ask her to go to the dining room first, if she doesn't go, I would point at the room, then when she gets there, I will bring in the food"*, P4.
>
> *"Know they will probably be accepting [new technology], especially for those at a mild to moderate stage. When you bring that technology though, you need to be repetitive, like this is how you turn it on, every single day until they kind of get it and then after that they will just use it"*, P3.

Although we did not discuss user interface elements with the participants at this point of the study, our discussions led to important points about the power of using visuals and audio messages. One of the formal caregivers emphasized the importance of using meaningful visuals to prompt the senior's memory. One of the suggestions was to incorporate personal and meaningful visuals into the design of our SSHS. In the context of using voice commands devices, one of the study participants raised the point that SwNCDs might freak out if they are to hear unfamiliar voices at home. Although this statement contradicts an early observation of a senior couple using GoogleHome devices, it appears that using a familiar voice is recommended to establish stronger connections.

Lastly, in terms of how the user experiences the system, our study participants highlighted the importance of keeping the system simple for both user categories, seniors and caregivers, to accommodate for a variety of user technology literacy. Furthermore, two of the study participants (P4 and P5) discussed the necessity of having multiple levels of system interventions. Therefore, it is essential to discuss the suitable levels of interventions for each family separately as it is practical to have a one-size-fits-all logic.

> *"That depends on the stage of the person; if we look at it at today's stage, I don't think I need that level of intervention. But like when there was one time when she lost her wallet, and she lost all her credit cards and driving licence there was that panicking and I would think technology like this could be required then"*, P1.
>
> *"There is a concern here, regarding using the computer and internet. I have an iPad, but I try to keep it simple. My husband has a computer, and he is on it all the time because he was on the board [community management board]. So regarding using your suggestion, if you are not savvy about it and know how to work it, that would be a problem"*, P2.

5.6.4 Fourth theme: caregiver worries and coping mechanisms

In this theme, we present findings describing worries and coping mechanisms reported by caregivers when caring for SwNCDs. Understanding these effects provides and researcher with important insights into the caregiver's experience. These insights can be taken into account when introducing supportive smart home concepts. Table 5.6 presents this theme, its sub-themes and their references.

The caregiver worries

In our discussions about caregiver worries, we learned that these worries are either related to the senior's safety or their well-being. In terms of safety, the top two worries were,

Table 5.6: The caregiver worries and coping mechanisms theme and the two sub-themes with their references

Sub-theme	Code	No. of participants	No. of references
Caregiver worries	Leaving stove on	5	8
	Worries of missing medication	5	7
	Staying at home to improve decline	1	3
	Fear of falling	1	2
	When to move to a facility	1	1
	Risk of wandering	1	1
Coping mechanisms	Reduce paranoia by closing curtains	1	1
	Sticky notes to remember	1	1
	Check on the stove periodically	1	1
	Google Home	1	1

understandably, leaving the stove on for long periods of time or missing vital medication. In this part of the thesis, we will not further discuss these two issues as they have been thoroughly discussed in previous sections. Another set of worries related to falling at home alone and unable to ask for help or wandering outdoors when no one is at home.

Seniors and caregivers believe aging in place yields better cognitive management and thus better quality of life. In fact, studies suggest that seniors aging in place show better cognitive decline management [TLBL+18b, AB16]. The last worry was reaching the point where moving to a seniors' facility is needed. It is worth noting that this particular topic is subjective, where families with different backgrounds could have different inputs.

> *"My client spent almost four years when she went to the senior's home, her decent [cognitive decline] was more rapid, that is what her family tell me as at that time I knew of her and didn't know her as well as I do now. She is not improving so much now, but at least she is stable since we moved her back home"*, P4.

> *"I always worry that if I don't take care of her [participant's mother], she will start getting worse, and then her doctor would ask us to move her to a nursing home. That is the last thing I want for her. So I will blame myself if that happens"*, P6.

Coping mechanisms

When we discussed some of these worries with the participants, we investigated their coping mechanisms to understand what was/was not working for them. For instance, the informal caregivers checked on the stove periodically to ensure it was not left on for long periods. One participant who described a safety paranoia with their father talked about closing all curtains and locking all doors in the evening to reduce the paranoia. Formal caregivers use sticky notes around the house to remind their clients of specific tasks such as taking medication or exercising. The senior couple we visited used a combination of sticky notes and GoogleHome to keep up with their medications.

> *"I would simply go turn the stove off, and then I will mention it to him. At this point, I got into the habit of after he made something to be boiled or cooked, I will go and checkup. I don't do it all the time because I myself forget. I mentioned this to him but I don't go over it more and more"*, P2.
>
> *"I also take medication. And because I left sticky notes on the mirror, he would remember to take his drugs and sometimes he even brings mine. We are working together. It is wonderful"*, P2 .

5.7 Discussions

5.7.1 User scenarios

The issues that come with NCDs are diverse, depending on the individual case and the stage of illness. In this study, we focus only on seniors at an early stage of illness. Although we recruited participants who are either seniors at an early stage or caregivers of seniors at an early stage, we identified 23 common issues for seniors aging in place; please refer to Table 5.3 for details. As was presented in the previous section, these issues are related to either daily living, health or personality changes. Some of these issues cannot be addressed using SSHS at this time, such as assisting the user in choosing the correct words to express themselves.

Addressing issues such as wandering or falling was explored in the literature. However, modern technology such as the Apple Watch[5] can solve such problems, and thus the need for more research addressing these two issues is reduced. Integrating wearable devices such as the Apple Watch into the SSHS would be valuable.

We identified a third set of issues that can be addressed in an SSHS. The two most reported cases are cooking safety and a medication reminder system. Understandably, these two issues are related to short-term memory loss, typically the first change that comes with NCDs. A smart home system aware of the stove and the medicine dispenser in the living space can provide reminders, and tailored memory prompts to the senior user. In addition, with the immersive user experience, the system can provide spatial prompts supported with visual content.

The last set of issues may not be the main focus of a SSHS but should be considered when designing any system feature. For instance, study participants reported seniors to have higher levels of frustration and get easily irritated. These issues are important to consider when designing the system user experience and user interface.

5.7.2 User system interaction

A proper design should account for both end-users needs but with more emphasis on the senior user. Since a one-size-fits-all design is not the right approach for this type of technology [AB18a], SSHS should provide a proper level of customization. Since the informal caregiver is the closest person to the senior, it is expected that they (the informal caregiver) would take the system administrator role. Therefore, an SSHS should support two user modes; caregiver mode and senior user mode.

[5] https://www.apple.com/ca/watch

Caregiver mode

In our discussions with the caregiver participants, we were encouraged to keep the system simple to accommodate all caregiver backgrounds. Therefore, the primary function of the caregiver mode is to set up, customize and maintain the system. Furthermore, caregivers should be able to monitor certain activities (stove, medication, wandering, etc.) and intervene when needed. Therefore, the main features of the caregiver mode can be summarized as follows:

1. Setting up the system for the first time: including introducing IoT devices to the system, setting up automation (e.g., if the stove is on for 20 minutes, then send me a message), and choosing suitable memory prompts and interventions.

2. Re-customizing the system: in case a system feature was not effective in supporting the senior user or in case the user's illness has progressed, the caregiver may find themselves in need of trying a different or new technique.

3. Monitoring: in a typical day, a caregiver would need to check the system to monitor certain activities. It must be established that the caregiver has consent from the senior user to access such private and confidential information. However, from a system design perspective, an SSHS should provide simple and easy access to the monitoring feature. In our discussion about this feature with caregivers, they recommended avoiding technical language and using more human-like language, such as medication was not taken yet or your father drank water four times today.

4. Intervening: in some cases, remote interventions are required for safety reasons. In the cooking safety scenario, all study participants highlighted the importance of being able to turn off the stove remotely at some point.

Senior user mode

The senior user mode is what the user will be dealing with most of the time. The user-system interaction is crucial as it determines the success or failure of adopting the proposed technology. Therefore, it is important to address two main aspects adequately; the method of interaction and system functionality.

1. **Interaction method:**

   As discussed earlier in this thesis, we intended to use Mixed Reality (MR) technology for user-system interactions. Understandably, MR was not at the center of this requirements elicitation study as we are still at the stage of gathering system and design requirements. However, in this part of the discussion, based on what we learned from the requirements elicitation, we will reflect on the potential for integrating MR into the supportive smart home system. As described in chapter two, MR unlocks natural and intuitive human-augmentations (holographic) interactions. In this model, designing seamless UXs tailored for SwNCDs is more feasible [BA20]. A major benefit of using a head-mounted MR device is that it allows users to interact with the home system instantly and effortlessly. Additionally, it offers hands-free interactions without isolating the users from their environment [RDMG20a]. The possibility to display virtual augmentations everywhere around the user enables free movement while ensuring users still receive prompts.

   Moreover, designing a User Interface (UI) for an MR application is not bound to traditional elements, such as buttons, windows or menus, allowing for more design liberty [GBJMACU15]. Integrating SSHS and MR unlocks new possibilities for homecare. For instance, an IoT device could trigger an MR application to display an interactive augmentation designed specifically for SwNCDs homecare. Additionally, it is possible to combine holographic/augmentation prompts with wearable IoT devices to receive vibration signals or haptic feedback. This approach can potentially improve user responsiveness by engaging more than one sense. Immersive smart homes, with careful and empathetic UX and UI design, could improve overall system usability and reduce homecare challenges. For these reasons, using MR for user-system interaction is a strong candidate.

2. **System functions:**

   According to our findings, the system can provide the user with mainly two functions; sending reminders and memory prompts. For a system to send reminders simply means the system should be able to send a message to the user to remind them of a task. We noticed that some of our study participants used sticky notes, phone reminders, or in some cases, GoogleHome devices. While these methods can be effective in some scenarios, they all share one similar risk; the user can miss the reminder if they are not around the device. This argument further supports the potential for using head-mounted MR devices where such reminders cannot be missed as long the user is wearing the device.

   As for the memory prompts, based on our study findings, caregivers appeared to perform memory prompts most of the time manually. This is because a memory prompts usually comes after a reminder, and thus, it is subjected to a given situation. For instance, participant P4, when they described their experience of using memory prompts, said, *"I would ask my client to go to the dining room, if she does not know where the dining room is, I will prompt her by pointing at the room"*.

5.7.3 System levels of intervention

It is established that in a conventional caregiving setup, reminders are the first step to asking a senior to complete a daily task. The next step is to prompt their memory if they did not complete the task. A smart home system adds a third step which is taking action. Therefore, discussing these steps in the context of SSHS is important.

Reminders

As we saw in the findings section, seniors and caregivers used sticky notes, smartphones and GoogleHome devices for setting reminders. The benefit of an SSHS is that it can provide customized reminders suitable for the individual user. In the case of an SSHS that uses MR for user-system interactions, these reminders can be immersive and contain audio/visual components. Assuming that a head-mounted device would ensure delivering these reminders all the time, the design and content of these reminders require further investigation.

Memory prompts

Delivering effective memory prompts requires tracking the task, the user's position and proper prompt design. Tracking task completion is done via IoT devices, e.g., a smart plug to measure stove usage. However, as we saw in the previous chapter, tracking the user's location indoors is relatively challenging, and current methods lack accuracy [AMMW07]. Thanks to head-mounted MR devices, tracking the user's location can be done without needing external devices [BVS+21]. Therefore, these two technical challenges are relatively resolved. A remaining challenge is to explore various methods of delivering memory prompts explicitly designed for SwNCDs.

Taking actions

This option does not apply to all scenarios. For instance, in the case of an SSHS supporting finding personal items at home, the system cannot assist the user beyond sending reminders and prompts. In the case of monitoring the stove, however, the system can intervene and turn off the stove automatically. Whereas in the case of the medication reminder, the system can intervene by informing the caregiver if the user did not take their medication after several prompts. We received conflicting suggestions when we discussed these two scenarios with our study participants. Some participants wanted to intervene earlier than others. Deciding on when the system would intervene appears to be a subjective matter that needs to be decided by the senior and their caregiver. Therefore, an SSHS should allow for end-user customization.

5.7.4 Safety vs Privacy

At the end of every interview, we explained to every participant how IoT devices work and the type of data collected. In addition, we explained the importance of protecting the user's privacy. In order to assure the user's safety at home, an SSHS should be able to collect data using sensors which could eventually breach the user's privacy to a certain extent. All of our study participants reported that safety is more important than data privacy in the context of homecare. This statement was expected from the caregiver participants as they tend to worry about the safety of their loved ones. When we asked our senior participants, they reported the same perspective. While this is not a statistically representative sample, this attitude towards assistive technology can be justified when we compare SSHS and other conventional care options such as hiring an assistant or moving to a senior's facility.

According to one of our senior participants, *"I think safety rises over the privacy in this scenario. Especially if there is something that could lead to a dangerous situation like if her lack of sleeping could lead to more depression or more serious issues, then yes, we need to track it."*. Other study participants stated it *"I think safety should always come first! I would hope the family, if there is a bunch of siblings, someone should be appointed as the decision maker and from there they should support decisions made by the decision maker"*.

As we can see in the above quote, deciding to adopt a SSHS should always be a family decision. However, seniors can still legally provide their consent and make their own decisions at an early stage. Therefore, explaining the risks and rewards while designing SSHS at the highest level of data security is an essential requirement. For example, according to one of our senior participants who is also a caregiver to their spouse, *"No, I do not think that would be invading someone's privacy [by using remote monitoring]. However, I think the other person has to agree"*.

The findings discussed in this section indicate a positive attitude towards smart home technology despite the data privacy concerns. However, it is important to acknowledge that these opinions can be biased due to presenting smart home technology as an alternative to the less preferred options (senior facilities, nursing homes, etc.). A primarily online search for literature studies revealed papers that contradict the opinions that we gathered. For instance, in their discussions about data privacy, researchers in [EQH18] concluded their study with the following: *"A large number of older adults are marginally concerned, as they see their online participation as limited and harmless. Older adults were also grouped as either intense or relaxed pragmatists. We find that older adults across several categories share some privacy concerns, the most common being spam, unauthorized access to personal information, and information misuse"*. It is worth noting that the scope of this paper was not about the data privacy aspect of supportive smart homes. As for this PhD thesis, we highlight the importance of this topic and suggest further exploration by specialized data privacy researchers in future research.

5.8 Limitations

We limited our recruitment to three participant categories; SwNCDs, and informal and formal caregivers. Other types of formal caregivers did not join our study, such as occupational therapists and home assistants. In our study, we only recruited nurses; that is not to say occupational therapists and home assistants were intentionally excluded. The study findings were limited to six interviews and one site visit.

Lastly, the thematic analysis in this study was performed by a solo researcher; thus, all findings were extracted from scripts based on the researcher's interpretation. While following Braun and Clarke's guidelines for conducting thematic analysis streamlines the process, it does not wholly remove researcher bias [BC06]. Therefore, this method of analysis could impose a threat to the validity of the study findings.

5.9 Conclusion

This chapter discussed in detail a requirements elicitation study conducted over six interviews with one male and five female participants. Furthermore one site visit to a senior couple was facilitated for fly-on-the-wall observations. The study included seniors, and formal and informal caregivers. The thematic analysis method was used to analyze qualitative data. The analysis resulted in four main themes and multiple sub-themes; common issues, desired system features, system requirements, caregiver worries and coping mechanisms. Some of the important findings of this study are: a list of common issues that seniors and caregivers face at home desired system features, and system requirements.

When discussing these findings, it was clear that not all issues reported by the study participants can be addressed using a SSHS. Therefore, this chapter argues that a SSHS should support two user categories; seniors and their caregivers. Thus, the system should support two user modes; senior user mode and caregiver mode. The main purpose of the caregiver mode is to set up, customize and re-configure the system preferences when needed. More importantly, this mode should allow caregivers to monitor certain tasks/activities and intervene when needed.

The senior mode, on the other hand, is what the seniors use would experience in their daily lives. As was discussed in the previous section, our vision for a SSHS includes using MR for senior user interactions. This allows the user to interact with the system in an immersive fashion anytime and anywhere as long the device is worn.

Based on discussions in this chapter, the system should provide the user with three levels of intervention; sending reminders, tailored memory prompts and, taking actions. While these three options appear to be clear from a theoretical perspective, designing immersive reminders and prompts is a relatively new concept. To the best of our knowledge, there has not been any reported research work in this regard. While understanding the system requirements is essential for developing elementary prototypes, a significant focus is required to investigate how to design proper immersive user interfaces and user experiences tailored for SwNCDs. In the next chapter of this thesis, an early vision of an immersive IoT-based system prototype concept is introduced based on the findings of this study.

Chapter 6

Prototyping process

6.1 Chapter overview

This chapter presents the design and development of the initial system prototype. The chapter starts with a discussion of the selected two use cases, and it explains the rationale behind choosing these two cases. In the following section, a user persona is presented and discussed in detail. After that, the three system functions are presented; activity monitoring, reminding, and memory prompting [1]. The user flow of both use cases are discussed in detail in the following section, including detailed illustrations of the main user experience events, attention triggers and system actions. The last section describes the video prototypes production.

6.2 Use cases

In Chapter 4 and Chapter 5, we presented the first phase of the User-Centered Design (UCD), a systematic literature review and requirements elicitation study in which we dis-

[1] Parts of this chapter were copied from Alabood, L., & Maurer, F. (2022). An IoT-based Immersive Smart Home System for Seniors with Neurocognitive Disorders. In proceedings of the 3rd International Workshop on Empowering People in Dealing with Internet of Things Ecosystems, co-located with the AVI conference, Italy. According to the copy rights agreement, the authors reserve the right to copy or use the paper materials in other publications

cussed special requirements for designing SSHS requirements. In addition, we identified 23 common issues that SwNCDs aging in place and their caregivers face at home. These issues were broken down into three main categories: daily living, health, and personality changes related issues.

In this research phase, we will reflect on findings from the previous two studies to introduce an initial system prototype. The first step was to select two use cases (scenarios) to address in our system prototype. We decided to address two important issues; medication reminding and cooking safety. We selected these two cases for multiple reasons, which we summarize as follows:

1. According to our findings in the requirements elicitation study, these are the first two problems to appear among SwNCDs despite the type and stage of illness.

2. While some issues were raised by only caregivers or by only seniors, missing medication and cooking safety were a mutual concern.

3. These two issues directly affect the quality of life and the health of SwNCDs. Supporting seniors to take medication on time reduces the likelihood of developing serious health issues due to medication mismanagement (e.g., eye infection due to missing eye drop medication). Allowing seniors to prepare a meal safely improves their sense of independence.

4. In our discussion with caregivers about their constant worries when leaving their loved one/client alone at home, both of these issues were raised as the top two sources of worry.

5. The lessons that will learn from these two cases can be applied to other issues such as food reminding, drinking water, completing home exercises, wandering, and finding personal items at home.

6. When reflecting on our findings from the systematic literature review, we identified 30 SSHS concepts in the 'monitoring' category, while we only identified 10 studies in the 'supporting and assisting' category. This indicates an apparent lack of SSHS for directly supporting seniors and caregivers.

6.3 User persona

Using personas in Human-Computer Interaction (HCI) research is a powerful tool for creating a user character based on a user research. This character represents multiple aspects from different user research study's participants [CMS14]. Developing user personas is often executed during the second phase of the UCD process to guide the ideating and prototyping stages. Lene Nielsen, who specializes in personas in the context of computational design, identifies three types of personas: goal-directed, role-based, engaging, and fictional [Nie13]. Among these three, the goal-directed persona is the most suitable for this research as it is based entirely on user research data.

Initially, we develop a goal-directed persona for a SwNCDs living at home with his son, who often needs reminders to take his medication. In addition, he tends to forget the stove on. Before the ideation and prototyping stages, we reviewed the initial persona with one informal caregiver and one senior. The informal caregiver was middle-age lady who cared for her father who lives with a mid-stage dementia, whereas the senior participant was newly diagnosed with MCI. To reduce biases, both participants did not participate in the requirements elicitation study, and thus, they were unaware of its findings. After two iterations, we arrived at the persona that we summarized below. For a full persona description, please refer to Figure 6.1.

The story of Mark:

"Mark is a 70-year-old biology teacher from Calgary. At age 64, he retired and decided to go on a long trip to Alaska with his wife. Sadly, after coming back, his wife passed away.

Ever since, his son Bob, who lived in Edmonton, started to visit him in Calgary monthly. Bob started to worry more about Mark living alone, especially after he noticed how forgetful he became. Eventually, he managed to relocate to Calgary to live with his dad. Three months later, Mark was diagnosed with early-stage Dementia. Among a few issues that started to appear after the diagnosis, Bob was most concerned about Mark's medication. He was especially concerned since Mark had to take his antidepressant and a daily blood thinner pill to prevent a second blood clot. Bob knows how much Mark loves to cook, so he was also concerned about the stove situation, as it had happened a few times now that Mark had left the stove unattended. Luckily, when the smoke alarm went off, he could react".

6.4 System functionality

According to our systematic literature review study findings, SSHS offers three main functions: monitoring, supporting and assisting, and emergency response. In addition, findings from the requirements elicitation study suggest that SwNCDs and caregivers are interested in a SSHS concept that provides activity monitoring and promptings. Based on that, the initial design of our SSHS will support these desired features. In this PhD research, however, we introduce a novel approach to using immersive Mixed Reality (MR) technology for senior user-system interactions. In addition, we focus on the role of the caregiver throughout the entire system design.

6.4.1 Activity monitoring

As discussed in Chapter 4, supportive smart homes monitor residents' activities using ambient or wearable devices. In order to respect the user's privacy as much as possible, we rely solely on ambient IoT sensors and Apple Watch. This means the system will not collect audio/visual data. All IoT devices are connected to a local server running a HomeAssistant operating system (more on this in the System Architecture section in this chapter).

Figure 6.1: User persona (source of photo, free photos website: https://www.pixabay.com)

Caregivers can monitor medication intake and cooking activities via HomeAssistant mobile application. The user interface of the mobile application is fully customized. Accounting for caregivers with different technology literacy backgrounds, we designed the application homepage to display a map of the house and icons representing the medicine dispenser and the stove. Clinking these icons shows the device status and its usage history for the past 24 hours. For the stove, caregivers can use the toggle switch on the mobile app to turn it off remotely. See Figure 6.8, image D for the mobile app screenshot.

6.4.2 Reminders

The proposed design allows the system to send short and simple reminders when it is time to complete a task (taking medication) or to bring the user's attention to a running device that could lead to a dangerous situation (the stove in our case). The reminder is the first event fired by the system. These reminders are simple and brief.

6.4.3 Memory prompts

Memory prompts are system events triggered if the user does not respond to the system sending reminders. The purpose of these prompts is to provide objective instructions to the user on how to complete a task. Therefore, these prompts are dynamic and situational; they provide information to the user based on their location at home and the task they are supposed to complete. The system prototype will provide the user with visual, recorded videos and interactive augmentation memory prompts in our proposed design.

To better understand the nature, design and sequence of these prompts, we need to discuss them in the context of each user scenario. Therefore, a following section of this chapter discusses the user flow for each scenario in detail.

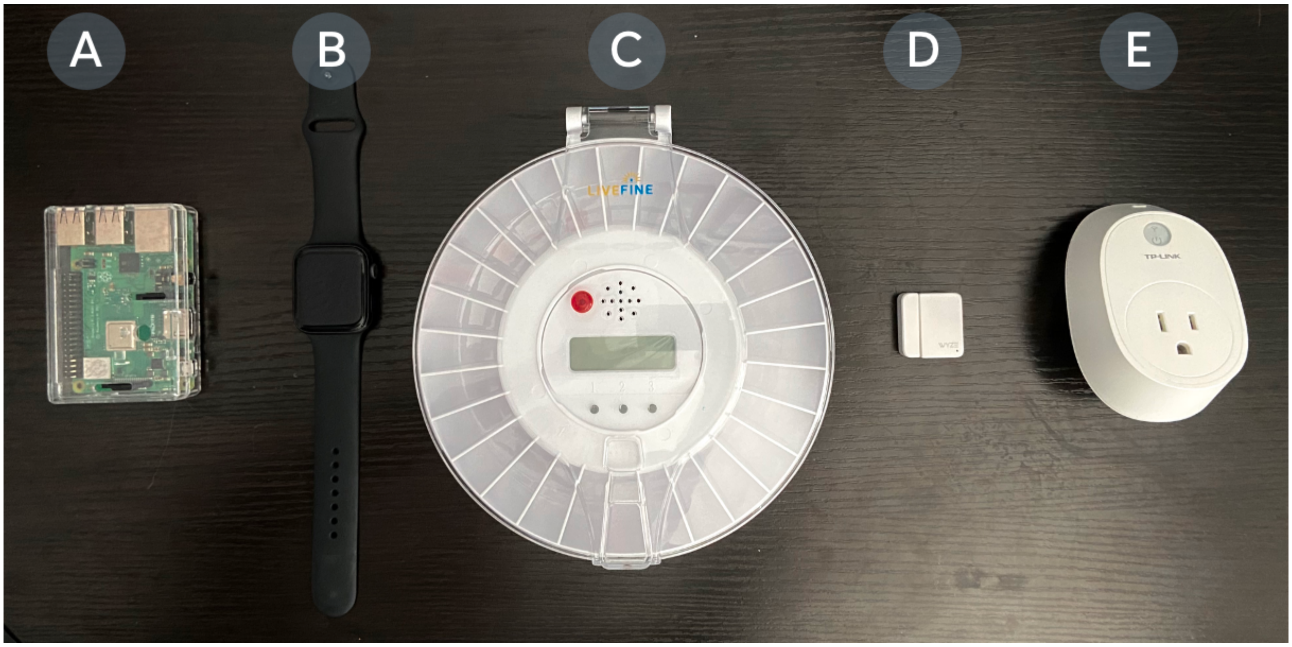


Figure 6.2: Devices used from the left to right. A) RaspberryPi microprocessor, B) Apple Watch, C) LiveFine medicine dispenser, D) Wyze break-beam sensor, E) TP-Link smart plug

6.5 System architecture and used devices

We used an open-source smart home operating system called HomeAssistant[2] running on a local server using a RaspberryPI[3] microprocessor. HomeAssistant comes with 1952 built-in 'Integrations' to connect with almost any commercially available IoT device. A primary benefit of this system architecture is to have a single platform for managing and monitoring the entire smart home system.

To address our two use cases, our system prototype utilized one Wyze[4] magnetic sensor attached to a motorized pill dispenser with 30 slots, allowing for only taking one dose at a time. The Wyze sensor tracks the usage of the dispenser. We also used a smart LED located above the pill dispenser. Moreover, an Apple Watch to track the user's sleeping status and to send vibration signals to capture their attention when needed is used. For the cooking safety scenario, we used a TP-Link smart electricity plug with electric current

[2] https://www.home-assistant.io
[3] https://www.raspberrypi.org/
[4] https://www.wyze.com

measuring capabilities to monitor and manage stove usage, see Figure 6.2 for pictures of the used devices.

Using HomeAssistant, we created automation recipes following simple if-this-then-that logic. In some cases, we wrote YAML scripts to create more complex automation related to monitoring IoT devices' status, firing different system responses and sending messages to the caregiver in the case of incomplete tasks. The HomeAssistant comes with a customized smartphone and an Apple Watch application. Accounting for various caregivers' technology literacy backgrounds, we customized the HomeAssistant mobile app homepage to display a house map with icons representing the stove and the pill dispenser. Taping on these icons would display more options—the local server exchanges data with an MR application via a single REST API. Figure 6.3 illustrates the proposed system architecture.

6.6 User scenarios

We heavily relied on our findings from the requirements elicitation study and the persona to develop the initial system prototype below. We made several UX design decisions to address some of the special requirements of NCDs that we identified in Chapter 5.

In UX research, there are two ways to present the user-system interactions: task flow and user flow. The task flow is usually straightforward and describes a one-direction flow of action (beginning to end). On the other hand, the user flow describes all potential user interactions and allows for branches (forks) in the flow [df20]. Typically, user flow maps look more complex but provide a complete image of all possible interactions. In this thesis, we present user flows only, as our intended end-users might respond differently every time they interact with the system. Thus all potential interactions should be reviewed carefully. Our proposed user flow consists of two main types of events: attention attraction and action delivery.

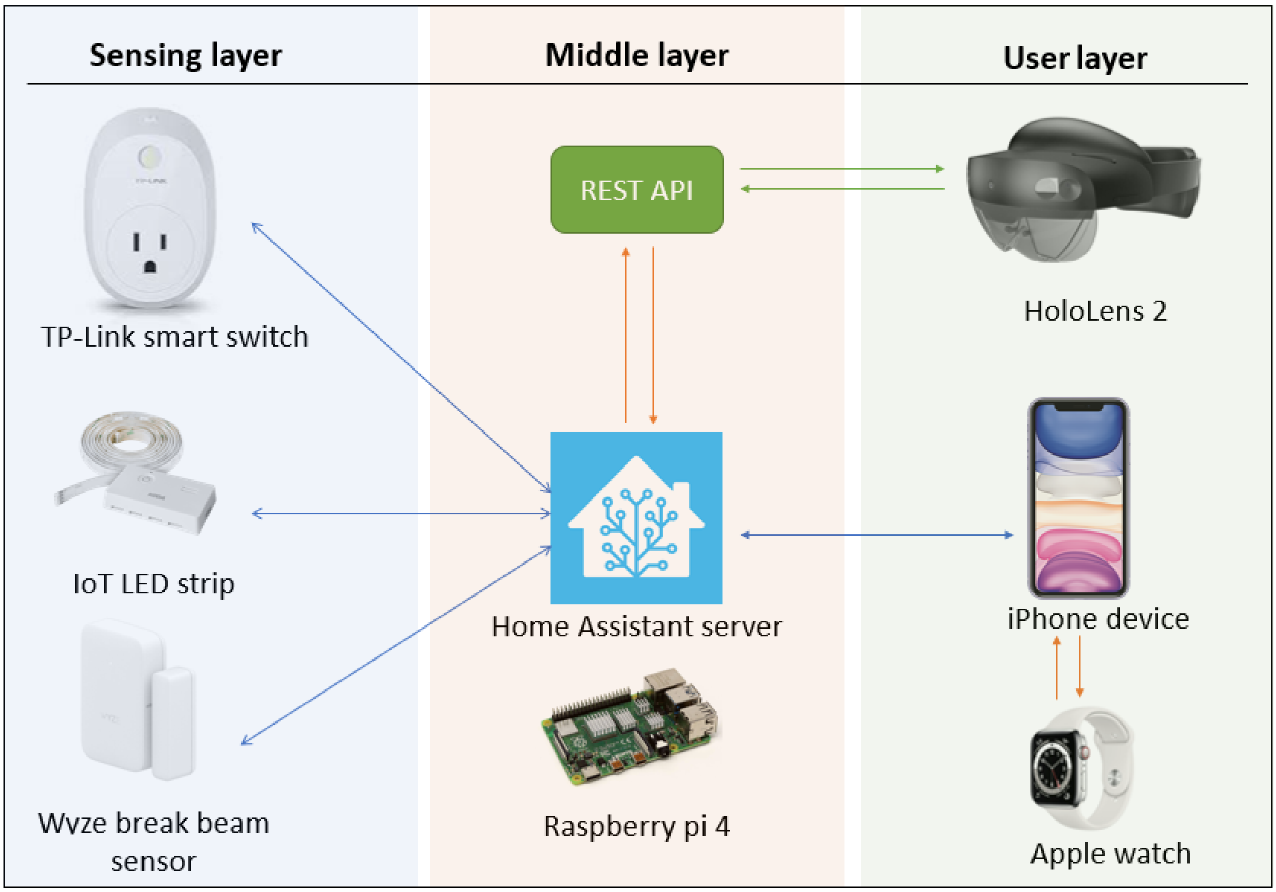


Figure 6.3: System architecture: all IoT devices connected to the local server which in turn exchanges information with the intended HoloLens app via a REST API. The local server runs a HomeAssistant operating system which supports a mobile and Apple Watch application

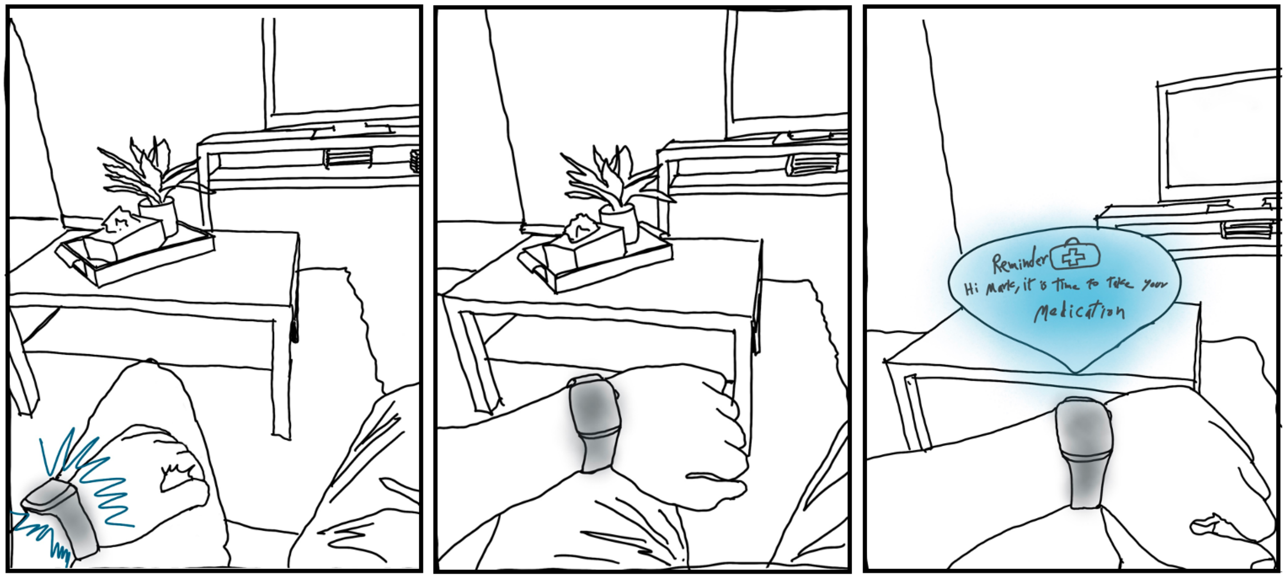


Figure 6.4: Hand sketch illustrating the attention attracting sequence, from left to right; A) Apple Watch vibrates first, B) attracts the user attention, C) a hologram is displayed above the wrist

6.6.1 Scenario one: medication reminder user flow

Attention Attraction

The system attempts to attract the user's attention to deliver either a reminder or a memory prompt. This event is fired at the beginning of every interaction. Ar first, the system sends a vibration signal to the Apple Watch to provide the user with a form of a haptic signal before displaying a message above the wrist area. As reported in Chapter 5, SwNCDs might suffer a slight neurodelay, and they tend to get confused with quick events; therefore, sending this vibration signal then displaying the hologram might gives them enough time to gather their attention and process the information. We assume that the typical and expected user response to the vibration signal is to look at the Apple Watch. Repeating the same sequence (vibration signal then smart home event) can establish a new user habit which is a key factor for successful adaptation [HSKW07]. Lastly, displaying these reminder messages near the wrist does not block the user's vision allowing for safe movement. See Figure 6.4 for the attention attraction illustration.

The augmentations reminders are only visible if the user is looking towards the watch. The content of these reminders includes text, icons, sounds, and video messages. The system will send multiple prompts in various fashions to remind the user to take their medication. If the user is not wearing their MR headset, a flashing LED light above the medicine dispenser is used to attract attention. Figure 6.5 presents user flow in detail. If the user ignores all prompts, the system will automatically escalate to the caregiver by sending a message to their HomeAssistant mobile application.

Delivering actions

The system will consistently check if the user completed the task (in this case, the task is to take the medication). The second course of actions after the reminders would be a memory prompt. In our initial design, we proposed the following flow:

1. If the user did not respond to the first reminder, the system will send a second reminder, and the augmentation message will be displayed for a longer time.

2. The next step is to display a recorded video message of the caregiver reminding the senior where and how to take their medication.

3. After two minutes, the system will automatically start flashing the LED light above the pill dispenser.

4. If the user does not ignore the prompt and walks towards the dispenser, every time they look in the direction of the dispenser, an augmentation message is displayed above the dispenser to help guide them.

5. If the user is near the dispenser but did not use it, the system will interpret this as the user either forgot what to do, and it will display a video on top of the dispenser; it is a video of the caregiver providing instructions on how to use the dispenser.

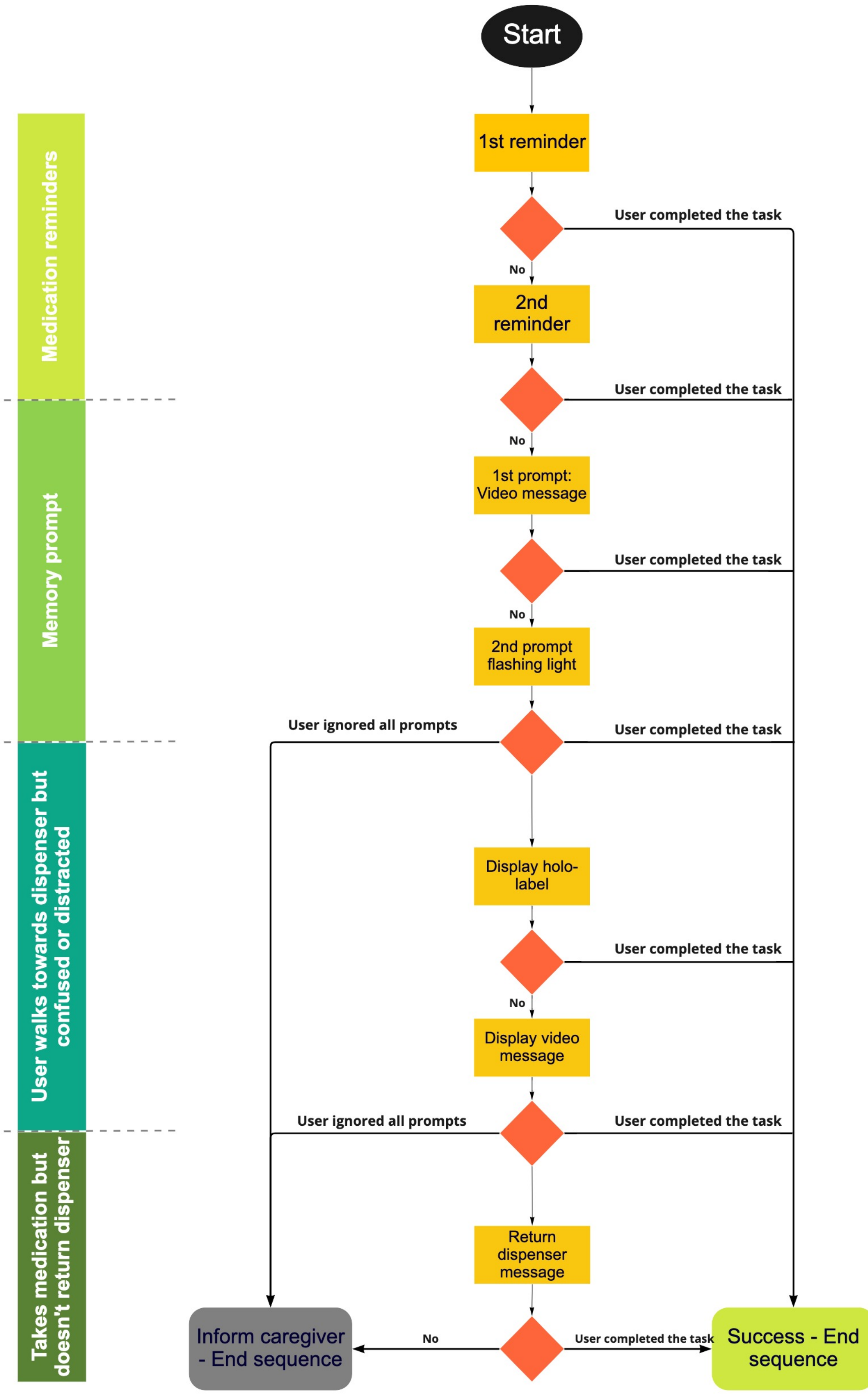


Figure 6.5: User flow diagram for the medication reminder scenario

6. If the user ignores all of these prompts, the system will notify the caregiver via their HomeAssistant app.
7. If the user does not ignore the prompts, picks up the dispenser, and takes the medication but does not return it, the system will display an augmentation prompt asking the user to return the dispenser.
8. If the user does not return it, the system will display a video message by the caregiver giving directions on how to return the dispenser.
9. Failure to return the device will inform the caregiver via their mobile phone application.

6.6.2 Scenario two: cooking safety

For the UX design to be consistent, we used the same attraction-delivery model. Two additional events were added to this scenario. First, if the user does not walk to the stove and turn it off, the system will project a big holographic pressable button to turn off the stove remotely. Second, the design also accounts for the possibility of the user turning on the stove, going to bed, and taking off their MR headset. These additions are discussed in the following subsection and presented in the user flow, see Figure 6.6.

Attention attraction

The attention attraction model used in this scenario is similar to the medication scenario. However, the system accounts for the possibility of the user taking off the MR headset. In this case, the system will send a long vibration signal to the Apple Watch with a simple short message, followed by a single button on the Apple Watch screen to turn off the stove remotely. Although it is possible to introduce more Apple Watch events, we decided to reduce the user interactions due to the small screen size and the high possibility of committing errors.

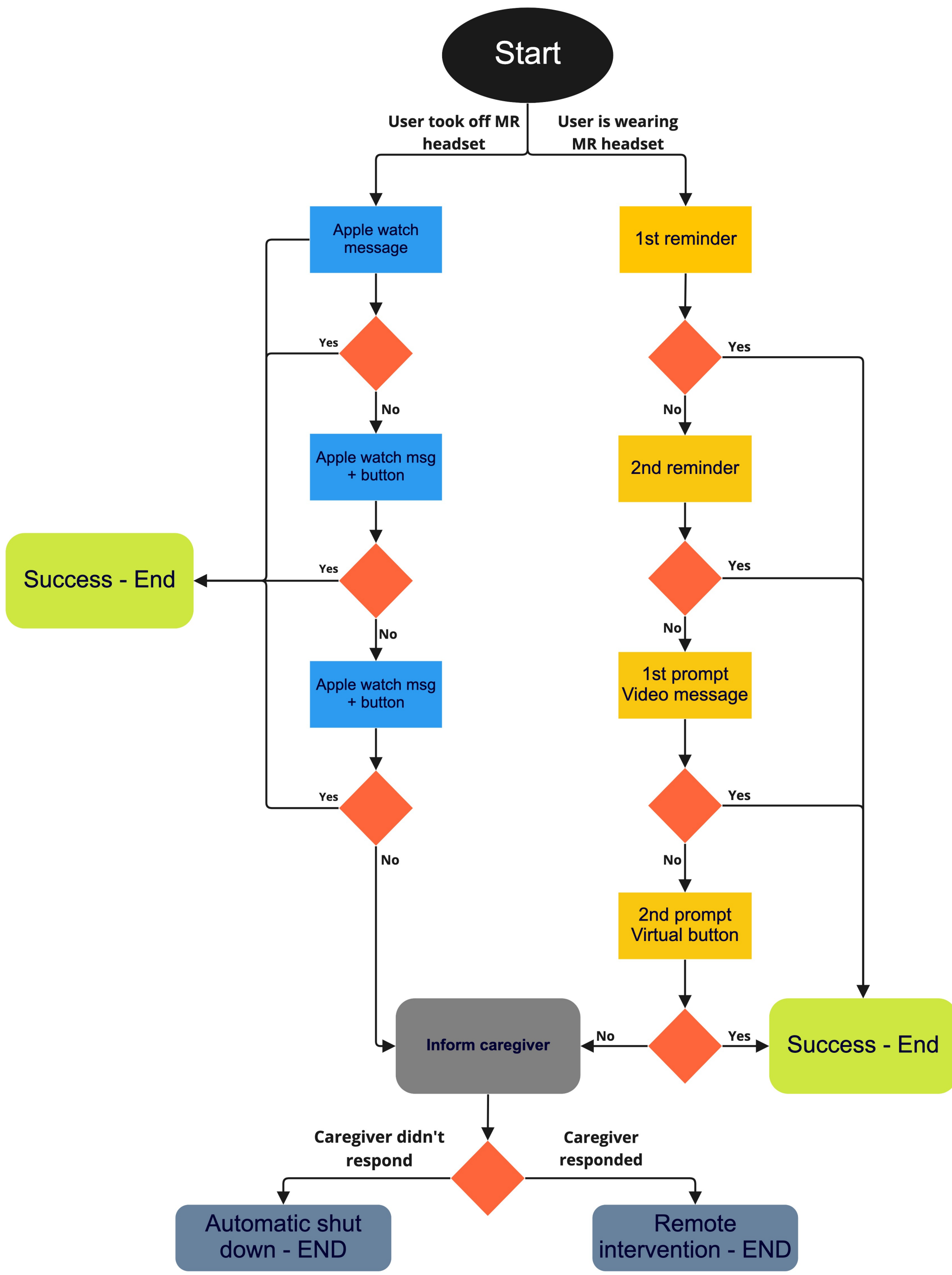


Figure 6.6: User flow chart for the cooking safety scenario

Delivering action

The sole purpose of all the reminders in this scenario is to keep the senior safe. Respecting the user and maintaining a sense of agency are at the center of the proposed user flow. The system or caregiver interventions are executed only when the user's safety is at risk. These design decisions align with our findings in the requirements elicitation study. The proposed user flow accounts for two possibilities: first, the user is awake, and second, the user is asleep / took off the MR headset.

A) The user is awake

1. If the stove is running for 30 min, the system will send a reminder.
2. After 30 minutes, the system will send another reminder.
3. If the user looks towards the stove, a memory prompt will be displayed above the knob.
4. After 10 minutes, the system will display a video message above the wrist showing the caregiver demonstrating how to turn off the stove.
5. After 5 minutes, the system will display a big virtual button in front of the user to turn off the stove remotely in front of the user.
6. If the user does not turn off the stove, the system will send an urgent message to the caregiver's app. The caregiver can call the senior user and ask them to turn off the stove or turn it off remotely.
7. After 10 minutes, the system will turn it off automatically if the stove is not turned off by the senior or the caregiver.

B) The user is asleep or took off the headset

1. After 5 minutes, the system sends a long vibration signal to the Apple Watch and displays a short message 'the stove is on.'

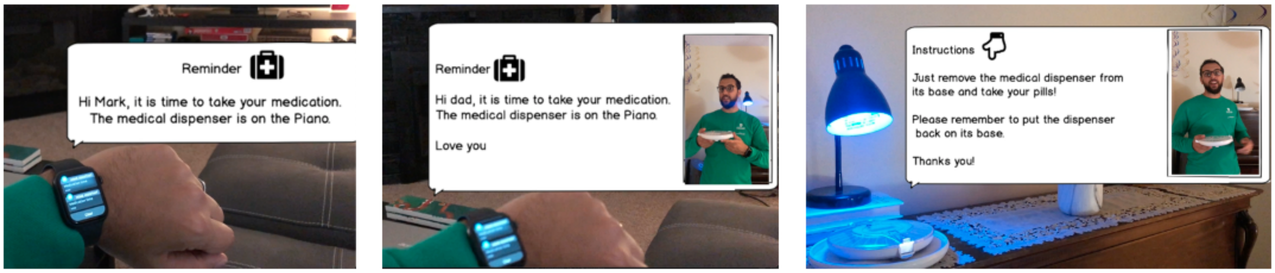


Figure 6.7: Screenshots of the video prototype. a) user receiving an augmentation reminder, b) video message showing a family member, c) flashing light and a video message to remind the user to return the dispenser

2. 5 minutes later, the system sends a prompt to the Apple Watch with a single button on the screen to turn off the stove.

3. After 5 minutes, the system will display the prompt again.

4. If the user does not turn off the stove, the system will notify the caregiver via their mobile app. If neither the caregiver nor the senior turn off the stove. The system will shut it down automatically.

6.7 Video prototypes

As was described in the system architecture section, connecting all IoT devices to the Home-Assistant server allowed us to customize all the required automation recipes using Home-Assistant's interface or via YAML scripts. Using the REST API (application programming interface), the HomeAssistant can share IoT device and automation status with external resources such as the HoloLens application. The next step was to develop a client runs on HoloLens to retrieve smart home information via the REST API.

We used Unity[5] game engine, Best HTTP library and C# programming language to develop the client application. The back-end part involved developing three classes; API manager, device manager and status manager. In this part of the thesis, we will stop at this

[5] https://unity3d.com/unity/whats-new/2020.3.0

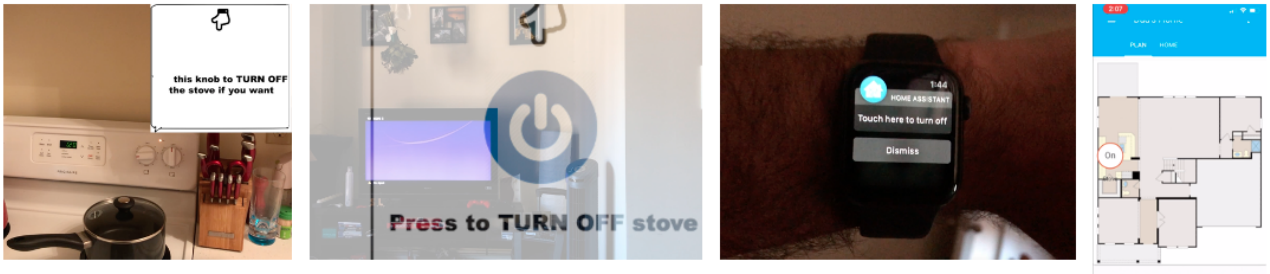


Figure 6.8: Screenshots of the video prototype. a) Memory prompts showing the user how turn off the stove, b) virtual button, c) the user receives a message on Apple Watch when taking off MR glasses, D) screenshot of the caregiver mobile app

brief description of the back-end work.

After building the back-end component of the HoloLens application on the Unity game engine, the plan was to develop the front end (the immersive user interface) and conduct an initial user evaluation to collect user feedback about the system design. However, due to the COVID-19 restrictions starting in Winter 2020, conducting in-person studies with senior citizens was not possible. To avoid unnecessary front-end development, we used a head-mounted camera to video record all possible interactions between the user and the system to create video prototypes instead. While recording these videos, we used the Wizard of Oz method [DJA93] to simulate the system responses to the user; the system responses were manually fired using command line codes or via the HomeAssistant web interface. Then we used a GUI prototyping software called Balsamiq to create visual UI elements such as messages and icons. Finally, with the help of video editing software (iMovie), we added these UI elements to the recorded videos.

After several iterations, we arrived at the final video prototypes; see Figures 6.7 and 6.8 for screenshots from the video prototypes. This agile technique increased the efficiency of the prototyping process by avoiding unnecessary front-end work at that stage when in-person user evaluation was not possible [ULH21, WMVW+17]. In the MR literature, video prototypes are becoming more common such as in [VSMW20]. However, researchers in [LNKA20] argue there is a lack of MR prototyping and design review techniques. The papers introduced PRONTO tool to help AR developers to create rapid AR prototypes and record videos to present UX design to team members and stakeholders. In our case, we used the video materials to obtain a research ethics approval to conduct an online Design Critique study with human subjects, which we will describe in detail in the next chapter.

6.8 Conclusion

This chapter discussed in detail the initial system prototype development. The current prototype addressed two use cases: medication reminders and cooking safety. These two cases were selected based on reflection from a previous systematic literature review and requirements elicitation studies. In addition, based on previous findings from the studies mentioned above, the system supports three main functions: activity monitoring for the caregivers, reminders, and memory prompts for the senior users. The caregivers interact with the system via a mobile application while seniors use an MR headset. The user-system interaction was discussed thoroughly, and design decisions were explained in this chapter. The current user flow consists of two major events: attention attractions and action delivery. After completing all back-end development work, the system prototype runs using a set of IoT devices and a local server. Due to the COVID-19 pandemic, it was not possible to evaluate the initial prototype in-person. Therefore, we proposed producing video prototypes presenting all possible user-system interactions from a first-person perspective. These videos were then used to evaluate the initial system design in a Design Critique study described in the next chapter.

Chapter 7

Prototype evaluation; a Design critique study

7.1 Chapter overview

This chapter presents the process of evaluating the initial system prototype. The Design Critique (DC) method - an evaluation method widely common in engineering and architecture - is used to conduct a remote prototype evaluation study. In order to streamline the DC process, a process of 10 steps is implemented and broken down into three phases; preparation, running DC sessions, and post-processing. Each of these steps is discussed in detail. Finally, this chapter presents the 24 study participants, discusses their backgrounds and affiliations to caring for SwNCDs. Notably, many participants played more than one role, such as being a formal and an informal caregiver simultaneously.

7.2 The Design Critique method

Collecting feedback is an integral part of any design process, especially in domains where creativity is essential, such as engineering, education, and architecture [HFP11, SRH+15, WML+09]. The Design Critique (DC) is one of the most common methods of collecting feedback from stakeholders and experts. Typically, collecting feedback includes participants from two major categories; end-users and experts, allowing designers to view design matters from different perspectives. This approach is believed to reduce costs and efforts by eliminating design issues as much as possible before moving to the testing, and implementation phases [BLRS07]. Integrating the DC method into the UCD process can improve systems' design by ensuring that prototyping and development are not completed blindly [RDAS16][1].

For instance, in architectural design, the DC is conducted with the client, potential users (e.g. company employees, workers, etc), and then with experts such as architects, civil, electrical and mechanical engineers. Then, after several critiquing rounds, the project moves to the implementation phase [DM08].

The HCI community has highlighted the importance and benefits of DC for HCI [FDB+11, SCF08]. The COVID-19 pandemic shed more light on the significance of remote design evaluation methods. A major benefit of remote DC studies is the accessibility to study participants beyond one geographical location. For instance, researchers in [RSK+11] described using the DC to evaluate the User Interface (UI) design of a smart home deployed in the TigrePlace assisted living facility in the USA. Another example in [AWW+22] presented important findings about evaluating a Virtual Reality (VR) system for neurosurgeons through a remote DC study.

As it was discussed in Chapter 3, we systematically surveyed the HCI literature to extract a generic DC process. Our generic DC process consists of ten unique steps broken down into three main phases: preparation, running DC sessions, and post-processing; please refer to Figure 7.1 for details. This systematic literature review study was submitted to the Information and Software Technology journal and is currently under the second review round. A copy of the study abstract is attached to Appendix A. In the following section of the chapter, we discuss how we implemented each of these 10 steps.

[1]Parts of this chapter are extracted from paper submitted to the Journal of Information and Software Technology. All authors of the paper approved using the paper materials in this thesis. Please refer to Appendix A for details

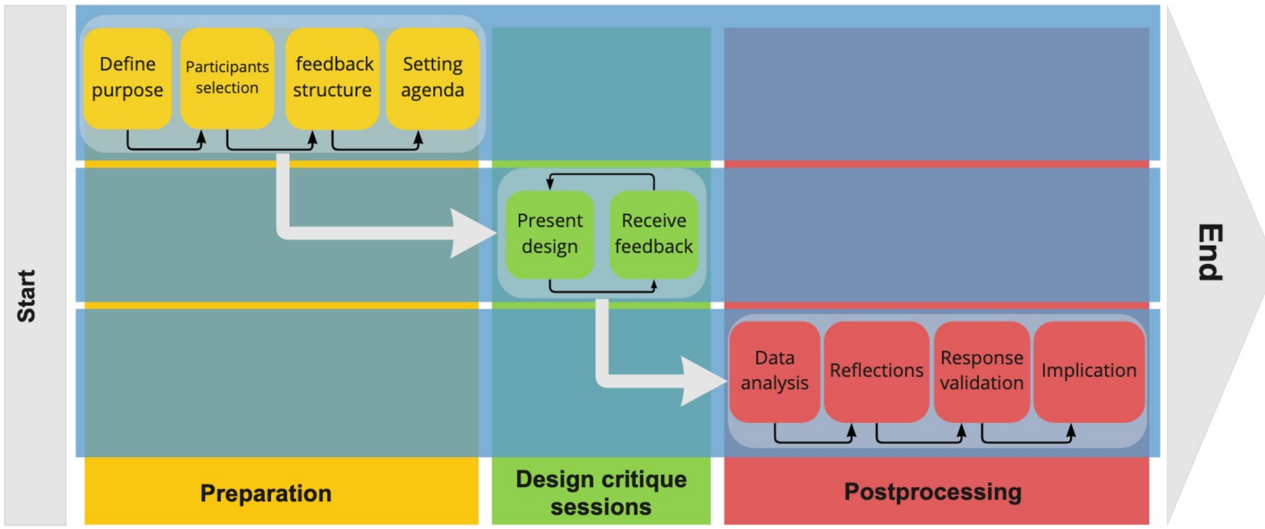


Figure 7.1: The Design Critique process used in the study

7.3 Prototype evaluation

7.3.1 Preparation phase

Step one: Define the purpose

The purpose of this study is to evaluate our initial system prototype design by collecting feedback from multiple participant categories. In addition, this study aims to extract recommendations for designing an immersive supportive smart home system for SwNCDs. Finally, these newly extracted recommendations will be used to reiterate our system design and propose a final high-fidelity system prototype.

Step two: Participants selection

As mentioned earlier, DC allows collecting feedback from various participant categories. In this PhD research, we recruiter SwNCDs, formal and informal caregivers, and domain experts (other researchers and industry partners). In addition, we propose conducting a round of sessions with XR developers. This round aims to discuss best practices and recommendations for developing MR applications for SwNCDs using the Microsoft Mixed Reality Toolkit and the HoloLens2. Chapter 8 presents findings from these two rounds.

With the help of Age Well NCE and Dementia and Alzheimer's societies, 24 participants across Canada and the US joined the study. Table 7.1 presents the breakdown of participant categories. Most study participants identified as were females. The average age for senior participants ranged from 65-85, within a total of seven participants. We had ten informal caregiver participants, including spouses and children. In the formal caregiver category, 5 participants included three nurses, one occupational therapist, and one social worker. The domain expert participants comprised one technology researcher, one commercial assistive technology developer, and one extended reality enthusiast. Finally, six academic MR developers with recent and ongoing industrial experience joined the study as technical experts. While the total number of participants is 24, it is notable that many participants played two or more roles. For instance, participant P4 is a retired social worker and senior aging in place while providing caregiving for her husband. Another example is participant P3, an 85-year-old senior, enthusiastic about introducing XR applications to fellow seniors. Figure 7.2 presents the ration of study participants based on their background. This diversity in participant backgrounds and roles allowed for collecting additional insightful qualitative feedback.

Step three: Deciding on feedback structure

All design critique sessions were conducted remotely via Zoom. Each session consists of three main activities: presenting design, reviewing design elements, then a semi-structured interview. All sessions were video or audio recorded and stored on a secure cloud solution.

Step four: Setting agenda

Before starting any session, the participant received a study description and a consent form. If the participant did not sign the consent form and sends it via email, the consenting took place at the beginning of the Zoom call and was video recorded. All sessions started with

Table 7.1: Overview of the study participants

Participant	Age	Sex	Location	Senior citizen	Informal caregiver	Formal caregiver	Domain expert	MR developer
P1	30-40	Female	Montreal			Yes	Yes	
P2	30-40	Female	Calgary				Yes	
P3	80-90	Male	Calgary	Yes			Yes	
P4	70-80	Female	Toronto	Yes	Yes	Yes		
P5	30-40	Female	Calgary		Yes			
P6	40-50	Male	Calgary		Yes			
P7	60-70	Female	Louisville	Yes				
P8	50-60	Female	Montreal		Yes			
P9	80-90	Female	Calgary	Yes	Yes			
P10	30-40	Female	Calgary			Yes		
P11	60-70	Female	Calgary	Yes		Yes		
P12	70-80	Female	Vancouver	Yes	Yes			
P13	40-50	Male	Edmonton		Yes			
P14	60-70	Female	Calgary	Yes	Yes			
P15	30-40	Female	Calgary		Yes			
P16	40-50	Female	Calgary		Yes			
P17	60-70	Female	Ottawa	Yes		Yes		
P18	40-50	Female	Calgary		Yes			
P19	20-30	Male	Calgary					Yes
P20	20-30	Male	Calgary					Yes
P21	20-30	Male	Calgary					Yes
P22	20-30	Female	Toronto					Yes
P23	20-30	Female	Edmonton					Yes
P24	20-30	Female	Calgary					Yes

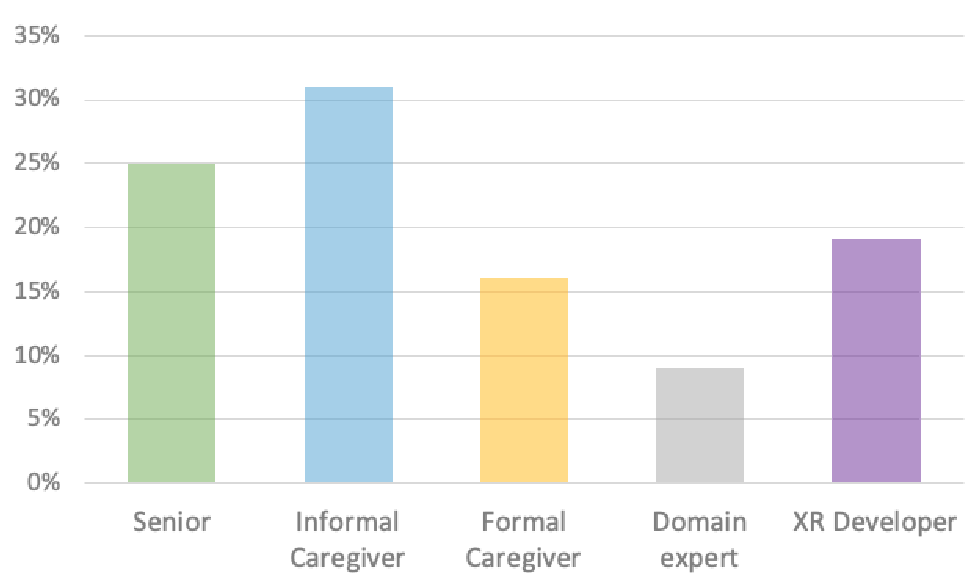


Figure 7.2: Participant category ratio based on their backgrounds

the same opening questions, such as asking about the participant's affiliations to SwNCDs and their experiences. Next, we asked if they have ever used any form of extended reality technology or if they have used any smart home devices at home. The session's next part revolved around presenting and discussing the video prototypes.

7.3.2 Running design critique sessions phase

Step five: Presenting the design

Before playing the video prototypes, participants were briefed about MR technology and how a user would interact with a smart home system via a head-mounted MR application. The most important idea communicated to the participants was that the video they were about to watch is a first-person perspective video displaying what the senior user would experience when wearing the MR headset. We first started with the medication reminding video prototype. After the participants watched the video, we asked if they had any questions and if they fully understood the content. Thereafter, we would replay the video and discuss specific aspects of the User Experience (UX) and the User Interface (UI) design. In total, we conducted 24 DC sessions with study participants across Canada and the USA, more on the study participants in the following section.

Step six: Receiving feedback and discussions

Various UX and UI elements were discussed, including scenario realism, memory prompt types, system interventions, UI language, visual design elements, and more. We invited participants to assist in our design process by asking them to describe three changes they would like to see in our next design iteration. Lastly, we addressed topics related to the overall experience of aging in place and how our suggested system could improve users' sense of safety, independence, and agency.

We used semi-structured interview questions to initiate a discussion. New questions were regularly added as we learned new and interesting information from previous participants.

The interview questions were completely different in the MR developers' DC round, where the questions were more concerned with the technical aspects of the system. Below is a small sample of the session questions; for a list of all questions, please refer to Appendix D.

- To what extent do you relate to the scenario in the short video? How accurate is this scenario? What should we change to make it more realistic?
- What are your thoughts on the notification style and intervention levels? How appropriate is the chronological order of the events scheme in our prototype design?
- What are your thoughts on the visual design of the reminder message?
- What do you think of the system language? For instance, do you find the sentences too long? What do you think of the terminology used?
- If you were to change three things about the user interface design, what would they be? And what would you do differently?

7.3.3 Post processing phase

Step seven: Data analysis

All design critique sessions were video recorded via Zoom and saved on a university secure cloud solution. Each session was transcripted in the form of a dialogue and imported as a case into NVivo software to conduct Thematic Analysis. Chapter 8 describes the entire thematic analysis process in detail.

Step eight: Reflections

In this study, we reflect on the analysis findings and propose two main discussions of the results. The first discussion concerns the relationship between the analysis findings and the study participants. For instance, what UX design recommendations did the senior participants provide? The second discussion attempted to explain the relationships between NCDs-related issues and the newly extracted design recommendations. Please refer to Chapter 8 for details.

Step eight: Response validation

In our case, we recorded interesting feedback and participants' input during DC sessions. When a participant brings up a point worth further investigation, we would ask the following study participants about this particular point. For instance, the P2 raised an important point regarding the use of 'do not forget to' or 'you forgot to in the user interface design. We then asked every participant about the appropriate terms when reminding an SwNCD to complete a task.

Step ten: Implications

We reiterated the design of our system prototype based on the study findings. We developed the front-end using the Unity game engine and Microsoft Mixed Reality Tool Kit (MRTK) to produce a high-fidelity system prototype. The front-end application runs on a Microsoft Hololens2 device. For a detailed description of the final system design, please refer to Chapter 9.

7.4 Conclusion

This chapter provided a detailed description of the DC study. Our process of conducting DC consisted of 10 steps divided into three main phases; preparation, running sessions and post-processing. A total of 24 study participants from Canada and the US joined the study, including SwNCDs, formal and informal caregivers, domain experts and MR developers. Evaluating the initial system prototype with this diverse group of participants allows for collecting important insights from all aging in place involved parties. In the third phase, a course of thematic analysis is concluded to analyse DC data. Some of the expected results include design recommendations for immersive smart home system and thorough discussions of these findings.

Chapter 8

Design Critique Data: Analysis, Findings, and Discussions

8.1 Chapter overview

This chapter presents the analysis and discussions of the qualitative data of the Design Critique (DC) study that was described in Chapter 7. In the first section of the analysis, the thematic analysis method is presented along with a brief overview of the thematic framework for both DC rounds; stakeholders and Extended Reality (XR) developers. The first round of DC resulted in six main themes related to design recommendations for immersive applications and supportive smart home systems(SSHS). The second round provides recommendations for implementing immersive applications for SwNCDs using the Microsoft Mixed Reality Toolkit (MRTK) and Unity engine.

The findings of both rounds are discussed from three different perspectives. The first discussion explores the relationship between the different stakeholders category and their input on the newly extracted design recommendations. In the second discussion, the interrelationships between the NCDs' related problems, design solutions and implementation recommendations are mapped out. Lastly, a brief discussion about user safety compared to data privacy is discussed. This chapter ends by presenting the limitations of this study and a conclusion.

8.2 Analysis

All DC sessions were video recorded and then transcribed separately. After that, all scripts were imported into NVivo software to perform a Thematic Analysis, which took place after all the DC sessions were completed. As mentioned in Chapter 3, the analysis follows the reflexive approach of thematic analysis in order to validate the coding process through identifying personal believes that may have affected the data analysis [BC19, COD+21, BC21b].

The initial coding process resulted in 126 codes. The next step was to merge redundant codes and choose appropriate descriptions. After multiple rounds of code reiterations, we identifying patterns in the codes and grouped them into theme. Our final thematic framework, which consisted of 6 main themes and a total of 118 unique codes. The same process was applied with the XR developers on the second DC round, resulting in 6 themes and 42 codes. We separated the thematic analysis files since the objectives of these two rounds were different. However, in the discussions section of this paper, we present the relationships between findings from both rounds. For additional materials about this DC evaluation, please refer to Appendix D.

8.3 Findings

This part describes the emerging themes and codes based on qualitative data gathered from seniors, caregivers, and domain expert participants. Due to the high number of codes, we will only provide an overview of each theme and its sub-themes while highlighting important codes and selected quotations. For an overview of the thematic framework, please refer to Table 8.1 For further details, please refer to the tables in each respective section.

Table 8.1: Overview of the thematic framework and number of references for each theme

Theme	No. of references
Design recommendations for supportive MR applications	205
Considerations for supportive smart home systems design	78
User scenarios	76
User support	62
Advantages of the proposed system	57
Concerns	54

8.3.1 First DC round: SwNCDs, caregivers and domain experts

First theme: Design recommendations for supportive MR applications

As shown in Table 8.2, these design recommendations are presented in two sub-themes, each broken down into two additional sub-themes. The 'user experience design recommendations' sub-theme presents findings related to user-system interaction. Notably, the most common code is related to using audio-visual feedback rather than visuals only; this code appeared in 27 and was reported by 13 participants.

Most participants highlighted the importance of keeping the UX design simple, consistent, and repetitive. This could be related to other feedback about keeping user efforts as low as possible. In terms of attracting the user's attention, participants suggested using multiple triggers to engage different senses; a vibration signal and audio simultaneously. In addition, using a familiar voice was suggested when delivering recorded messages or when the system reads out text. Instead of providing the user with pre-set responses (reminders and prompts), our participants suggested loading the system with a set of prompts designed for SwNCDs and allowing the caregiver to customize the sequence and timings. As for the 'user-system interaction' sub-theme, we identified important recommendations such as using gazing rather than hand interactions and potentially considering voice commands. Overall, participants suggested keeping the user-system interactions minimal.

> "*Sometimes, even in short sentences, I cannot comprehend what is being said, and it is like I just can't comprehend something. So I would need someone to*

Table 8.2: The design recommendations for supportive MR applications theme

Sub-theme	Sub-sub-theme	Codes	No. of Part.	No. of Refe.
UX design recommendations	System-User interaction	Use audio visual feedback	14	30
		Simple and repetitive steps	10	17
		Customized UX preferences	8	11
		Prompt methods work with different senses	5	11
		Aligns with the zero effort technology principle	3	6
		Supportive but not controlling	3	6
		Use music clues	3	5
		Integrate with user rituals	4	5
		Support different languages	3	5
		Familiar voice	4	4
		Reduce chance of errors	3	3
		Benefits from errorless learning method	1	1
		Proper sequence of attention triggers	1	1
	User-system interaction	Possibility of using voice commands	3	8
		Minimal - no interaction	5	8
		Mainly use gazing	1	1
UI design recommendations	Visual components	Use video messages	12	18
		Proper icons and visual expressions	12	17
		Possibility of using push buttons	7	8
		MR directional helpers	5	7
		High contrast message background colors	4	4
		Avoid triggering a startle response	4	4
		Smoothly and safely floating augmentations	3	3
		Fades in and out augmentations	1	1
	System language	Shorter sentences	7	9
		Respectful and non-technical language	5	6
		Avoid using irritating	3	4
		Bigger and clear fonts	1	2
		Consistency	1	1

read what is written. So that is why I said, you need to show the message and read it", P3.

"*I think personally, I'm only thinking, at my level, that the visual cue is great. [A] little icon I think is a good visual if it's not confusing and I would keep the sentences very short*", P5.

"I think you almost have to create different levels of the program depending on the person, you know some like the level of the dementia and most excites me some people could be like dementia, but they have different like you know even within

that category of what the medical system has categorized it gets to be different and only their family members can say that you know which level they can put what they're comfortable with it's it's hard to say just do it that way", P15

"According to the Zero Effort Technology principles, you wanted technology for seniors that is easy to use, and that is like more passive in a way that they don't have to do much action with it", P1

The second sub-theme is 'UI design recommendations,' which presents feedback on the visual components and the system language. The most common feedback from participants was the effectiveness of using video messages to prompt users. In addition, participants reported the importance of using less text and more icons and visual expressions. Using indoor navigation arrows was suggested to guide the user to indoor items such as the medical dispenser and the stove. However, any of these visual components should avoid triggering a startled response. Therefore, using fade-in-out effects coupled with smoothly floating augmentations is recommended. As for the system language, the system should always use respectful and simple language and avoid "irritating" terms such as 'remember to,' 'do not forget to,' and 'you forgot to.'

"For me, I think the best would be to see an actual family member [in a video message]. I think it's comforting to see a family member telling you about what you need to do", P3.

"I think you would always have to be just videos for my dad because I think it's better for him. The fact that there is ways to implement video into words letting you know and giving you that form of alert, I think that's fantastic", P18.

"Visuals are very important, kind of you seeing somebody moving their hand or turning their head or looking down. And I will tell you for men, the visuals are really important" P11

"Never say 'remember' or 'you need to do this', or 'you have forgotten to do this', because those are terms that seniors hate to hear because they know they forget. So if you really want to be on the good side, you're the kid talking in the on the screen [augmentation message] would be you like 'you forgotten to take your pills'! think of a nicer way to deliver the message", P4

Second theme: Considerations for supportive smart home systems design

The MR application and the smart home system work together to support the whole aging in place life choice. Therefore, it was important for us to discuss the design of the smart home system itself. We summarized our findings into two main sub-themes: 'software-related considerations' and 'hardware-related considerations'; Table 8.3 presents all the details of this theme.

Table 8.3: The considerations for supportive smart home systems design theme

Sub-theme	Codes	No. of Participants	No. of References
Software related considerations	Supports real-time remote intervention	8	14
	Task completion verification	3	4
	Pre-set to start for risky tasks (oven, iron, etc.)	4	4
	Escalate to the caregiver when system failure	4	4
	Inform caregiver if user didn't use the wearables	2	2
	Send reminder if the user leaves the kitchen for 10 min	2	2
	Reminder to take pills before leaving the house	1	1
	Verify that caregiver received and read message	1	1
Hardware related considerations	Use typical wearable devices such as a watch	7	8
	Use external attention triggers such as lights	6	8
	Rely more on sensor data	2	2
	Modality of the system	1	2
	Integrate panic button to the system	1	1
	Possibly display message on TV	1	1
	Commercially available devices	1	1
	Shouldn't trigger paranoia	1	1
	Longer triggers due to neuro-delay response	1	1

From a software perspective, participants emphasized the importance of having a real-time remote intervention functionality where caregivers can access the smart home system anytime. The other major consideration is to allow for task completion verification. In addition, participants preferred the caregiver to be informed if the user at home did not wear the MR or the Apple watch device. Most importantly, the system should support emergency response for critical situations such as falling. It is worth mentioning that newer versions of the Apple Watch support emergency responses such as falling.

Furthermore, there were a few suggestions to increase the safety of the cooking assistant functionality. For instance, one of the suggestions was to pre-set the cooking timer for the stove to start. Another suggestion was to keep prompting the user if they left the kitchen for 10 minutes. Lastly, one of the participants raised a point that the system should be able to verify if the caregiver saw a notification regarding an uncompleted task and the system to take action in case the caregiver doesn't respond.

> *"Just like with all the apps, you get a notification. You know, dad just started cooking something, or dad just started vacuuming or, like, just simple things like that, just to be able to know. Because you worry about them, so just to get notifications so that you have peace of mind, you know what they're doing and if they are stuck somewhere"*, P12.

> *"You know the other thing too is, because it's in that dispenser and you know I can always check and see for sure what's what's going on. Did they pick up the dispenser and didn't put it back? Can I also know where did they put it?"*, P12

As for the hardware considerations, we were encouraged to use typical wearable devices that can easily integrate into the user's daily rituals. Some SwNCDs have difficulties recognizing new objects, leading to device misuse. In some rare cases, unfamiliar devices can lead to paranoia. Some study participants recommended embodying new smart home devices with more familiar objects when possible. In our discussions regarding using Apple Watch to attract the user's attention, one study participant suggested increasing the vibration signal up to 30 seconds to accommodate the neuro-delay usually associated with NCDs. Because most NCDs are progressive in nature, participants appreciated the modality of the system where new IoT devices and new automation recipes can be introduced.

"Even though, when they see that first message, and then they start to proceed to the medication, they might forget by that point, but maybe that light flashing will grab their curiosity, and maybe they would walk through it. So the next time they get the message, they would be more willing to take it or be more receptive to it", P14.

"I think it's a good visual [using external light] that they'll want to walk over there, or see what's happening in that corner, and why, 'why is this light going off?", so I think it's a good visual", P8.

"We usually get right now [prompts]. It might be too short for somebody with dementia to remember. The longer it vibrates, the better it will trigger their attention because they might have neuro delay. So the longer it vibrates, it just gives their response the time to go to the brain and then to the eyes to look. Maybe half of a minute would be good!", P14.

Third theme: User scenarios

In this theme, we present user feedback about the two user scenarios addressed in the video prototypes. Evaluating the used scenarios allows us to verify their realism and relevance to the user; Table 8.4 presents this theme and all related codes. The findings in this theme are divided into three sub-themes; medication reminder, the stove reminder, and participants suggested scenarios that can be addressed in future work. In the medication reminder scenario, most of the feedback was positive, and participants felt they could relate to the scenario and found the suggested prompts appropriate. Two participants suggested different timings between the reminders and prompts.

"I think it is accurate, now for my mother, she doesn't take a whole lot of prescriptions, she simply doesn't want to. But I can relate more to my wife's parents, who are both in their 80s and they have about seven different prescriptions each

and yes, getting to look at expiry dates, making sure everything's the way it's supposed to be is very difficult, it's a time-consuming effort", P6.

I think that's enough because you get the first reminder, then you get the second reminder and then a family member comes in the last one. I think that it is because you're getting chances. I don't know if I'm using the right word but you're being given a chance. Like three times, I think that would be helpful, P7.

In our initial prototype, the system would allow the user to use the stove for up to 60 minutes before involving the caregiver or the system intervening automatically. A few participants found 60 minutes of cooking time to be average for making food in their culture. However, caregivers and domain experts reported that most seniors do not cook big meals, and thus they do not need long cooking times. What was evident in this theme is that the system has to be able to accommodate the needs of people from different cultures and different households. In addition, some participants suggested different time intervals between the prompts, which calls for more system customizability.

I wouldn't wait as long. I would try to get their attention a little quicker. And maybe go a little harder on the messages. If you're going to burn the house down, that's a bit more immediate., P6.

"Yeah I am thinking about the reminder, which is in 30 minutes, and then in 60 minutes, and then in 70 minutes. In [participant state their country of origin], we cook for 70 minutes but I don't think an older couple would need that much time to prepare a meal here", P16.

Participants suggested other important case scenarios such as assisting with wandering, hydration, air conditioning management and eating reminders. Most of these case scenarios were reported in the previous requirement elicitation study (see Chapter 5). However, finding solutions for the social isolation problem remained the most suggested topic among

Table 8.4: The user scenarios theme

Sub-theme	Code	No. of Participants	No. of References
Med reminder scenario	Current prompts are appropriate	7	8
	Sequence of prompts can be customizable	5	6
	Suggested timing for reminders	2	2
Stove reminder scenario	Shorter time between reminders	11	14
	Account for the different meal times	5	6
	Stove should support auto switch off	4	5
	Culture can affect cooking time	3	4
	Suggested timing for stove	3	3
	Stove sends separate notifications (oven vs burner)	1	2
Suggested case scenario	Connect with other users	3	5
	Create joyful user experiences (gamifying)	2	2
	Detect and support user if they wander	2	2
	Assist with hydration	2	2
	Air conditioning management	1	1
	Eating reminder	1	1

all participant categories. Other participants suggested creating a joyful user experience. It appears that gamefying the system is worth investigating in future research.

Fourth theme: User support

This theme presented findings related to the two types of user support; seniors and caregivers. Table 8.5 presents the theme in detail. Most participants agreed that the suggested system could be useful for seniors in the early-mid stage of NCDs. While early introduction increases the likelihood of full adoption and success, participants suggested that seniors at the early-mid stage of illness can learn how to use new technology if it leads to more independence and a stronger sense of agency. Participants added that future senior generations would be less challenged in adopting new technologies. We were encouraged to account for all potential caregiver users such as spouses, grandchildren, or friends with different technology literacy levels. Caregivers (formal and informal) asked how to set up the system for the first time and configure its preferences.

"I've lost so much of myself. Lost my independence. You get to a point where

Table 8.5: The user support theme

Sub-theme	Codes	No. of Part.	No. of Refer.
NCDs special requirements	Possibility to get confused	6	7
	Risky episodes lead to moving to a seniors facility	3	6
	Attention span issues	3	4
	Issues with learning new technology	2	3
	Possibility of getting disoriented when waking up	2	2
	Possibility of hallucination for Lewy Body Dementia	1	1
	Difficulty recognizing words	1	1
	Lack of motivation	1	1
Early- Mid stage NCDs support	Near future seniors will adopt easier	8	14
	Early-Middle stage are suitable potential users	7	11
	Seniors can learn simple tech if it helps	2	2
	Early introduction to tech is key	1	2
Late stage NCDs support	Hard to adopt tech in the 90yr range	2	2
	Late stage might adopt if technology is simplified	1	1
Caregiver Support	Counts for different caregiver categories	2	3

you really have to rely so much on someone. I think the glasses [the system with the MR headset] would really help someone that may not have advanced to later stages, probably beginning middle stage", P7.

"one of piece of feedback I get often, especially from caregivers, they're not going to switch to a more complicated technology, even if, maybe it saves them like a little bit of time or it's a little has a few better features if they're already used to using something. If they're familiar with it and there's multiple people using it, who are familiar with it and they're unlikely to switch. So you always need to account to role of the caregiver too", P2

Participants highlighted important issues affecting the user-system interaction, such as attention span. SwNCDs can get confused and lose attention easily. Therefore, the system should always account for these possibilities. Some of the suggestions to overcome this challenge include relying on a combination of augmentations and real-world attention attractions such as actual flashing lights or sounds. Participants raised other major issues such as difficulties recognizing words and morning disorientation. While discussing these topics, we learned from one of the domain experts that seniors living with Lewy Body Dementia could experience episodes of hallucinations and, hence, using MR applications might not be suitable in this case.

> *"I think it would be helpful, I think it's simple enough, I don't think it's complicated. The dispenser with the light that's pretty cool because visually that's just so cool like something flashing will get their attention. The combination of the smart glasses [MR headset] and the light should be enough to get their attention and motivate them"*, P5

> *"In some dementia types, they have difficulty in recognizing the words. They read it like okay I'm reading this but they don't have the idea of what they're reading, so when you have familiar visual cues, I think it will be easier"*, P1

> *"Someone with frontal lobe dementia [Lewy Body Dementia] can hallucinate and so that was kind of my only thought like if something popped up and they weren't associating it with the reminder"*, P2

Fifth theme: Advantages of the proposed system

While we understand that users in this study did not experience the system we envision first-hand, we discussed its potential advantages and their concerns to re-iterate our design with their input. Table 8.6 presents the theme, sub-themes, and code references. The findings presented in this theme indicate that the system could improve the quality of life for the aging population by making aging in place more accessible. Improving the sense of independence and agency for the user while providing the caregiver with peace of mind was a common comment. Other participants described our suggested system as 'enabling' because it provides people with more aging options, which eventually could reduce the financial cost for individuals and healthcare systems. Some participants highlighted how the COVID-19 pandemic highlighted the importance of exploring alternative homecare options.

Table 8.6: The advantages of the suggested system theme

Sub-theme	Codes	No. of Part.	No. of Refer.
Better Usability	MR glasses can provide effortless interactions	7	9
	Solve the problem of using smart phones	2	3
	MR glasses have a greater potential in managing emergencies	3	3
Better life quality	Makes aging in place more accessible	8	16
	Improves the sense of independence and agency	7	8
	Brings piece of mind	6	7
	Less pressure on the caregiver	4	6
	Allows for more aging options	2	2
	Encourages users to stay active	2	2
	Decrease feeling of loneliness	2	2
	COVID-19 highlighted the importance of this tech	1	1
	Better case management	1	1
	Less financial cost	1	1
	Reduced potential risk	1	1
	This system enables people	1	1
	Less pressure on the healthcare system	1	1
Functional benefits	Cooking support could enable independence	4	7
	The medication reminder assists in managing user's health	7	7

Using MR head-mounted display comes with a set of advantages. First, by introducing a seamless MR user experience, seniors do not need to use mobile phone applications, increasing overall system usability. Furthermore, mixed reality UI design is not bound to traditional graphical user interface design elements (menus, buttons, windows, etc.). As a result, from a functional perspective, the system could enable users to keep up with their daily living activities.

> *"so yeah, family dynamics is really interesting. You know this because the majority of people want to live in their own home forever if they can afford it. I think your approach is really good too. Because it's probably only realized in the last few years, as we started getting into this whole area of aging and the issue of dementia memory loss, how serious it is."*, P3

> *"Us the seniors and the caregivers would totally appreciate it [the proposed sys-*

tem], because the parent wants to continue living at home and they [the family] want them to continue living at home safely and independently and they're going to feel better", P4

"It's different I think, with the system that you're talking about, like you guys has a better chance of him, remembering a little bit more, and knowing that he's not alone. Also, he doesn't like using iPad and smartphones", P17

Sixth theme: Concerns

This theme summarizes all concerns reported in the DC study. The theme consists of three sub-themes: hardware, senior user-related, and safety and privacy concerns.

Participants raised concerns about the system hardware, such as the medical dispenser and the possibility of the user misplacing or losing it. Accounting for hardware failure was a common point of feedback, and users questioned how the system would respond if one device stopped working. As for the wearable devices, participants wondered how the system could support the user to keep devices charged. Since most older adults wear prescription glasses, MR glasses should be prescription compatible and accommodate hearing aids. Table 8.7 presents details of the 'concerns' theme.

Another set of feedback related to the senior users themselves; reading capability and willingness to use the wearable devices. On the social side, one participant raised questions about how future design considers fighting stigmatization.

The last topic in this theme is privacy and safety. While we are aware of data privacy concerns associated with IoT devices, our participants from all categories did not express significant concerns about this issue. Only two participants asked if the MR glasses can be misused to breach the user's privacy (what if health insurance companies could have access to the user data? a participant wondered). Another informal caregiver participant asked if they could access the MR headset remotely to see what the user was doing at home. This response to data privacy can be related to the lack of understanding of capacity of these

Table 8.7: The concerns theme

Sub-theme	Codes	No. of Parti.	No. of Refer.
Hardware concerns	Medication dispenser device-related concerns	5	8
	Charging wearable devices	4	5
	Hardware failure concerns	4	4
	MR glasses should match prescription	1	1
	Hearing aid support	1	1
Senior user related concerns	Cost related concerns	4	7
	Reading capability is required	3	4
	Potential of not wearing wearable devices	4	4
	Falling	1	1
	Possibility of stigmatization	1	1
	Medication often changes	1	1
Safety and privacy	Safety over data privacy	6	8
	Concerns about storing system data	3	4
	Safety is a key	2	3
	Misusing MR glasses	2	2

technologies in collecting private information. Section 8.4.3 provides a detailed discussion about user safety and data privacy.

> *"You see, here [in Canada], we have a system at the pharmacy that they put them [the pills] in little pill packs, all very handy, but then in your system, the family member would have to fill those. Then maybe this device might get lost at home"*, P8.
>
> *"My other question would be, what if they're not charging their their watch? they're not charging the glasses"*, P14
>
> *"The system is an advantage, but if it crashes, then it's everything is paused, is that correct?"*, P15

8.3.2 Second DC round: Extended reality developers

This chapter section presents findings from the second round of DC with XR developers. Our initial coding process yielded 65 codes, later reduced to 44 and categorized into six themes. Table 8.8 presents the entire thematic framework for this round. All discussions in this round revolved around a best practice of using the MRTK2 and Unity engine. It is worth noting that the MRTK2 is the most advanced and most common development kit for MR applications. In addition, it supports a wide range of platforms and devices, including the HoloLens, Magic Leap and Oculus Quest. Therefore, the recommendation in this section would apply to most commercially available MR headsets.

First theme: User interaction

Our XR developer participants recommend relying on the MRTK built-in hand tracking scripts to detect the approximate Apple Watch location. In order to verify that the user is watching the video messages, using the eye tracking script was suggested. Alternatively, checking the head 'gaze' 3D Victor's collision with the hand wrist can accomplish the same result without eye tracking.

One common problem in MR is that attaching a virtual object to a real-world item can block the user's vision. For instance, the virtual medicine dispenser would hide the real-world one. Virtual components should fade in/out using 'fade rendering mode' to avoid this problem. This way, the virtual object would completely fade off when the user walks toward the dispenser.

Reading text in an MR environment can be challenging for the user for multiple reasons: angle of view, distance, and collision with other objects. Our study participants suggested using the MRTK 'billboarding' script to guarantee that text and videos are readable and watchable all the time. This script allows augmentations to automatically self-orient themselves towards the user.

"I think it's nice to have that, going back to the customization of this for the

Table 8.8: Thematic framework of the XR developers DC sessions

Theme	Codes	No. of Part.	No. of Ref.
User interaction	Billboarding to keep augmentations facing user	3	5
	MRTK hand tracker feature	4	5
	Drag and drop for anchoring new virtual objects	3	5
	Use eye tracking script to verify user interaction	3	4
	QR codes to mark, detect, or place object	2	3
	Password protect the caregiver mode	2	3
	Gazing and tracing	2	3
	Left hand menu for setting up the system	2	2
	Follow me menu	2	2
	Use labels for verbal interaction	1	1
Prompting in MR	Directional solvers	3	6
	Use familiar avatars	2	4
	Animated augmentations	3	3
	Use practical systems	3	3
	ToolTip feature	1	2
	Audio-visual prompts	1	1
Challenges	Use RFID tags to track the dispenser	4	5
	ML to detect medical dispenser in space	3	3
	Verify that user is watching the video	3	3
	Account for limited processing power	2	3
	Avoid seizure triggers	2	2
	Count for device latency	1	1
	External cameras to track dispenser	1	1
	Orienting the system after user takes off glasses	1	1
	Identify wearable devices in the environment	1	1
Using text in MR	Avoid using computer text	4	6
	Images instead of texts is an option	4	6
	Text Pro when text is needed	2	2
	3D texts is an option	1	1
Hologram design recommendations	Use canvases for images and videos	5	6
	Stabilization script to deal with shakiness	2	3
	Use MRTK materials not Unity materials	1	2
	Keep messages transparent	1	1
	Use MRTK banner component	1	1
	Account for the user's distance from objects	1	1
Spatial awareness related	Configure the spatial awareness profile	3	4
	Use spatial sound feature	1	1
	Spatial mapping to add new virtual objects	1	1
	Disable rendering spatial awareness	1	1

caregiver, I think it's nice for you to be able to tailor these sort of reminders and responses to the person you're caring for. You can use the 'left-hand menu' prefab that comes with the MRTK", P19.

"As for the actual hovering above the hand, the 'billboarding' is great, like what

you've done billboarding and position tracking to the hand is great. I just think that, you should also be aware of the size of these messages so it is not too big", P21.

As mentioned earlier, participants wondered how the caregiver would set up the system and reconfigure its preferences. We discussed these concerns with our XR developers and received a number of important recommendations. For instance, the caregiver mode can be triggered using a verbal keyword or a hidden virtual button protected with a password. This technique reduces the chances of the senior user mistakenly accessing the caregiver mode. During the setup phase, the caregiver would walk around the house to add the virtual components to the real world (align the virtual dispenser with the real one). Using 'follow me' menus or a 'left-hand menu' was suggested as an easy solution. Although there are several ways to add a virtual item to the real world, in our specific case, developers suggested using simple techniques such as scanning QR codes or simply using grab and drop. For instance, the caregiver can have the virtual medical dispenser object on the 'left-hand menu', then they simply drag and place it on top of the actual medical dispenser and hit the 'complete' button on the hand menu.

"You probably need two levels of users for the app, one is like someone who can modify it and just someone who's just passively using it. Access that caregiver menu you essentially just say a verbal password or click on the settings button somewhere, and it brings up a thing like entering a password", P20.

"Dragging and dropping is what I would do in your case, so I know that it is [virtual objects] placed correctly in the place that I want as a caregiver. Also, it is super easy to do", P20.

Second theme: Promoting in MR

If the system wants to direct the user's attention to a distant object, using Unity 'particle system' would be an excellent visual attraction. Another option is to use MRTK 'directional solver', which provides the user with a dynamic arrow pointing towards a target. This features can be used as an indoor navigation tool. The system could display self-orienting 'tooltips' or an animated hologram for near objects. Although the purpose of 'tooltips' is to add augmentation illustrations, we can use them as spatial labels in our case. For instance, a 'tooltip' can be added to the medicine dispenser, and every time the user looks at the device, the 'tooltip' is displayed. Additional attention attractions such as spatial, audio or sound cues can be integrated. Besides using the MRTK built-in features, XR developers highlighted the possibility of using animated cues or familiar avatars, which can be created using a single picture. However, the rendering quality of these avatars is relatively low, and it is unclear how SwNCDs can perceive these images.

"So you can take the light for instance [the flashing light], and then you can replace it with a virtual effect around the object, Unity particle systems are very good at that.", P22.

" [The directional solver] it's like an arrow right you could make it visible, that is an option it's not very realistic if you don't map the space, as it could show up on the wall sometimes. But it is totally possible like how you would show arrows you could show that in a very realistic way if the app is maps the space and generate a mesh", P23.

Third theme: Using text in MR

Users' micro-movements can negatively affect text readability on MR headsets. To avoid displaying unreadable text, our XR developer participants discourage using default Unity text and use 'Text Pro' instead. This type of text was explicitly introduced to overcome such problems in extended reality applications. Alternatively, 3D text or images containing text can replace using text entirely.

"For example, we have simple text, and we have 'text pro.' Some times you can get away with using simple text, but you should use "text pro' when you can

because it is intended for XR development. In either case, there are times when it is hard to read depending on the background, which you can't control all the time in MR", P24.

Fourth theme: Hologram design recommendations

Augmentations should not become a safety hazard, especially in a homecare setup. Therefore, in our case, hologram messages should be transparent. This can be accomplished by using either MRTK transparent materials. In the case of displaying videos and images, the system should always account for the distance between the user and these objects. Our participants raised questions regarding displaying a video message above the dispenser device and how the system would respond if the user is far from the message displayed. In either scenario, using 'canvases' or MRTK 'banners' is common practice for displaying videos in MR. An important suggestion was to use additional hologram stabilization scripts to keep messages clear if the senior user sufferers from notable limb shakiness due to Parkinson's disease or other illnesses.

> *"Bring the materials from MRTK, especially for the background material. You could also use from MRTK canvases. This is something that I will do to have my own personalized canvas and then bring the material and the backgrounds to it. This would work very nicely on the HoloLens"*, P24.

> *"I know you wanted to position some augmentations above the hand, but that might effect the readability because their hands [SwNCDs] might be shaky. So you might have to write a threshold script to handle shakiness"*, P23.

Fifth theme: Using the spatial awareness feature

The MRTK has a default setting for the 'spatial awareness' profile. Depending on the MRTK version, the spatial awareness mesh can be visible, which could startle the user (it will display two victors shooting from each hand forward). Therefore, the spatial awareness profile should be configured to disable rendering 3D meshes. The 'spatial sound' feature can be beneficial in our case to deliver audio messages and music cues. For instance, the virtual medical dispenser object can play spatial music to guide the user to its location. In addition, virtual components can be integrated into the real world in a very realistic way allowing other features such as the 'directional solver' to provide accurate indoor navigation prompts.

> *"By default, you won't have the spatial recognition [spatial mapping], but I think that if you enable the special spatial mapping in the profile, you can use that for finding the accurate location of the medicine dispenser for example"*, P24.

> *"You can use the spatial sound if you want to simulate 3D sound source. I personally haven't tried it yet but I think it can be beneficial for your project you just need to further research it"*, P19.

Sixth theme: Challenges

In the medication reminders scenario, we assume that the user will always return the medical dispenser; otherwise, they will receive notifications. We chose this design because the system needs to know the location of the medical dispenser device. The MRTK supports 'object detection' and 'world lock'; however, the user needs to wear the headset long enough to re-scan the environment and identify the item's new location. If the user places the medical dispenser in a location that cannot be scanned (inside the closet), the system will not have any location reference to the device. An alternative technique is to use external IoT trackers such as RFID or Apple tags. However, these tags suffer the required accuracy for indoor localization (where 2 meters could mean two different rooms). A perfect solution would be to use an external or a depth camera, but, as mentioned earlier, this approach leads to severe privacy invasion and is not recommended. The HoloLens2 device comes with a few limitations such as latency, limited processing power, limited field of view, and most importantly, the problem of re-orienting the system after restarting the device.

"So the most immediate issue of kind of both of those meditations is how are you matching the coordinate frame of your app to the coordinate frame of the real world?. Just because you set it up in the application the first time, as soon as you shut off the application and move and turn it back on your coordinate frame is no longer set. So there needs to be some way that you're able to turn on the application and get the coordinate frame back", P20.

"Actually the HoloLens2 is quite capable in general. The downside is the a latency issue due to the a graphics card. It has also to do with the GPU processing. And so, with that the delay comes from having to calculate the view, every time and the projections is made. So you shouldn't always account for this limitation and be careful with your hologram design", P21.

8.4 Discussions

The first part of the discussion focuses on exploring important relationships between the study findings and participant categories. In the second section, we map out the interrelationships between the NCDs' related problems, suggested solutions and implementation recommendations. Lastly, we briefly discuss participants' data privacy and user safety inputs.

8.4.1 Participant categories and suggested recommendations

During the Thematic Analysis, every interview transcript was assigned several attributes such as participant category, age, location, and sex. In order to investigate the input of each participant's category, we used the NVivo software to perform several 'Cross Matrix Queries' [1]: running queries for each participant category against all codes (a total of 27 themes and sub-themes * 4 participant categories = 108 queries). Participants raised other major issues

[1] Please refer to Appendix D, section D for screenshots and details about Cross Matrix quires

such as difficulties recognizing words and morning disorientation. This spreadsheet was then used to create the stretch cords diagram in Figure 8.1 using Tableau[2] software and the Show Me More plug-in. It worth noting that the figure doesn't include findings from the second DC round as purpose of including XR developers was to extract implementation recommendations and thus, the discussions were different. Section 8.4.2, however, discuss findings from the XR developers' DC round.

Seniors' input

Among all discussed topics, senior participants provided more input on the user interface and user experience design themes than other themes. During the DC sessions, participants were very engaged. They would voluntarily give comments about the UX aspect of the system, such as using audio-visual feedback or familiar voices. In the initial prototype, we used a black-white wireframe rendering style. Seniors liked the simplicity and minimalism of the UI design, but they commented on using proper text and more use of icons, visual expressions, and video messages.

In addition, participants discussed how the suggested system could improve their overall quality of life. Another notable contribution was to the user scenario and user support themes, where the value of the suggested system to people at early-mild stages of illness was discussed. A reasonable explanation for these findings is that senior participants could realize the potential usefulness suggested system in improving the quality of their lives.

This positive engagement indicates the effectiveness of video prototypes in evaluating MR application designs remotely. To this point, previous work such as [AWW+22, ULH21, LNKA20] reported using video prototypes and storyboards to elicit important design recommendations. The majority of participants in these studies were cognitively healthy people. Whereas in our study, a considerable proportion of study participants were SwNCDs. One of the participants was diagnosed with an advanced case of dementia, and she lives with her

[2] https://www.tableau.com

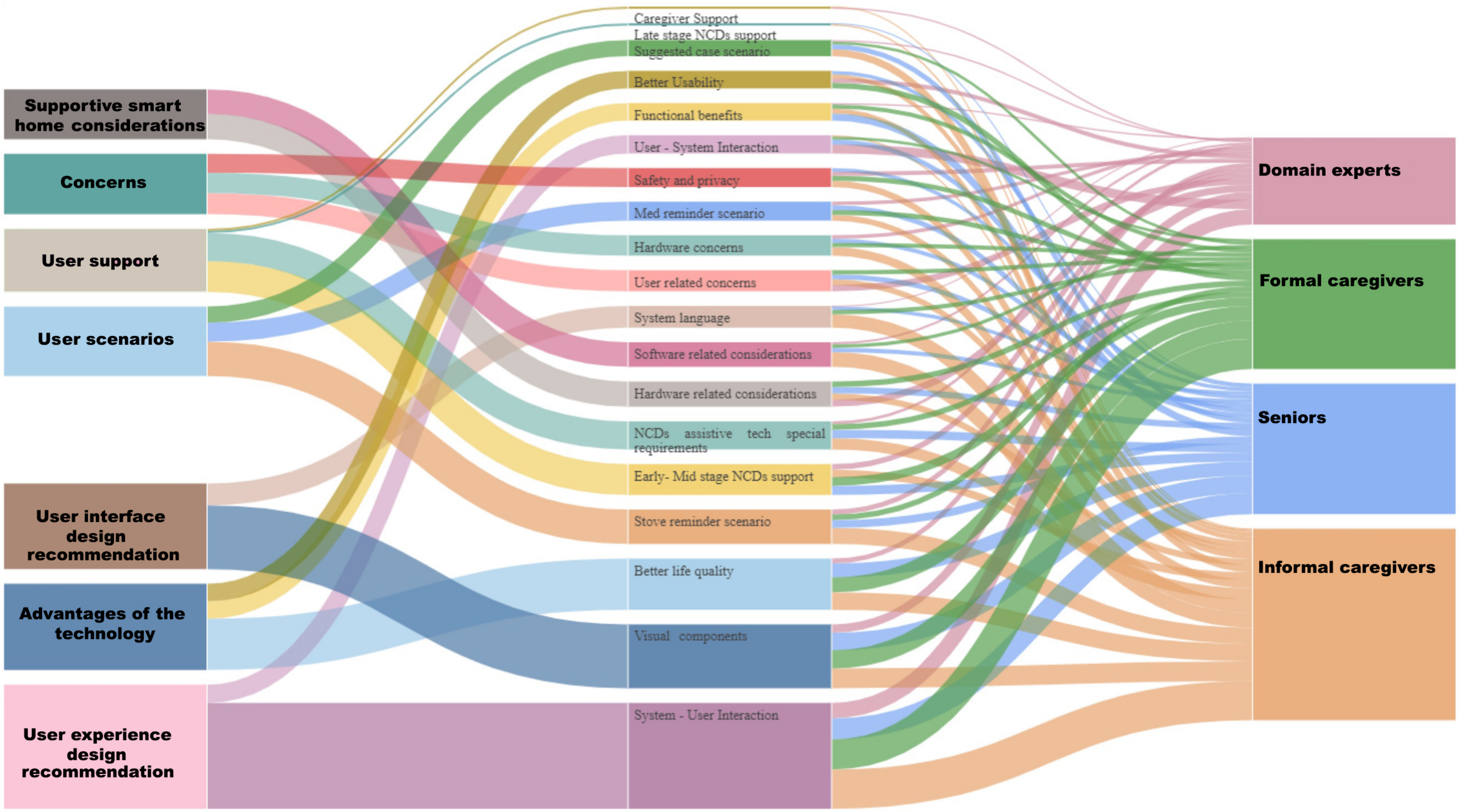


Figure 8.1: Participant categories contribution to the thematic framework development.

husband and her brother. The participants provided important insights regarding the system prototypes' UI and UX design, indicating that they understood the proposed concepts. When the participant was presented with the cooking safety scenario, she was emotional, and as she was crying, she stated, "If I had such technology five years ago, my life could have been different." While there is no empirical evidence to support the participant's claim, it is clear that the participants understood the proposed solution well, could relate to it, and realized its potential.

Informal caregivers' input

Compared to the senior participants, caregivers were more interested in the system's usability aspect, which was well reflected in their feedback regarding the overall user experience design of the system. Despite the proposed technology's importance and usefulness, usability plays an essential role in adaptation [RBD+18], which explains the caregivers' input.

Informal caregivers provided the majority of feedback and recommendations regarding the SSHS design. For instance, the 'system language' sub-theme is mainly extracted from informal caregiver feedback. Previous research has proposed recommendations for designing UI for SwNCDs; however, these recommendations were targeting touch-surface devices and were more concerned about the visual design aspects (font size, colours, etc.) [SVB+21, CGGM17]. Our study findings go beyond that, where we explore immersive user interface design elements and discuss new topics such as system language and proper terminology.

Although none of the DC study participants was involved in the requirements elicitation study, the importance of the remote monitoring and remote intervention system feature was discussed extensively. Previous research work reported that caregivers often feel anxious and even guilty when leaving the person they care for alone at home [GALC+20, LAW+10] which can explain the interests of our study participants in the remote monitoring and intervention feature.

Lastly, the informal caregiver discussed two main hardware-related issues. Firstly, considering the situation where the senior user takes off both wearable devices, thus, using ambient devices such as LED lights and speakers was encouraged. Secondly, to develop a reliable backup plan in case one system component stops responding. This can be linked to a common technique in designing automated systems where a backup plan is always required when the user safety is at risk [ZLN+15]. A common strategy is to automate the backup plan itself. For instance, the server would notify the caregiver if an IoT device goes offline.

Formal caregiver's input

Since formal caregivers have longer experience with different SwNCDs, their feedback was different and more specific. Although the number of formal caregivers was fewer than the informal caregivers in our study, the feedback was diverse and evidence-based. For instance, one of the participants was a nurse who specialized in NCDs care. The participant advised us to allow longer notification times (e.g.: more prolonged vibrations, longer music cues) to accommodate for potential neuro-delay caused by NCDs.

Another participant highlighted the importance of accounting for people with different attention spans. For example, sometimes, if a senior is immersed in a TV show or a book, it might require triggering more than one sense to get their attention. Therefore, a combination of watch vibration, sounds and visuals, and video messages were suggested to increase the chances of user responsiveness.

Generally, when a user is immersed in a 3D environment, getting their attention to a specific location is harder. The reason for this is the 360 view where the information is displayed everywhere around the user and not on a limited surface (such as a screen, phone, tablet) [DBFA20, SMO20]. In our case, to simplify the user-system interaction, we limited displaying augmentations to two locations above the user's Apple Watch and IoT devices (dispenser and stove). Although our participants did not explore this topic from such a technical perspective, they wanted to emphasize the importance of triggering the user's attention to see these augmentations. Hence, they emphasized using a long vibration signal before displaying a hologram above the wrist and using different music cues for each task. There is a big body of literature reporting the strong bond between music cues and memory [CD05, Lar01, SSBA10]. In our discussions with the XR developers, we took music cues a step further by suggesting using MRTK spatial music (virtual 3D sound system). A major potential benefit of this technique is that these music cues can now be related to a specific task and location at home. In other words, music will be played from a specific location (virtually), inviting the user to complete a task (e.g., take pills). Combining visual, audio and spatial memories could build a stronger bond.

Domain experts' input

Among all participant categories, the assistive technology domain experts expressed support for allowing more user-system interaction, such as voice recognition. One of the participants, an 85 years old assistive technology enthusiast, reported a few successful stories of seniors adopting voice command devices such as Alexa. Two of our participants in the requirement elicitation study in Chapter 5 used GoolgeHome devices at home for reminders. While the HoloLens supports voice commands, we suggest not using this feature in our system. There are three reasons for this decision. Firstly, keeping the system completely informative rather than interactive reduces the chances of user errors. Secondly, interacting with voice-based interfaces requires remembering key phrases and speaking in a computer-like language, which could be frustrating for some SwNCDs [VLI+13, SVB+21]. Thirdly, both of our use cases do not require user interactions, except for a single event in the cooking safety scenario, where users can push a virtual button to turn off the stove remotely.

One critical feedback we received from an occupational therapist was for the system to benefit from standard therapy practices such as the 'Errorless Learning' method [MS12]. The main principle of this practice is to design a task with minimal possibilities for user error. Then, repeating the same task precisely the same way each time, a new habit develops [HSKW07].

8.4.2 Interrelationships; NCDs related problems, solutions and implementation

This discussion section explores the interrelationships between NCDs-related problems, recommended solutions and implementation suggestions. As seen in Figure 8.2, we identify NCDs-related problems that affect a senior's daily living activities in the first part. It is crucial to clarify that the problems discussed in this section are related to our two use cases and do not represent all the issues that come with NCDs. After that, we describe how these problems may affect the user's ability to benefit from a supportive smart home system. In the next part, we highlight the proper system responses for these problems and the recommended design solutions. Lastly, we link our findings from the second DC round with XR developers to describe development recommendations for implementing these solutions on HoloLens2. For details, please refer to the mind map in Figure 8.2 illustrating all interrelationships.

Problems

Common NCD-related problems such as cognitive decline, short-term memory loss, the progressive nature of NCDs and confusion can cause frustration and higher levels of stress and anxiety for seniors [CLML12, KNO86]. Learning new skills becomes more difficult due to multiple factors, including the short-term memory loss [AB16]. Some informal caregivers highlighted the lack of motivation among SwNCD and attention issues. These problems, in addition to the typical neuro-delay, negatively affect the senior's engagement. In many cases of dementia, comprehending text or complicated speech can be difficult, which affects the senior's desire and ability to read [OGA+05].

Suggested solutions

A general role of caregiving is to create a supportive empathetic environment without controlling the senior's life [AB18b]. Typically, seniors who experience positive and kind homecare tend to be more cooperative [SZCS+19]. In SSHS, designers should allow for customization

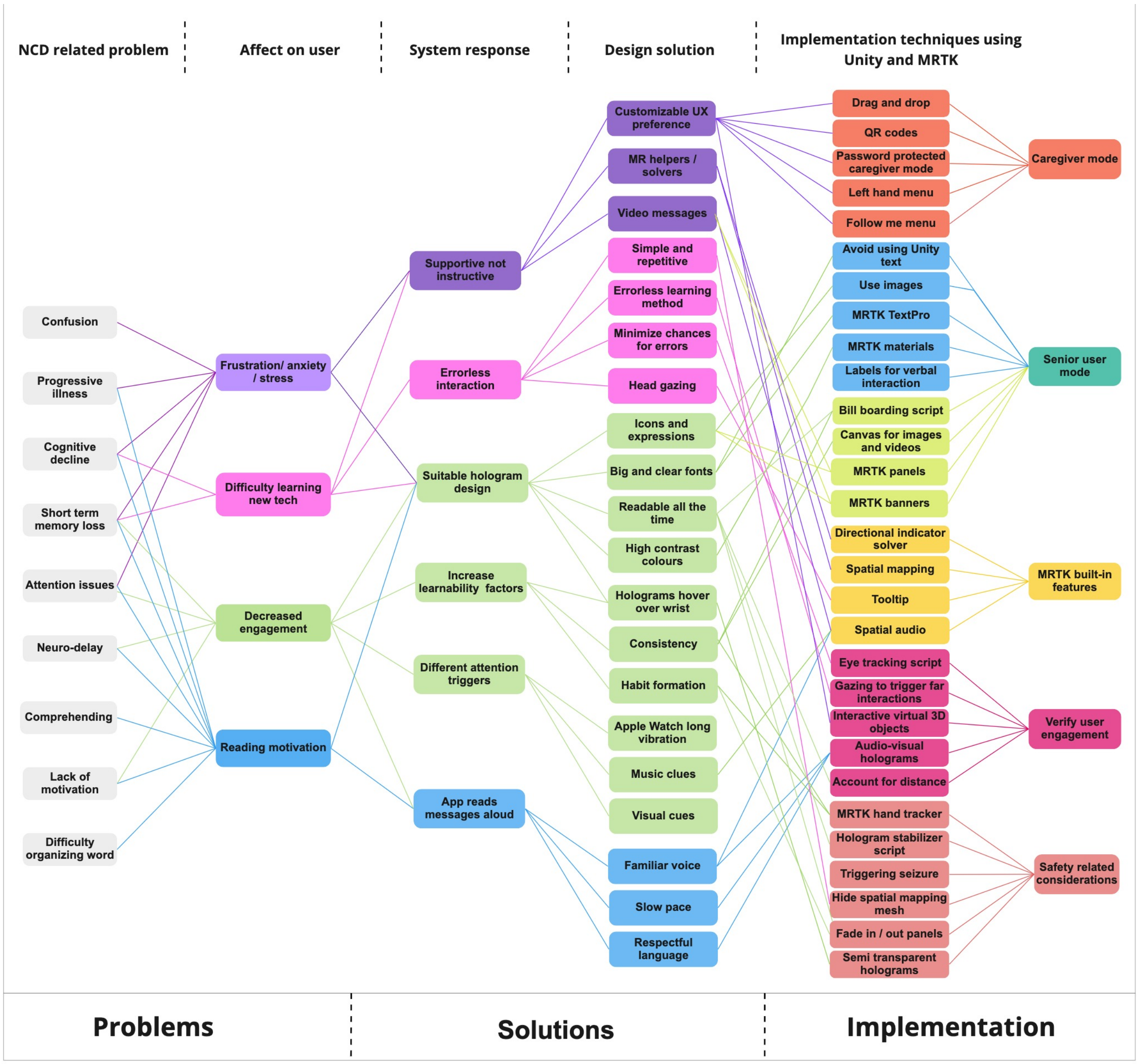


Figure 8.2: interrelationships between the problems, suggested solutions and implementation recommendations. Related elements are grouped together and colour coded

where seniors and their caregivers can configure system preferences such as types of notifications, timing, memory prompts and proper interventions. Reducing chances for user errors should be centred on the UX design. This can be accomplished by using simple and repetitive prompts, gazing to trigger augmentations and reducing the user-system interactions. The design of augmentations should be far from complicated or artistic as the goal is to be informative in the simplest possible way. Using icons, expressions, and clear big-size fonts are recommended for homecare. Part of keeping messages clear is to choose proper background colours. However, user safety should be taken into consideration when displaying augmentations. Therefore, we suggest that all hologram messages should be projected near the left/right-hand wrist. This design solution reduces the chances of the user tripping and falling.

Furthermore, displaying augmentations in this continuous fashion could trigger a formulation of a new habit for the user [HSKW07]. Lastly, the motivation to read text decreases over time among seniors, thus, it is recommended to use short and simple phrases written in respectful language that avoids using irritating words. In addition, the system should play pre-recorded audio messages (read-aloud notifications), especially when the user suffers from attention and focus-related issues.

Implementation recommendations

A supportive MR application should consist of two user interfaces; caregiver and senior user. The caregiver is expected to setup-up the system when it runs for the first time. Several preferences can be customized, such as timings, the proper sequence of memory prompts, and system interventions. All these options are pre-loaded in the system for their caregiver. The MRTK 'Left hand' menu or a 'follow me' menu provides an easy way to complete the system setup. For the system to identify the location of target IoT devices such as a medical dispenser or stove, there must be a virtual object representing these devices in the MR application. Therefore, the next step is for the caregivers to anchor these IoT devices by placing their corresponding virtual objects on top. Two suggested techniques to complete this step; scanning QR codes or setting a virtual object to be 'gradable.' This way, a caregiver can simply 'grab' and 'drop' virtual components into the real world. Finally, the caregiver mode should be protected all the time by either using a verbal keyword or a hidden button with a secure password. This will prevent any other users from mistakenly re-configuring the system.

Although using text will be minimal, it is important to ensure fonts are stable and clear all the time. Therefore, using 'text-pro' and text images is highly recommended. To keep augmentations readable all the time, additional stabilization scripts should be an option for users who suffer from notable limb shakiness. In order to introduce a smooth experience for the user, augmentations may fade in/out, reducing the startle response.

Since we use near-hand augmentations for delivering reminders, it is important that these objects can self-orient to remain readable for the user. This can be accomplished using MRTK scripts such as the 'billboarding.' For stationary objects, MRTK 'tooltips' can serve the same purpose. When walking toward an interactive object such as the medical dispenser, the virtual object should fade off, allowing the user to interact with real-world items. As for indoor navigation, attaching a 'directional solver' script to a tracked object is sufficient to provide the user with a dynamic visual cue. The 'spatial sound' feature adjusts sound output in real-time based on the user's location and distance from the source. One way to incorporate proper visuals and icons is to use 3D objects such as a pill model. In the case of displaying a video message, the 'eye tracking' or 'head gaze collider' script can be used to verify whether the user is looking at the message or not; a video message should pause until the user looks back.

8.4.3 Privacy and user safety

During the DC critique study presented in this chapter, we revisited the privacy vs safety topic. This time, we had the chance to discuss this topic with 19 seniors, caregivers, and domain experts. This time, the outcome of our discussions was not significantly different from previous discussions. Most caregivers and seniors agreed that safety overrides data privacy, provided the personal data is not shared with other individuals without the senior's consent. One of the participants is a senior citizen who has worked for many years in assisted living facilities management. She compared the privacy of seniors living in assisted living facilities and those who live at home and use smart home solutions. Her point was that people would sacrifice their privacy as soon as they move to an assisted facility. She added that some families would use 'baby camera' devices to be able to check on their loved ones even when they live in a facility. It is important to note that using visible cameras can increase anxiety and paranoia among SwNCDs, as reported by [CMN+07].

On the other hand, using hidden cameras comes with another set of ethical and privacy concerns. Therefore, obtaining the resident's (the senior) consent would always be required. Another participant, a domain expert known for giving presentations about assistive technology and data privacy, shared a similar perspective. She highlighted the importance of providing users with complete disclosures about their personal data and potential risk as the primary step before adopting any new technology. Below are three quotations from three participants; a formal caregiver/senior, an informal caregiver and a domain expert.

> *"In many retirement homes, we had families who wanted to see how their parents was. So they would have the baby cameras so they would know if something wrong happened. I use the term baby cam, but you know what I mean, a camera 24 hours a day...... With the smart home thing -if that's a possibility- then you can eventually know whether the stove got turned off or not. You may not have to go, you can react remotely. Also, you don't have to monitor them 24 hours right? The system will do that"*, P4 (senior, retired formal caregiver).

> *"Honestly, It doesn't affect me [data privacy] and I'll say it doesn't bother me at all. I don't mind because I kind of wish this [supportive smart home technology] was around when my grandma was around or when my other family members who*

had dementia were around. Because the more data that you guys are collecting, the more it will help next generation of Alzheimer's or dementia. What scares me more, is if something wrong happens to them and I am not at home", P18 (informal caregiver).

"I've done presentations on privacy to seniors. For instance, the older adults, I knew who are living with forms of dementia, or just alone they're very willing to sacrifice their [data] privacy. To have the autonomy that they have it's usually the family members who were more concerned. And so what I've started saying to people, if you're not a celebrity or a criminal does it really matter?. Eventually, no one is forced to adopt technology and they can make their own decisions", P2 (domain researcher, occupational therapist).

In our three studies, we arrived at the same conclusion; user safety overrides data privacy. However, to maintain a high level of academic integrity, it is important to discuss the additional privacy concern that comes with the HoloLens2 device and other MR headsets. The HoloLens2 uses a camera, a microphone, and a depth sensor [UBG+20]. Below is a short summary of the purpose of each device:

1. Microphone: to listen to user's voice commands and to capture audio data for first-person-perspective video recording (if needed).

2. Camera: mainly used for video recordings. In addition, it can capture images and merge them with 3D meshes to create realistic models.

3. Depth sensor: the most important device for the Hololens as it generates 3D meshes for the surrounding environment, supports spatial interactions and captures hand gestures.

In our suggested system, the only device needed is a depth sensor. As for the camera and microphone, they can both be disabled via the MRTK profile in Unity before building and

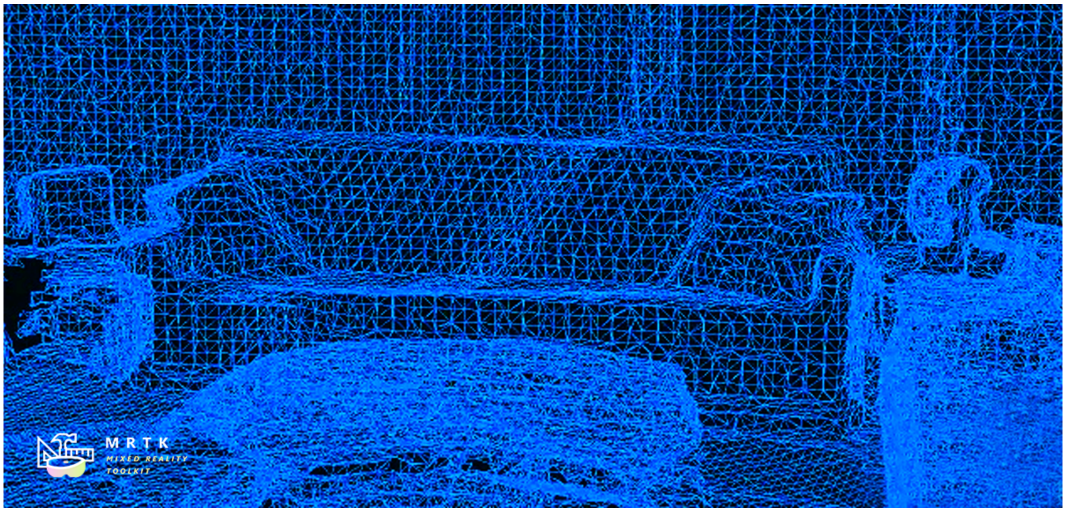


Figure 8.3: 3D mesh created by Hololens2. Source: Microsoft MRTK 2.8 documentation web page

deploying the application on the head-mounted device. However, that does not wholly eliminate the privacy concern. The depth sensor can create -relatively- accurate 3D meshes of the surrounding environment but without any textures or materials, see Figure 8.3. Therefore, in advance, it is important to communicate this privacy concern in addition to the previously discussed IoT-related concerns to potential end-users. For more discussions about the data privacy aspect of SSHS, please refer to Chapter 5.

8.5 Limitations

Although the design critique study allowed us to evaluate the design with 24 participants from five different categories across Canada and the US, this sample was not selected randomly. Instead, we recruited most participants who expressed interest if they met the inclusion criteria. Running more sessions with more participants could introduce new information that we might have missed in our study. To this point, we conducted this study using only two use cases; additional sessions with more use cases would be required to establish the proposed design recommendations further.

Previous work suggested that common testing approaches such as the System Usability

Scale, NASA-TLX, and Player Experience Inventory are unsuitable for SwNCDs [GMM+16, KRK+21]. Therefore, our approach of utilizing the DC is considered an alternative method of evaluating supportive systems with senior participants in a qualitative way. Furthermore, due to the COVID-19 pandemic, we used video prototypes to evaluate the proposed system prototype remotely. While the findings indicate that this approach is effective in collecting feedback and extracting design recommendations [AWW+22, WMVW+17], participants are yet to experience the system first-hand.

Lastly, the thematic analysis in this study was performed by a solo researcher; thus, all findings were extracted from scripts based on the researcher's interpretation. While following Braun and Clarke's guidelines for conducting thematic analysis streamlines the process, it does not entirely remove researcher bias. Therefore, this method of analysis could impose a threat to the validity of the study findings.

8.6 Conclusion

This chapter presented in detail the findings of the two DC study rounds. The First round of DC resulted in six main themes introducing new design recommendations and considerations for IoT-based immersive smart home systems. These themes introduced novel contributions to the body of immersive user interface and user experience design for SwNCDs literature. The second DC round resulted in a number of implementation recommendations and best practices extracted from our experienced XR developers.

In the discussions section, we explored our findings from three different perspectives. Evidently, informal caregivers were responsible for most newly extracted design recommendations. Achieving higher levels of system usability was the main focus of informal caregivers. Senior users were the second largest contributing category in our study—most of their input was related to the user experience and interface design aspects. In addition, they discussed the two use cases in detail and highlighted the advantages of the proposed system. Generally, system usefulness and adaptation recommendations were central to senior participants' input.

Similarly, formal caregivers and domain experts introduced valuable input on all topics. However, they focused more on the two main components of the smart home system itself (hardware and software), which lead to the development of an entire theme. Understandably, these two participant categories provided more evidence-based feedback.

The interrelationship between NCDs-related problems, the proposed design solution and the implementation solution were discussed extensively and supplemented with a mind map visualization. This discussion provided evidence-based explanations of how NCDs can affect the daily living of seniors aging in place and how an immersive smart home system can respond to these challenges. Implementation recommendations were presented accordingly. This discussion provides the future researcher with a clear road map on accommodating NCDs-related challenges using an immersive smart home system. Although the discussion only addressed two use cases, the lessons learned can be applied to other similar use cases, as discussed in Chapter 5. The last part of our discussion addressed an important topic; user safety and data privacy. This discussion was presented in two previous studies (Chapters 4 and 5). Given that at this phase of our study, we propose using the HoloLens2 device for senior user interaction, it was necessary to report the privacy concerns that comes with it. Finally, the chapter was concluded by reporting the limitations of this study.

Chapter 9

High-Fidelity Prototype - Usability Evaluation

9.1 Chapter overview

This chapter presents the final high-fidelity system prototype developed based on the Design Critique study findings. The first section of this chapter highlights the major changes in this iteration. The caregiver mode is a new addition to the system design with three main tasks; setting up the medication reminder feature, cooking support and reconfiguring the system preferences when needed. In the following sub-section, we present the final provided memory prompts. In order to evaluate the usability of the final high-fidelity prototype, we conducted a usability study consisting of two phases; cognitive walkthrough evaluation followed by heuristic evaluation. The findings of the cognitive walkthrough are presented in two sub-section. These findings are then discussed from a heuristic evaluation perspective using Jakob Nielsen and Rolf Molich's ten usability heuristics. Finally, the chapter is concluded by reporting limitations.

9.2 High-Fidelity system prototype

Changes in this iteration include updating the User Experience (UX), User Interface (UI), and the design of the memory prompts. In some cases, the design of the memory prompts was improved, and in other cases, we introduced completely new prompts based on the DC findings. In this iteration, the UI design is entirely implemented on the HoloLens 2 using the Microsoft Mixed Reality Toolkit (MRTK) and Unity game engine. In addition, based on the DC study, in this high-fidelity prototype, we introduced two user modes; senior user and caregiver mode. The following three sections describe an overview of these changes. For detailed descriptions, please refer to Appendix E.

9.3 Senior user mode

By default, the system uses the attention/action model to deliver the first reminder to the user to complete their task. Figure E.3 shows how the reminder message is displayed above the wrist and other screenshots of the UI, as seen from the senior user perspective. This message's design is minimal, while the content is picked carefully to avoid sensitive words such as 'remember to' or 'do not forget to.' In addition, the text is displayed in prominent and readable font with only two simple words. Furthermore, the reminder message accounts for users with less motivation to read; therefore, we included two virtual medical pills floating (in the case of the medication reminder) around the message to give the user a visual cue. The same reminder message is displayed again in the second reminder but with a short music cue. The sequence of the memory prompts passed the first two reminders is entirely set by the caregiver. Failure to complete the task results in notifying the caregiver. Appendix E describes the senior user mode, presenting all events for both use cases.

User-system interactions are limited to head gazing; the system will only display augmentations to the user above the wrist area if the user is looking in that direction. Augmentations are displayed in some memory prompts above the required task (above the medicine dispenser or the stove). In the case of cooking support, the system will display a virtual button in front of the user to turn off the stove remotely. This is the only event where near-hand user-system interactions are available as an option.

9.4 Caregiver mode

The purpose of the caregiver mode is to set up the system when it runs for the first and to customize preferences when needed. Accounting for caregivers with different technology skills was an essential consideration throughout the design process. We have made a number of important design decisions to simplify the caregiver mode as much as possible. The user experience flow is set to have a linear flow with a beginning and end of each user task while allowing for easy error-recovery. To avoid using technical language, we selected terms related to caregiving, such as 'set a memory prompt' or 'set a cooking safety range.' Figure E.4 presents screenshots of the caregiver mode UI as seen from the Hololens device. Accessing the caregiver mode is protected with a verbal key phrase and a password. When running the application as a caregiver, users are presented with a simple window containing two buttons only (medication and cooking support); pushing a button will guide the user through the customization process for the selected feature.

9.5 Built-in memory prompts

The current prototype provides six built-in memory prompts: visual cues, music cues, indoor navigation, spatial labels, video messages, and audio messages. All prompts are dynamic; they work with both use cases and provide prompts to the user based on their location concerning the intended task.

1. **Visual cues:** This is a animated visualization displayed around the dispenser or the stove control panel. The Unity 'particle system' feature is used to design this cue. It

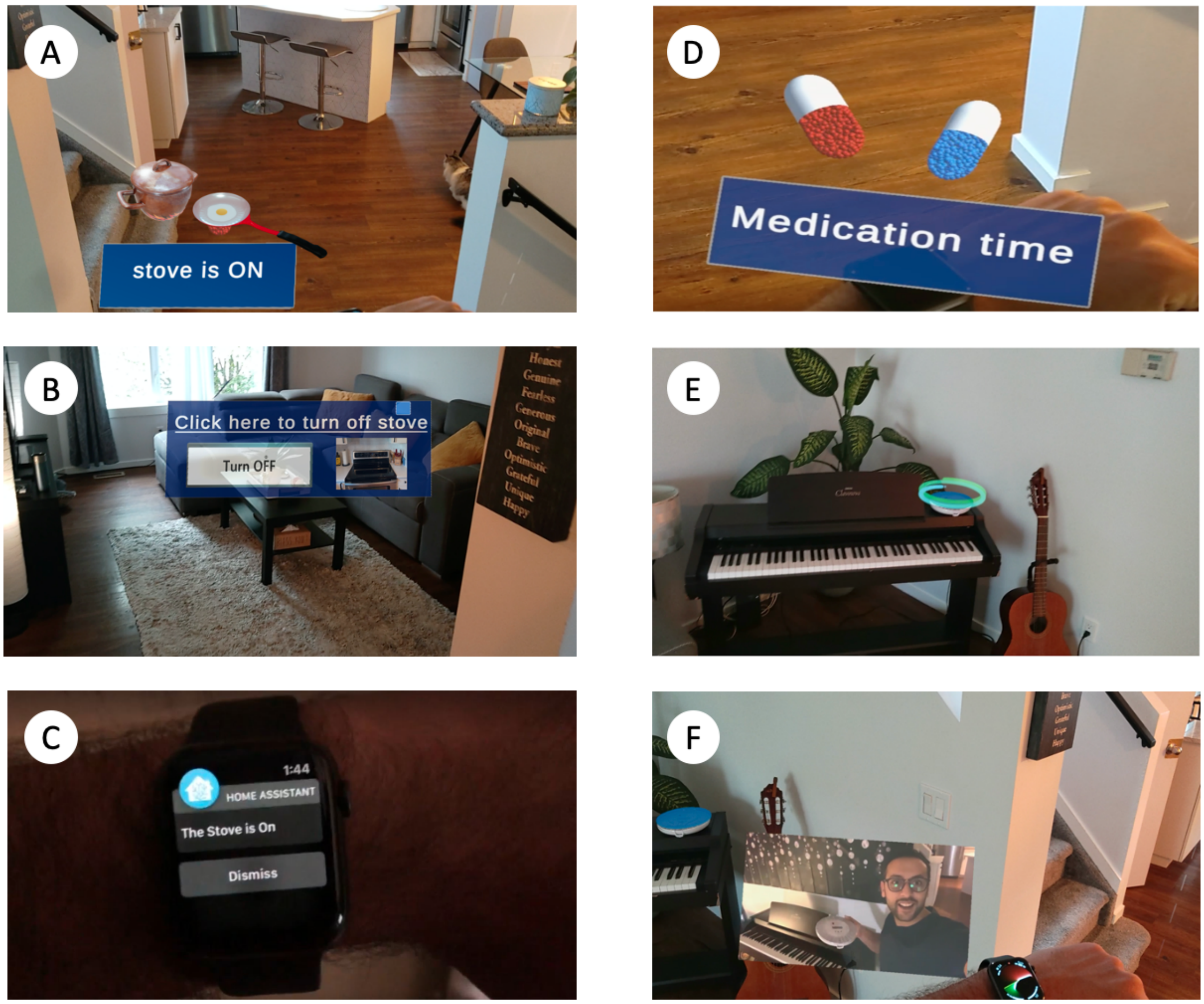


Figure 9.1: Sample of the senior user mode user interface screenshots presenting reminders and selected memory prompts. A) The user receives a holograph reminder above the wrist about the stove. B) A virtual button to turn off the stove remotely. C) The user took off the headset while the stove was running, D) Augmentation reminder to take medication. E) visual cue around the dispenser to attract the user's attention. F) video message as seen by the senior user

Figure 9.2: Sample of the caregiver mode user interface screenshots. A) shows the caregiver aligning the virtual object with the stove. B) the caregiver is adding a new prompt. C) modifying existing prompts, D) customizing a prompt. E) setting cooking safety range. F) selecting a function

consists of two glowing rings that rotate consonantly around the virtual object. The rings are coloured in two light shades of blue and green, known to be soothing colours.

2. **Music cue:** As was discussed in earlier chapters, music is known for formulating strong bound with memories. Moreover, according to our requirements elicitation and DC study, repetition helps SwNCDs to learn new habits. Based on these two points, we introduced music cues to the system where soothing music is played when the system wants to remind the user to complete a task (take medication or turn off the stove). Thanks to the spatial awareness, the HoloLens2 creates a 'spatial audio' experience where the user feels that the music is played from the IoT device itself. If the user follows the music, they will end up right in front of the device.

3. **Indoor navigation:** This prompt displays a dynamic arrow that will guide the user to the IoT device to complete a task. The arrow will disappear only if the user is looking at the device.

4. **Spatial labels:** In conventional homecare, caregivers and SwNCDs use sticky notes to label home items. Inspired by this technique, we introduced these virtual labels that can be displayed above IoT devices. These labels are self-orienting objects; they will track the user's head and self-orient themselves to face the user, making them readable from any angle, all the time.

5. **Video messages:** This type of prompt was the favourite among all DC participants as it engages the senior user's sight and hearing and provides a visual of a familiar person. After the log vibration signal, these video messages will be displayed above the senior user's writs. In addition, we incorporated a feature to check if the user is looking at the video; if they are not, the message will stop and repeat itself shortly after that.

6. **Verbal messages:** As we learned in the DC study, SwNCDs can struggle with reduced

mortification to read. Also, their attention span can be negatively affected, making comprehending the text difficult. Therefore, in this memory prompt, the application will read the reminder using a pre-recorded audio message by a familiar voice (caregiver, family member, etc.)

9.6 Usability evaluation

As it was explained in Chapter 3, as a final step of the User-Centered Design process, we proposed to conduct a lightweight usability evaluation consisting of two stages; cognitive walkthroughs and then heuristic evaluation. To accomplish this goal, we followed the guidelines built on Lewis and Polosn's CE+ theory of exploratory learning [PL90] to develop a standard walkthrough process to identify and report usability issues. After that, we used Jakob Nielsen and Rolf Molich's usability heuristics to discuss our cognitive walkthrough findings [NM90].

9.6.1 Cognitive walkthrough

The cognitive walkthrough is a usability engineering tool that allows design teams to evaluate user interface designs in a systematic method that simulates the end-user's perspective. Due to the special requirements of our end-users (both: caregivers and seniors), we divided our set of questions into two groups[RFR95].

For evaluating caregiver user tasks, we used the three questions from the Nielsen Norman Group [Sal22] which are based on Lewis and Polosn's early mentioned work [NM90, RFR95]. In addition, we added two new questions that are more suitable for our caregiver end-users. The first added question is to assess if a task can be completed by users with different technology skills, which is important to assure that the user interface design accounts for most potential users. The second added question is to examine error recovery. Table 9.1 presents cognitive walkthrough questions for both user tasks.

Table 9.1: Cognitive walkthrough questions for senior and caregiver user tasks

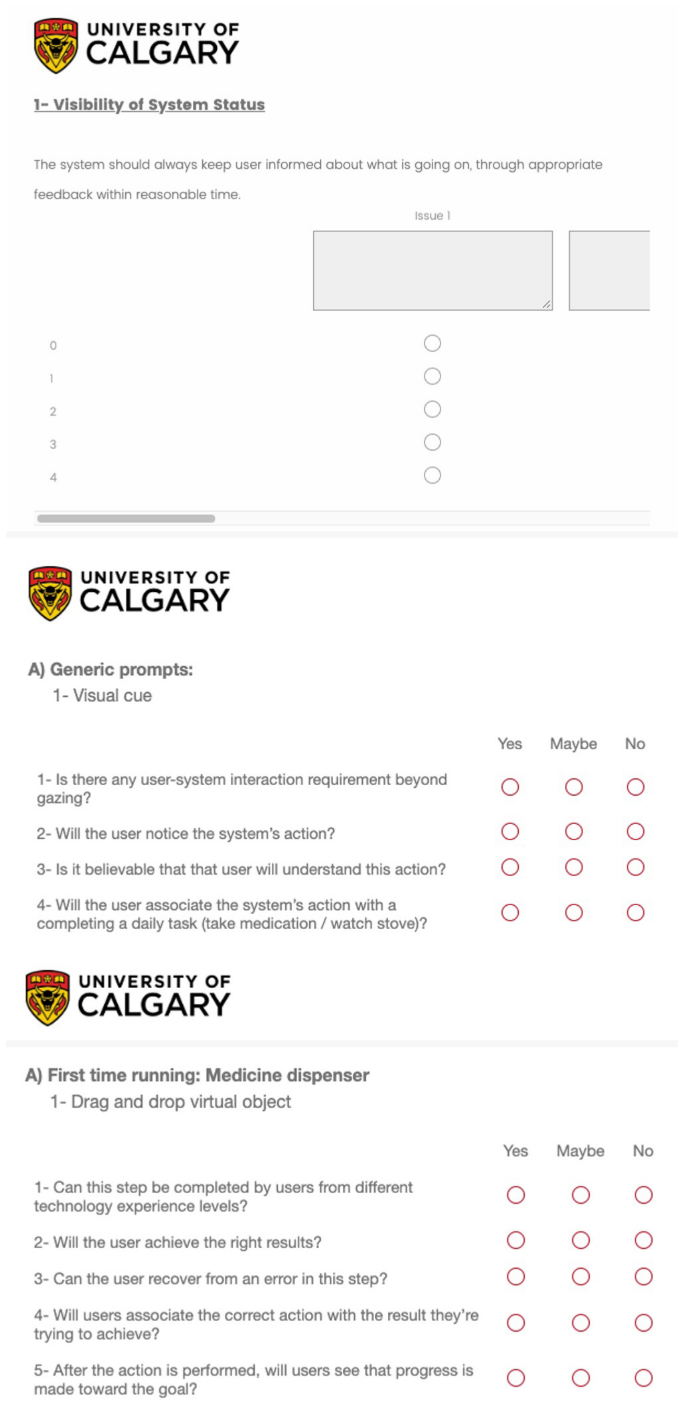
Cognitive walkthrough questions for caregiver tasks	Cognitive walkthrough questions for senior user tasks
1- Can this step be completed by users from different technology experience levels? (new questions) 2- Will the user achieve the right results? 3- Will the user recover from an error in this step? (new questions) 4- Will users associate the correct action with the result they are trying to achieve? 5- After the action is performed, will users see that progress is made toward the goal?	1- Is there any user-system interaction requirement beyond gazing? 2- Will the user notice the system's action? 3- Is it believable that that user will understand this action? 4- Will the user associate the system's action with completing a daily task (take medication / watch stove)?

For the senior user tasks, we referred to our previous DC study to identify important measurements required for every user-system interaction then we introduced the below four questions. The first question examines if there are any required interactions beyond head gazing. The second question examines the system's ability to attract the user's attention. The third question is about the user's ability to comprehend system actions. The last question assesses the association between system actions and real-life user tasks (medication, stove etc.).

9.6.2 Online survey

We used Qualtrics XM to create two surveys for the cognitive walkthroughs; caregiver and senior user tasks. Figure 9.3 presents screenshots of the survey questions. Each survey presented all user tasks in proper sequence along with the cognitive walkthrough questions. Evaluators had to answer the same set of questions for every user task. Understandably, there are three choices to answer the questions; yes, no or maybe. We used a Miro[1] online shared board to present a flow of screenshots and video domes of all user tasks in the same sequence as the surveys. Evaluators followed the screenshots and videos on Miro for each task, then filled up the online survey. This step was repeated for each user task independently and anonymously. Each evaluator would answer: (5 questions * 24 caregiver tasks) + (4 questions * 13 senior user tasks) = 172 questions.

[1] https://miro.com



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1- Visibility of System Status

The system should always keep user informed about what is going on, through appropriate feedback within reasonable time.

Issue 1

0
1
2
3
4

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A) Generic prompts:

1- Visual cue

	Yes	Maybe	No
1- Is there any user-system interaction requirement beyond gazing?	○	○	○
2- Will the user notice the system's action?	○	○	○
3- Is it believable that that user will understand this action?	○	○	○
4- Will the user associate the system's action with a completing a daily task (take medication / watch stove)?	○	○	○

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A) First time running: Medicine dispenser

1- Drag and drop virtual object

	Yes	Maybe	No
1- Can this step be completed by users from different technology experience levels?	○	○	○
2- Will the user achieve the right results?	○	○	○
3- Can the user recover from an error in this step?	○	○	○
4- Will users associate the correct action with the result they're trying to achieve?	○	○	○
5- After the action is performed, will users see that progress is made toward the goal?	○	○	○

Figure 9.3: Sample of the cognitive walkthrough surveys and the online heuristic evaluation form. Top, heuristic evaluation from. Middle, cognitive walkthrough for senior user tasks. Button, cognitive walkthrough for caregiver user tasks

9.6.3 Heuristic evaluation

The goal of the heuristic evaluation is to report detected usability using the established Jakob Nielsen and Rolf Molich usability heuristics [df19, NM90] (Please refer to Chapter three, for a detailed list of these ten usability heuristics). If the evaluator answered any of the cognitive walkthrough questions with a 'no,' they would refer to the heuristic evaluation web form, which we also created on Qualtrics. The form presents the ten usability heuristics and allows evaluators to report found issues and rate their severity on a scale. Our issue severity scale consists of the following five degrees:

1. Does not require any actions at this stage
2. Cosmetic only: can be fixed if extra time is available
3. Minor usability problem: fixing this should be given a priority
4. considerable usability problem: should be given high priority
5. Usability catastrophe: imperative to fix this before releasing

9.6.4 Study participants

As was recommended by the Interaction Design Foundation, both heuristic evaluation and the walkthroughs should be completed independently by 3-5 evaluators [df19]. These evaluators should be considered experts in designing similar applications and working with similar end-user groups as well. We recruited four evaluators, all of whom are Mixed Reality (MR) developers. In addition, all evaluators have 2-3 years of experience in academic research as they specialize in designing MR applications for challenged populations, including people on the spectrum of autism. Given their experience, the evaluators were familiar with the different design requirements and user categories; caregivers and primary end-users.

9.7 Cognitive walkthrough findings

After reviewing the survey results, we found that evaluators answered 596 of the cognitive walkthrough questions positively, 49 neutrally (maybe), and 22 questions negatively. Therefore, in the following two sub-sections, we present important findings for the user tasks that received feedback from the evaluators.

9.7.1 Senior user tasks

In the medication reminder case, we have only two tasks: the default reminder (Apple watch vibration then a message above the wrist), followed by transitioning to the first memory prompts in case the user does not respond to the reminder. Evaluators did not report any issues regarding these two tasks. As seen in Figure 9.4, participants found both tasks achievable by the senior user.

In the cooking support scenario, we have a total of 5 tasks; as seen in the same Figure 9.4, evaluators answered with 'no' to only three questions related to user two tasks only. In other words, the evaluators identified potential usability issues in two tasks only. In the 'virtual turn stove off button' task, evaluators noted that such task requires hand interaction with the system where the senior user would reach out to a virtual button to turn off the stove remotely. Similarly, if the user takes off their MR headset while the stove is on, the system will display a button on the Apple Watch to turn off the stove remotely, which would also require hand interaction. To this point, evaluators reported that the message above the button on the Apple Watch interaction does not include the word 'stove'; thus, the user might not associate it with the real-life task (turn of the stove). Other evaluators thought these hand interactions were simple and inviting (pushing a single button only), and senior users might be able to complete these tasks. Lastly, some evaluators highlighted the chances of missing the reminder on the Apple Watch device if the screen sleep time is short. For detailed descriptions of all these tasks, please refer to Appendix E.

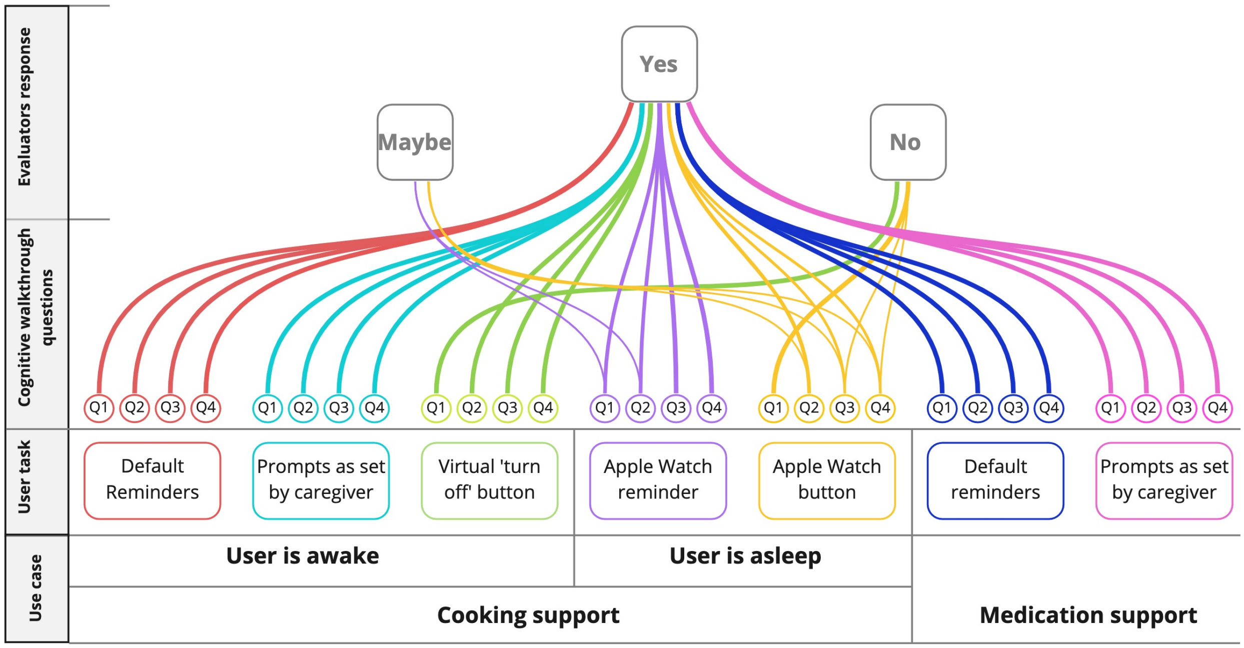

Figure 9.4: Stretch cords diagram illustrating all senior user tasks and the four evaluators responses to the cognitive walkthrough questions. Each circle represents a walkthrough question, starting left to right. The evaluators answers to the cognitive walkthrough questions are represented by a single stretch chord. The thickness of each chord represents the number of responses

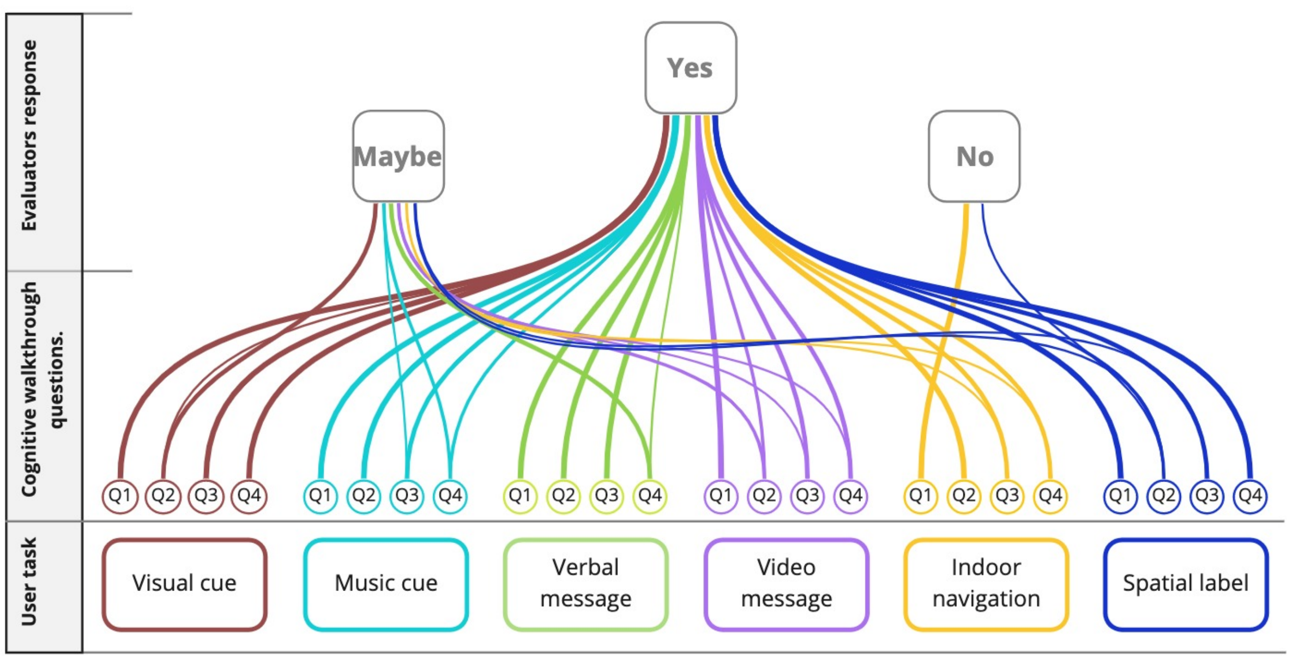

Figure 9.5: Stretch cords diagram illustrating all senior user memory prompts and the four evaluators responses to the cognitive walkthrough questions.

As for the memory prompts, evaluators answered with 'yes' to the majority of cognitive walkthrough questions for all six tasks; see Figure 9.5 for details. However, two usability issues were reported by some evaluators; firstly, the 'indoor navigation' prompts requires the user to follow the arrow to find the IoT device (dispenser/stove), which is relatively easy if the user and the device are in the same room. However, if the user is in a different room, they need to walk to the device's room to see it. Another issue was related to the spatial labels; some evaluators found the font too small for senior users. Finally, evaluators advised limiting the number of times the video message will be played to avoid frustrating the user.

9.7.2 Caregiver user

Figure 9.6 and Figure 9.7 illustrates the cognitive walkthrough results for all caregiver user tasks. The first section of the walkthrough examined all the tasks related to setting the medication support functionality. For the vast majority of these tasks, evaluators thought it was achievable by the caregiver, except for the 'complete adding prompts' task. However, evaluators discovered a usability issue related to navigating between all prompts before completing the setup process. In addition, some evaluators wondered if the caregiver would know how to confirm the final location of the virtual object. Both issues were reported again in the cooking support as well. One new issue was found in the task related to 'setting cooking safety range' where the window should have a 'set range' and 'complete' buttons, which can confuse the participant.

The second set of caregiver tasks was related to reconfiguring system preferences. Similarly, the evaluator responded positively to the majority of the cognitive walkthrough questions related to these tasks. However, they identified two important usability issues pertaining to the 'modify existing prompts' task. Firstly, the user interface allows for multiple selections while the user can actually modify only one prompt at a time. Secondly, it is unclear to the user how to delete an existing prompt and start over. Figure 9.8 illustrates cognitive walkthrough responses for all these tasks.

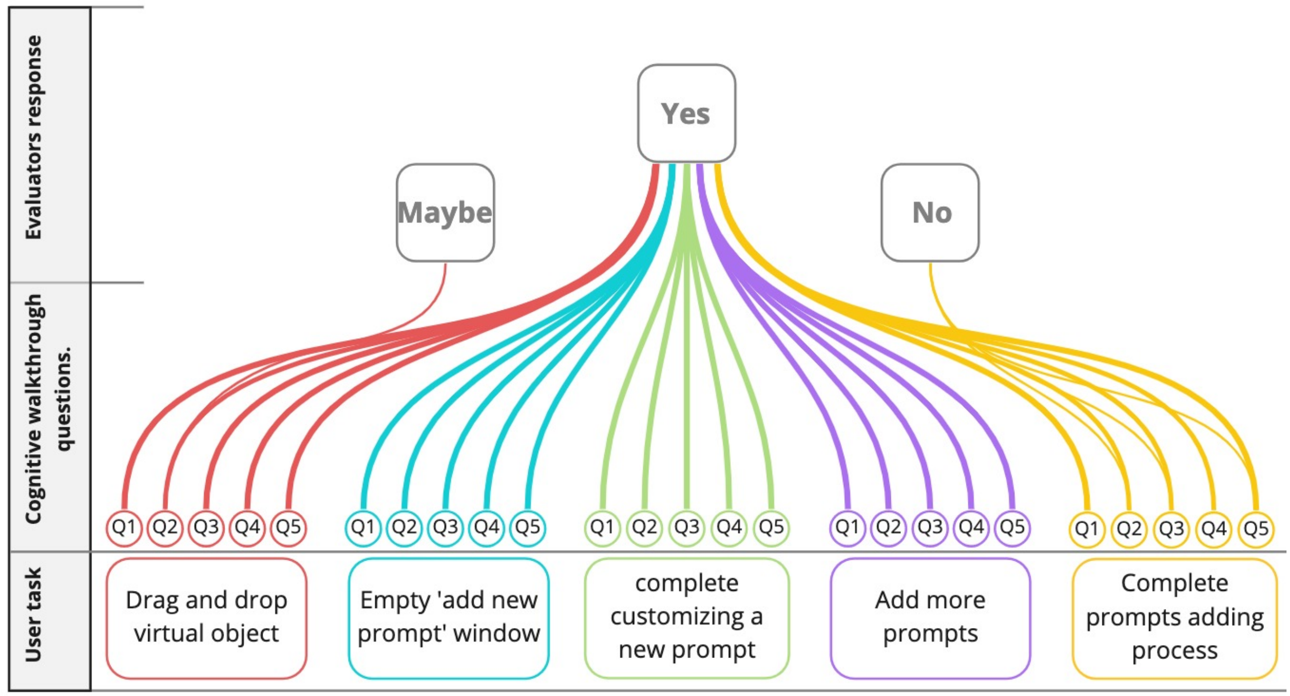

Figure 9.6: Stretch cords diagram illustrating evaluators responses to the caregiver user tasks when setting up the medication support feature for the first time.

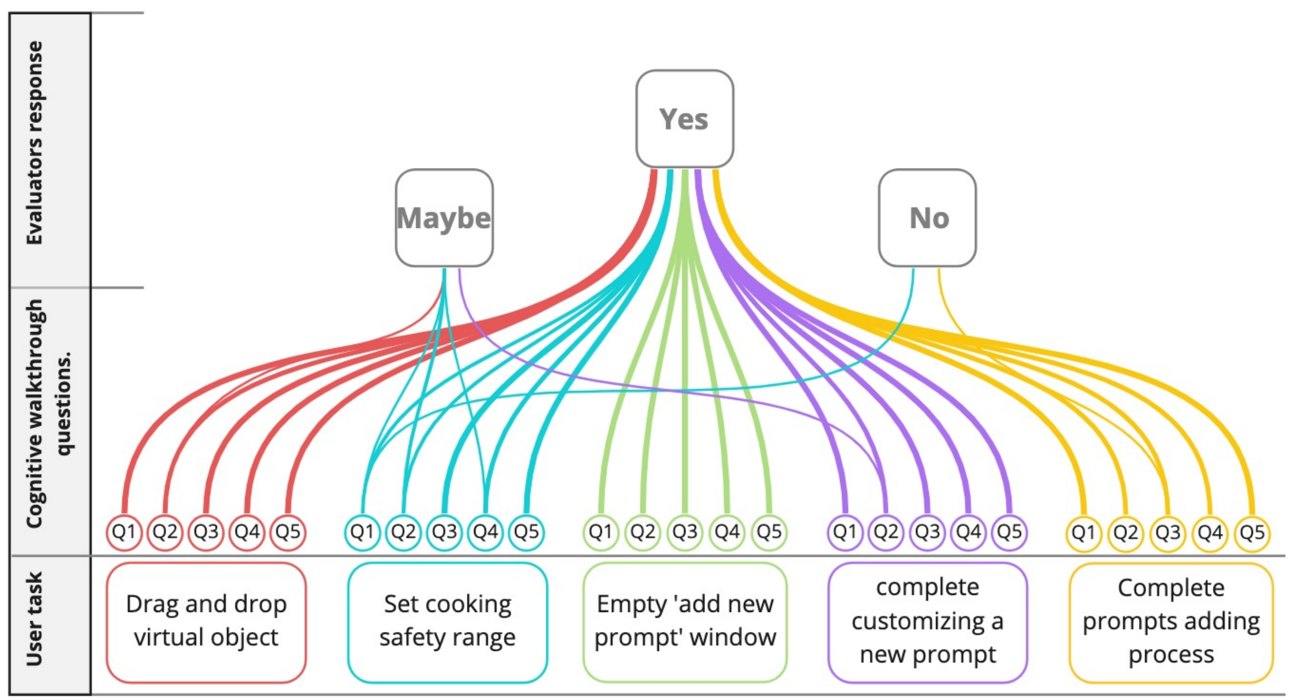

Figure 9.7: Stretch cords diagram illustrating evaluators responses to the caregiver user tasks when setting up the cooking support feature for the first time.

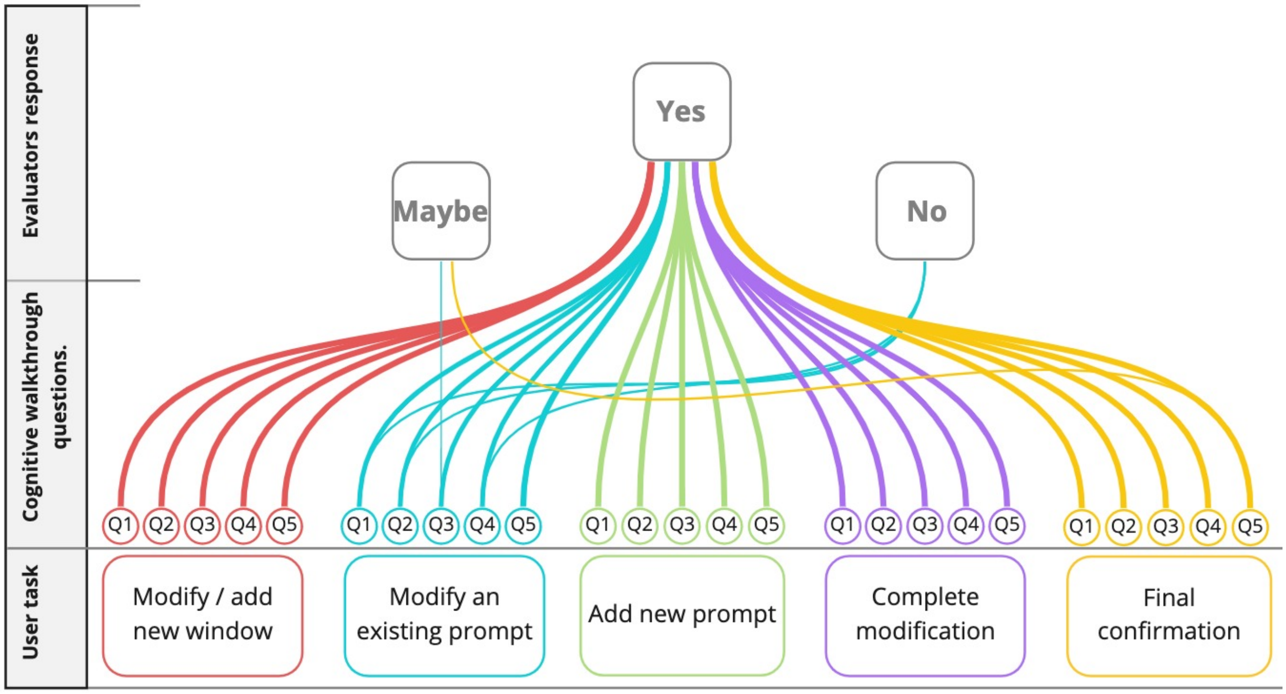

Figure 9.8: Stretch cords diagram illustrating evaluators responses to the caregiver user tasks when reconfiguring system preferences.

9.8 Heuristic evaluation discussion

In this section of the chapter, we discuss all usability issues that were identified in the cognitive walkthrough evaluation based on the established ten usability heuristics they violate. The severity of these issues, along with suggested solutions, are discussed as well.

9.8.1 Senior user tasks

Figure 9.9 presents relationships between the task, the reported issue, their severity, and the usability heuristics they violate. Three identified issues scored the lowest on the heuristic evaluation severity scale. These issues were related to the nature of mixed reality user interfaces themselves, where users may not see visual elements if they are in a completely different space. One solution to this type of problem is to use a concept called 'directional solver,' which we have already integrated into the system as a memory prompt and called 'indoor navigation. Therefore, caregivers can couple any memory prompt with the 'indoor

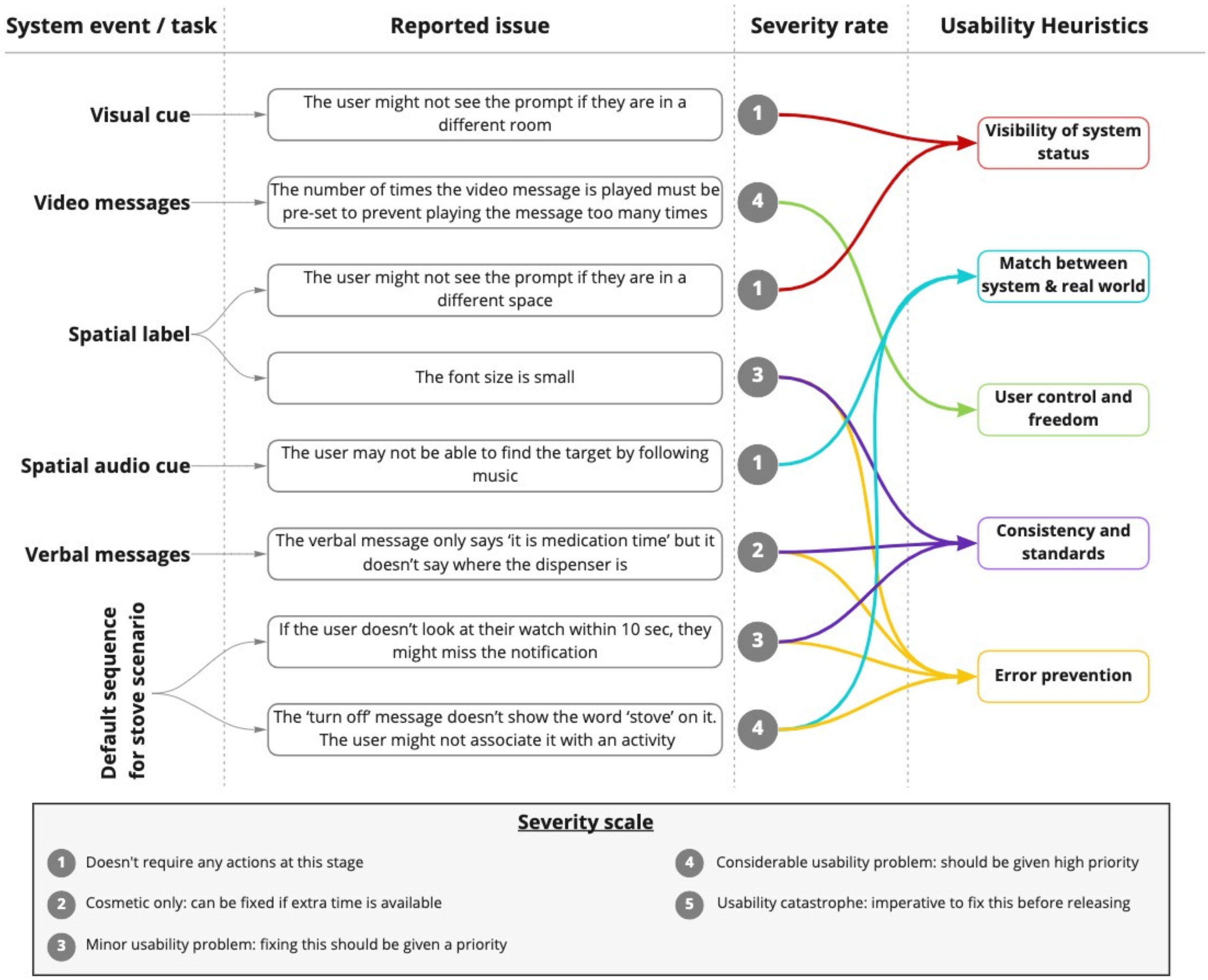

Figure 9.9: Diagram presenting all reported usability issues for the senior user tasks, their severity rating, and linked to the usability heuristic they violate. Diagram is presented left to right

navigation' if needed. Understandably, these three issues fall under the 'visibility of the system status' heuristic.

Only one issue was identified as 'cosmetic'; the verbal messages only remind the user to complete a task, but it does not say how and where. Other prompts, however, can provide further information if the user did not respond to the verbal message. This issue falls under 'consistency and standards and the 'error prevention' heuristics.

Two other issues were reported as minor usability problems that require attention at this stage. First, the spatial label memory prompts text appeared to be small that SwNCDs might not be able to read it if they were 1.5 meters away. This issue violates the 'consistency and standards' and 'error prevention' heuristics, and it must be addressed by either increasing the font size or writing an auto adjustment script for the label's text regarding the user's distance. The other issue is related to the Apple Watch application where the user might miss the stove notification if they didn't look at the watch within the first 10 seconds. One solution to this problem is to increase the active screen time on the watch itself simply.

We found two considerable usability problems only. The first problem is related to the number of times the video message is played. In the current design, if the user stops watching the video message halfway through, the message will stop and reply the next time the user looks towards their wrist (the Apple Watch). This issue violates the 'user control and freedom' heuristic as they may feel stuck in a loop until it is time for the next prompt. There are two possible solutions; a) set the time the video message can be replayed, and b) reduce the number of times the message can be replayed before moving to the following prompt. The second considerable usability issue is pertaining to the remote stove turning off button on the Apple Watch. The current message says 'press the button to turn off.' However, the Apple Watch did not display the entire message due to the limited screen space. The suggested solution is to reduce the message to "press to turn off the stove" to assure full display of the message on the watch.

9.8.2 Caregiver user tasks

Figure 9.10 demonstrate all reported issues, their severity and the usability heuristics they violate for the caregiver user tasks. Some evaluators reported a considerable usability issue pertaining to confirming the final location of the virtual dispenser object. The current design requires users to double tap on the virtual object to set the final location, which violates the 'visibility of system status' heuristic. The user may mistakenly double tap on the object while they are still moving it around. There are several ways to address this issue, such as using verbal commands or simply adding a 'confirm location' button. Another considerable usability issue in this task is the lack of clear navigation options between the different user interface windows. At some point, the user might get stuck in a window and cannot move back to a previous window which negatively affects the user task's consistency.

In setting up the cooking support feature, an issue was reported as a 'cosmetic issue' pertaining to the caregiver using a slider to set the cooking safety range. The evaluator commented that the user might not link the slider value (per foot) to real-world measurements and wondered if it was possible to use hand pointing to draw a 'safe zone' similar to Virtual Reality systems. Evaluators identified one considerable issue in this same task. The 'setting safety range' window has a default value of 8 feet. The current user interface displays 'set range' and 'complete' buttons, which can confuse the user. Evaluators suggested using the 'complete' button to set the new range, save changes and exit the menu.

Two minor usability issues were found in the 'editing existing preferences' user task that may violate the 'error prevention' heuristic. First, when caregivers want to edit existing prompts, they are presented with a window displaying check boxes next to every available prompt. These check boxes indicate that a user can edit multiple prompts simultaneously, while the application does not support that. Therefore, these checkboxes should be changed to radio buttons, which only allow for a single selection. When a user accesses the editing window, a button says 'add more prompt,' which can be confusing according to our evaluators. This button allows the user to add more prompts from two different windows, which could increase the chances of errors. Therefore, this button should be removed from the editing window.

All evaluators noticed that if a caregiver wanted to remove an existing prompt, they would have to access the editing window and disable the toggle switch(s). This issue was reported as a considerable usability issue as it restricts the user's freedom from deleting the prompt directly. A suggested solution is to add a 'delete button' for easy interactions.

Besides setting up the MR application, caregivers can interact with the system using the HomeAssistant mobile application to either monitor IoT device usage or remotely control

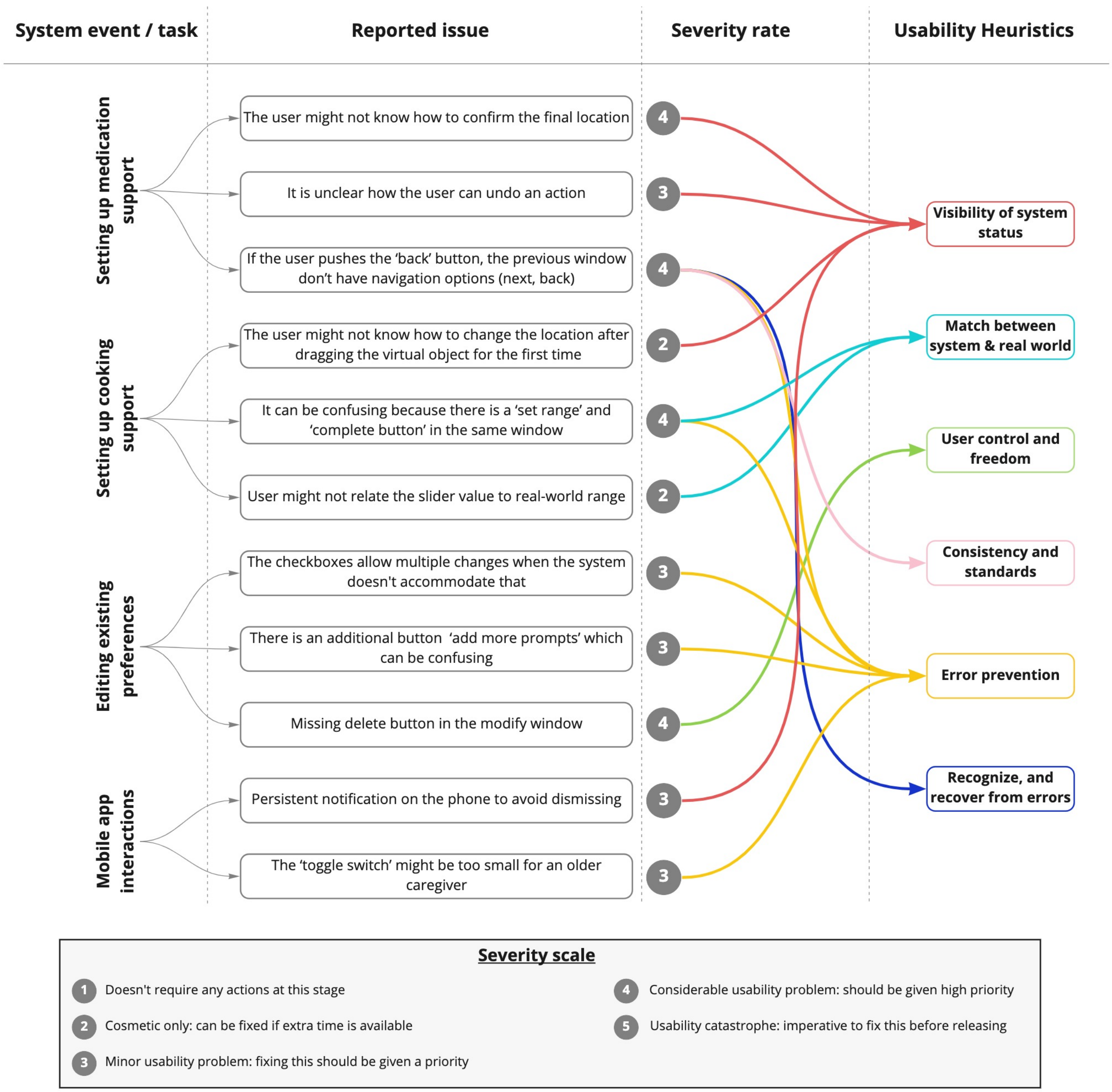

Figure 9.10: Diagram presenting all reported usability issues for the caregiver user tasks, their severity rating, and linked to the usability heuristic they violate. The diagram is presented left to right.

the stove. Therefore, it was important to include the mobile application user tasks in the heuristic evaluation. We identified two minor usability issues in these tasks. Firstly, when the system sends a notification to the caregiver, this notification is subjected to the mobile phone settings (seeping, driving, do not disturb mode, etc.), which means the caregiver can miss these notifications. User can edit their phone settings to allow delivering HomeAssistant notifications despite the mobile phone mode if they prefer that.

As seen in Figures 9.12 and 9.11, visibility of the system status, 'error prevention' and 'matches between system and real world' were the most discussed usability heuristics. The majority of the user tasks didn't suffer any usability issues, according to our evaluation. Most tasks that received feedback from the evaluators were classified as either minor or neglectable. Furthermore, we did not identify any major usability issues. The very low number of considerable usability issues indicates that our suggested design, based on the DC study, has high usability potential.

9.9 Limitations

Heuristic evaluations are powerful in detecting usability problems by reviewing user-system interaction with a small group of domain experts at the final design and development stage. However, the evaluators' experience and personal perspectives can affect the evaluation results. To improve the quality of the final results, we incorporated an additional step by conducting a systematic cognitive walkthrough process where evaluators had to answer specific usability questions for every user task. While this step can reduce evaluators' biases, it does not eliminates them. Therefore, testing the prototype with end-users is required to support the findings further.

The Interactive Design Foundation argues that finding experienced heuristic evaluators can be more challenging than running usability testings [df19]. This emphasizes the importance of finding evaluators with sufficient experience in the same field. In our case, we had only one MR expert who worked with SwNCDs. In our search for more evaluators, we found a research group working on MR applications for people with neurodevelopmental disorders (mainly Autism) and their caregivers. This group follows a similar user-centred design approach as ours. All group members were graduate students with 2-4 years of experience in their field. Three graduated students were recruited as evaluators based on some similarities between both projects and their experiences. This adds two additional limitations to this study. Firstly, these three evaluators have not worked with the same end-user group; therefore, they might have missed identifying usability issues during the evaluation. Secondly, these students worked in a different research lab at the University of Calgary and thus, selection bias could form a threat to the validity of this evaluation.

9.10 Conclusion

This chapter described the final high-fidelity system prototype running on a HoloLens2 device and a set of IoT devices. The design of this iteration emerged from the findings of the Design Critique study. Several changes and new features were Incorporated in this iteration, including two user modes (senior user and caregiver user), six types of dynamic memory prompt designed specifically for SwNCDs homecare, and customization support. To validate updated Ho-Fi prototype design, we conducted a usability evaluation with domain experts (MR experts) consisting of two stages. In the first stage, we asked four evaluators to run a cognitive walkthrough process by reviewing every user-system interaction and answering a questionnaire consisting of a set of usability questions for every user task. Through answering these questions, evaluators identified usability problems. We conducted a heuristic evaluation in the next stage using Jakob Nielsen and Rolf Molich's ten usability heuristics.

Our evaluators reported only two considerable usability issues for the senior user tasks. The first issue is regarding the use of the Apple Watch to allow the senior user to remotely turn off the stove if they take off the MR headset. The second issue pertains to the number of times a video message can be played if the user continuously looks away before the message is ended. Two minor usability problems were found related to the font size of the spatial label prompts and the time of displaying a reminder on the Apple Watch (if the user takes off the glasses).

The evaluation identified only four considerable usability problems in the caregiver tasks. The first two issues were related to setting the medication support feature. For example, in the same task, caregivers might get stuck on a certain window due to the absence of navigation buttons (next, back). Another considerable problem found in the setting of the cooking support feature where selecting the cooking safety range can be confusing due to an additional unnecessary step. In addition, the evaluation identified five other minor usability problems, such as having different buttons that lead to similar output, size and appearance of some UI elements, and difficulty undoing an event. We provided solutions for each of these problems in our discussion section.

As discussed earlier, none of the evaluators found any major usability problems (the severest on the 0-4 scale). Furthermore, the number of considerable and minor usability problems identified by evaluators is relatively low, indicating a high usability scale. Finally, the overall positive evaluation outcome can be attributed to our proposed process of early gathering of system requirements, video prototyping and the Design Critique evaluation. However, further user testing is required to support this claim.

Chapter 10

Conclusion

10.1 Overview of the thesis contributions

In this thesis, we proposed a novel utilization of commercial IoT devices and Mixed Reality (MR) technology to support aging in place for seniors living with neurocognitive disorders. In addition, we followed a comprehensive process of investigating, designing, prototyping and evaluating the proposed system. Our process provides a road map for future researcher and introduces new design recommendations to the body of supportive and immersive technology literature.

Our systematic literature review provided a state-of-the-art review of important work and introduced a taxonomy of the literature which was missing prior to this work. Our review can assist future researchers in identify research gaps and common practices in the field. Furthermore, our discussions of the review results introduce insights into the different design approaches, the techniques of collecting smart home data, common prototyping and evaluating methods and finally, the benefits and limitations of each approach.

Our requirements elicitation study explored special requirements for designing supportive smart home systems for SwNCDs. This study provided evidence-based desired system features, user considerations and design considerations. Furthermore, the study identified 23 challenges seniors and their caregivers face at home. We divided these challenges into three categories and discussed how a smart home system could address some of these challenges.

One major challenge with most IoT ecosystems is that devices from different makers do not communicate with each other. Therefore, we explored using the HomeAssitant operating system to run a local server that works as a single point of control for the entire smart home system. Furthermore, it allows IoT devices to communicate with each other without needing to write code for different APIs.

The design process introduced in this thesis sheds light on the importance of understanding user flow and task flow for this target population. In addition, our rapid video prototypes allowed us to evaluate our system design with various stakeholders remotely across Canada and the USA.

One of the most important contributions of this thesis is the proposed Design Critique (DC) framework. To our knowledge and based on another systematic literature review that we conducted by the end of December 2021, this thesis is the first to implement such a systematic DC process in HCI research. We used this process to evaluate to initial system prototype remotely with 24 participants across Canada and the US. Our findings indicate that this method effectively elicited meaningful feedback, which allowed us to extract design recommendations for immersive smart homes for SwNCDs. Future researchers and designers can use our suggested recommendations to introduce systems tailored for SwNCDs' needs.

Moreover, we discussed our newly extracted recommendations and guidelines from multiple stakeholders involved in aging in place for SwNCDs. Our discussion provided highlights about the concerns of each stakeholder category. Our last discussion in the DC study explored the interrelationships between NCDs-related problems, how they affect the user's daily living and how an immersive smart home system can respond to these challenges. We visualized these relationships in a 'mind map,' which can provide future researchers with reference to all these important relationships. Lastly, we conducted a second round of DC with six MR developers to elicit recommended practices for implementing such solutions using Microsoft Mixed Reality Toolkit and Hololens 2 device.

In the last part of this thesis, we used our design recommendations to reiterate the initial design and develop a high-fertility system prototype on the Hololens 2. To evaluate this prototype, we conducted cognitive walkthroughs and heuristic evaluation with four assistive MR application experts. Our evaluation shows that none of the evaluators found serious usability violations for all user tasks. Furthermore, the majority of the reported issues scored either minor or negligible on the severity rating scale. This indicates to the effectiveness of our proposed design and evaluation process.

10.2 Research questions

10.2.1 Supportive smart home systems; taxonomy, design approaches, prototypes and data

Our systematic literature review presented in Chapter 4 identified three main categories of supportive smart homes based on their function: monitoring, supporting, and emergency response. Among these three categories, smart homes accounted for the majority of identified work for monitoring purposes. Within this category, we found three different sub-categories: activities of daily living monitoring, cognitive health monitoring, and physiological health monitoring. As for the support category, we identified three types of smart homes: memory prompts, cooking assistance and personal hygiene support. Finally, two types of smart home concepts were identified under the emergency response category: fall and wandering detection.

Although it is recommended to follow a User-Centred Design approach when designing supportive smart homes, our findings indicate that 46% of the studies did not report any form of user research. Whereas 32% of the work we reviewed extracted system requirements from previous literature or solely relied on previous requirement elicitation studies. Only 22% of studies reported conducting user research and following a completed User-Centered

Design process.

Using high-fidelity system prototypes appeared to be the most common form of prototyping. In many studies, these prototypes were field-deployed for various user testing including accuracy testings, usability scale, usefulness and acceptance levels. On the other hand, low-fidelity prototypes were used the least. The use of these prototypes was sufficient when the testing was limited to functional aspects of the system (e.g: testing the accuracy of detection various indoor wandering patterns).

From a high level, we identified two different techniques of collecting smart home data depending on the sensing technology: ambient sensing and hybrid sensing. One benefit of ambient sensing is that the system can collect important data without the need for wearable devices. On the other hand, taking off the wearable device can affect the system's functionality in the case of hybrid sensing. In either case, in our review we highlighted the effectiveness of using sensor data only and explored the downsides of using video cameras. Therefore, we suggest future researchers to avoid such intrusive approaches and use sensor data only (ambient or hybrid).

10.2.2 The special requirements for designing supportive smart home systems for SwNCDs

According to our requirements elicitation study in Chapter 5, we learned that there are several unique requirements for designing smart home systems for SwNCDs. We divide these requirements into; user considerations and design requirements. It is recommended that the system should support two user modes; senior user and caregiver user. For the senior user, it is required that the supportive smart home maintain a sense of agency and consider the user's feelings and dignity by providing multiple tailored memory prompts before intervening, and use a respectful system language. Investigating the user experience and user interface design are essential requirements during the design phase to assure higher usability rates, especially for this target population. Furthermore, user-system interactions may consider illness-related issues such as the potential neurological signal delay that negatively affect seniors' responses. In any case, respecting the senior's will and obtaining their consent while consulting with their primary caregivers is required prior to technology adaptation

As for the design requirements, simplicity appears to be a key factor for learning new skills and improving technology acceptance. It is recommended that the design of any user interface to be simple and objective, while avoiding any unnecessary artistic content that requites interpretation. In terms of user experience design, engaging more than one sense could yield better results for SwNCDs, such as audio messages and visual cues, rather than relying on text only. As for the user experience aspect, the system may provide different levels of interventions and various ways of memory prompts to accommodate the various needs of different users.

Neurocognitive disorders come with challenges that can affect the person's life on multiple levels, including the negative effect on completing activities of daily living, possible effects on physical health, and personality changes for some individuals. Some issues related to daily living activities can be addressed using a smart home, such as: leaving home appliances on, losing a sense of time and disorienting, or losing personal items at home. Similarly, home health-related issues can also be supported, such as: taking medication on time, monitoring water intake and food consumption, or monitoring sleeping patterns. Our findings indicate that seniors and caregivers appreciate two desired smart home system functions; activity monitoring and memory prompting. The activity monitoring allows the caregiver to observe certain activities at home which can come with 'piece of mind'. Whereas, the memory prompting can provide higher sense of agency by giving the senior user multiple chances to complete tasks independently.

10.2.3 Designing immersive MR applications for SwNCDs

Our MR application aims to facilitate an immersive, seamless, and hands-free interaction between the user and the smart home system. These features allows SwNCDs to interact with such system only when needed without the need for carrying and interacting with touch surface device. Accommodating the special requirements of NCDs when designing an MR application can be done through a careful, empathetic and user-centred design approach. According to our DC study, it is recommended that the MR application design be more informative than interactive. In other words, the user interaction would be limited to necessities such as delivering a reminder or a memory prompt when needed. In addition, minimizing hand interaction and relying more on head gazing where the user is not required to take any action beyond looking at an object was an important finding in our DC study. This minimalism reduces the complexity of user-system interactions and thus, it can reduce user errors.

We learned that there are several user experience design considerations that could accommodate the user's special requirements, such as using simple and repetitive steps, combining different sensory triggers when trying to capture the user's attention, developing a consistent attraction-action sequence, using audio/visual cues, and using a familiar a voice when developing audio messages.

As for the user interface design aspect, we identified recommendations for the system's visual design and the used language. SwNCDs may struggle with learning new technologies; therefore, it is encouraged to use simple system language that is far from being technical (e.g: time for medication). The same consideration may also be applicable to the caregiver, as spouses represent a considerable proportion of informal caregivers who do not necessarily have a strong technology background. From a visual design perspective, our findings show that it is recommended to use fade-in-out and smooth floating effects when displaying a hologram to avoid triggering a startled response. Near interaction augmentations may be displayed close enough to the user but not in front of them to avoid tripping and falling incidents. Reminder messages may use short text, icons and expressions with high contrast colours displayed on transparent backgrounds. Using expressive graphics and short text could increase the chances for user response as the motivation for reading could decrease when living with NCDs.

10.2.4 Stakeholders perspectives on the proposed system design

In this thesis, we included four different types of groups involved in aging in place and caregiving for SwNCDs; seniors, informal caregivers, formal caregivers, and domain experts (researcher, industry partners, etc.). According to our DC study, it appears that SwNCDs are interested in smart home features that could improve their quality of life and provide a sense of agency and independence by supporting simple reminders and memory prompts. Therefore, discussing the usefulness aspect of the smart home system was at the center of their input.

Informal caregivers appeared to be more concerned about usability-related aspects such as user experience and user interface design details. In addition, they suggested that major usability issues could lead to technology adaptation failure, even if the technology is useful. Hence, we noticed an emphasis on user interface and user experience design details such as proper system language, effective attention capturing techniques, proper visual elements design, and concerns about reducing user errors when interacting with the system.

Formal caregivers provided more insights on how NCDs and other health-related issues can affect the design of an immersive smart home system. For instance, incorporating hearing aid devices and accounting for sight issues were proposed as important factors for successful utilization. Additionally, they highlight the importance of accounting for NCDs-specific issues such as neuro-delay, attention span, and sensory activation.

Finally, domain experts proposed benefiting from existing dementia therapy techniques such as the Errorless Learning Method by designing user tasks with minimal chances for user errors. In addition, they suggested incorporating more user-system interactions for seniors with an early-mid stage of NCDs, such as simple hand interactions or voice commands; these interactions may be removed as the user's condition progress. Finally, reviewing medical history prior to technology adaptation with the clinical practitioners was suggested by some domain experts. For instance, seniors diagnosed with Lewy Body Dementia may experience hallucinations, and thus, using MR technology for this population requires further investigation.

10.3 Future work

Our proposed process resulted in a new set of recommendations for immersive supportive smart homes dedicated to SwNCDs. To further establish these findings, we suggest future research to incorporate these recommendations, add more use cases and conduct user studies to test the usability scale of such systems.

From a theoretical perspective, we recognized the limitations of conventional prototype evaluation methods. The COVID-19 pandemic shed more light on the importance of findings and alternative evaluations methods. In this thesis, we implemented a systematic process of conducting Design Critique studies remotely. We encourage future research to further explore our proposed process particularly in the field of assistive technologies. In this regard, we suggest investigating the evaluation of assistive technologies remotely using Virtual and Cross Reality. This approach can increase accessibility to small participant populations such as SwNCDs or people with other forms of cognitive disabilities.

Finally, the field of immersive supportive technologies is as new as the technology itself. We recognize all the limitations of emerging technologies, but we also foresee the tremendous future potential for such technology. We hope this humble work has added a few bricks to pave the way for future researchers.

The end

By: Lorans Alabood, son of Waheda

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Appendix A

Design Critique SLR paper abstract

A systematic literature review of the Design Critique method

Abstract

- **Context:** The Design Critique (DC) method is becoming more common in Human Computer Interaction (HCI) and User Experience (UX) studies as the need for new evaluation methods of emerging technologies is increasing. However, there is an clear lack of guidelines on how to conduct DC studies in the UX context.
- **Objective:** The goal of this paper is to provide an overview of the DC method in the fields of UX. In addition, this paper aims to propose a generic process of running DC studies in the same context.
- **Methods:** We present a systematic literature review of the DC method. Moreover, we conduct a course of thematic analysis on the selected papers to identify the various DC processes and explore the following attributes: participant categories, data collection methods, and data analysis methods in each process.
- **Results:** We identified three different trends of DC processes: detailed, moderate and minimal. In addition, we proposed a generic DC process consisting of 10 steps divided into three main phases: preparation, conducting design critique, and pro-processing. We found that domain experts represent the majority of studies participants. Using interviews to collect qualitative data and using script coding analysis are the two most common methods of collecting and analyzing data.
- **Conclusion:** Conducting DC studies can improve overall systems usability by addressing design flaws at an early stage of development. The process of conducting a DC varies, depending on the project goals and states. The DC method aligns well with the small light-weight steps approach in Agile methods.

Keywords: Design Critique, Human-centered design, User-experience research, AgileUX, systematic literature review

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Figure A.1: A screenshot of the Design Critique SLR paper's abstract. The paper is authored by: Lorans Alabood, Zahra Aminolroaya, Dianna Yim, Omar Addam, Frank Maurer. All authors approved using this paper in this thesis. At this point we are only able to share a screenshot of the abstract as the paper is accepted and currently is under a final process of production. Venue: the Information and Software Technology journal. Publisher: Elsevier

Appendix B

Supportive smart home SLR study appendix

B.1 Overview

This appendix provides additional information about the screening process of the systematic literature review study presented in Chapter Four. The appendix presents screenshots of the raw data as it was retrieved from the three sources; GoogleScholar, ACM Digital Library, and IEEE Xplore. The Publish or Perish software is used to perform these online queries.

B.2 Publish or Perish software screenshot

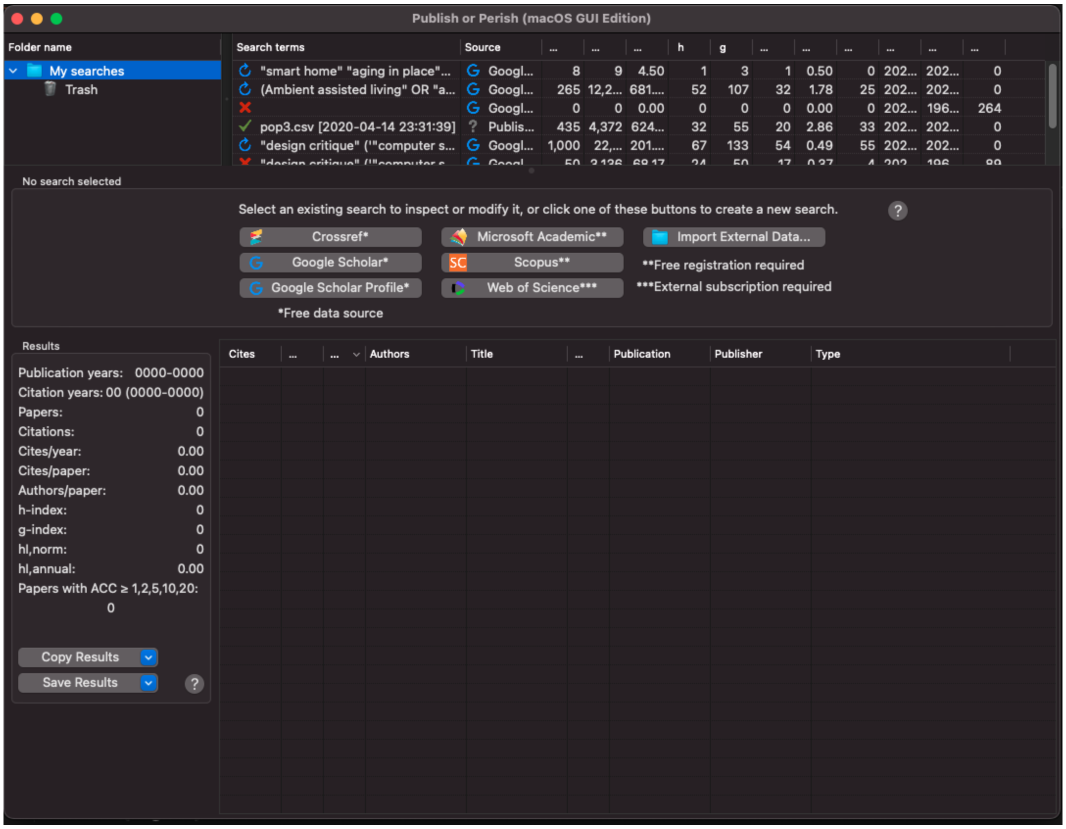


Figure B.1: Screenshot of the Publish or Perish software showing previous search queries

B.3 Raw data

Authors	Title	Year	Source	Publisher
CA Ciro	Maximizing ADL performance to facilitate aging in place for people with dementia	2014	Nursing Clinics	nursing.theclinics.com
MJ Rantz, M Skubic, SJ Miller, C Galambos...	Sensor technology to support aging in place	2013	Journal of the American ...	Elsevier
K Kim, SS Gollamudi, S Steinhubl	Digital technology to enable aging in place	2017	Experimental gerontology	Elsevier
CJ Su, CY Chiang	IAServ: An intelligent home care web services platform in a cloud for aging-in-place	2013	International journal of environmental research and ...	mdpi.com
A Piau, E Campo, P Rumeau, B Vellas...	Aging society and gerontechnology: A solution for an independent living?	2014	The journal of nutrition ...	Springer
M Amiribesheli, A Bouchachia	Smart homes design for people with dementia	2015	2015 International Conference ...	ieeexplore.ieee.org
M Rantz, K Lane, LJ Phillips, LA Despins, C Galambos...	Enhanced registered nurse care coordination with sensor technology: Impact on length of stay and cost in aging in place housing	2015	Nursing outlook	Elsevier
I Rawtaer	In-home sensors for assessment of cognitive and psychological health of older adults: a pilot study	2018	Age	researchgate.net
M Eldib, NB Bo, F Deboeverie, X Xie, W Philips...	Behavior analysis for aging-in-place using similarity heatmaps	2014	Proceedings of the ...	dl.acm.org
EM Schomakers, J Offermann-van Heek...	Attitudes towards aging and the acceptance of ICT for aging in place	2018	... Aspects of IT for the Aged ...	Springer
AS Crandall, DJ Cook	Behaviometrics for identifying smart home residents	2013	Human Aspects in Ambient Intelligence	Springer
Q Yang, C Miao, Z Shen	Digital services innovation for aging-in-place	2015	IEEE International Conference on ...	ieeexplore.ieee.org
VK Ravishankar, W Burleson...	Smart home strategies for user-centered functional assessment of older adults	2015	International Journal of ...	ntumems.net
H Biermann, J Offermann-van Heek, S Himmel...	Ambient assisted living as support for aging in place: quantitative users' acceptance study on ultrasonic whistles	2018	JMIR aging	aging.jmir.org
AJ Astell, N Bouranis, J Hoey, A Lindauer...	Technology and Dementia: The Future is Now	2019	Dementia and geriatric ...	karger.com
M Amiribesheli, A Bouchachia	Towards dementia-friendly smart homes	2016	2016 IEEE 40th annual ...	ieeexplore.ieee.org
A Lazar, HJ Thompson, SY Lin, G Demiris	Negotiating Relation Work with Telehealth Home Care Companionship Technologies That Support Aging in Place	2018	Proceedings of the ACM on ...	dl.acm.org
Y Gong, A Chandra	Developing an integrated display of health data for aging in place	2016	Human Factors and Ergonomics in ...	Wiley Online Library
M Brink	Future-proof platforms for aging-in-place	2013		michielbrink.nl
C Xiong, A Astell, A Mihailidis...	Needs and preferences for technology among Chinese family caregivers of persons with dementia: a pilot study	2018	... of rehabilitation and ...	journals.sagepub.com
CI Rezeanu	The Subjective and Objective Dimensions of Home in Later Life: Implications for Aging in Place	2014	Revista de Asistenţă Socială	ceeol.com
H Pigot, PY Nivollet, T Zayani, Y Adelise	Ubiquitous reminders to manage timetable in a smart home	2016	Proceedings of the 18th ...	dl.acm.org
M Leeuwerden	Assessing the impact of smart home and ambient assisted living technology on the dementia care value network and business model	2018		essay.utwente.nl
L Caroux, C Consel, L Dupuy...	Towards context-aware assistive applications for aging in place via real-life-proof activity detection	2018	Journal of Ambient ...	content.iospress.com
A GAUTHIER-BEAUPRÉ	Technology-Based Supports for Aging in Place: Are they Effective?		agewell-nih-appta.ca	

Figure B.2: Screenshot of the raw data tables prior to screening. Raw data as retrieved from GoogleScholar search engine, ACM and IEEE databases

B.4 During screening process

Abstract read	Full text read	included	Authors	Title
Yes	Yes	Yes	Bouchachia	A tailored smart home for dementia care
Yes	Yes	Yes	SMM Fattah, NM Sung, IY Ahn, M Ryu, J Yun	Building IoT services for aging in place using standard-based IoT platforms and heterogeneous IoT products
Yes	Yes	Yes	Charalampou, A Ntaliani...	An Acoustic-Based Smart Home System for People Suffering from Dementia
Yes	Yes	Yes	J Yu, N An, T Hassan, Q Kong	A pilot study on a smart home for elders based on continuous in-home unobtrusive monitoring technology
Yes	Yes	Yes	Chakravorty, T Wiktorski...	Enrichment of machine learning based activity classification in smart homes using ensemble learning
Yes	Yes	Yes	A Ianovski	A Smart Home Platform and Hybrid Indoor Positioning Systems for Enabling Aging in Place
Yes	Yes	Yes	Bhattacharya, A Ghose...	Early Detection of Mild Cognitive Impairment using Pervasive Sensing
Yes	Yes	Yes	I Lazarou, A Karakostas...	A novel and intelligent home monitoring system for care support of elders with cognitive impairment
Yes	Yes	Yes	Bonaccorsi, D Esposito, M Filippi...	RITA Project: an ambient assisted living solution for independent and safely living of aging population
Yes	Yes	Yes	J Vanus, J Belesova, R Martinek, J Nedoma...	Monitoring of the daily living activities in smart home care
Yes	Yes	Yes	Sheng, W.; Yang, D.; Liu, M.	context-aware wireless sensor networks for assisted living and residential monitoring
Yes	Yes	Yes	M Gochoo, TH Tan, V Velusamy, SH Liu...	Device-free non-privacy invasive classification of elderly travel patterns in a smart house using PIR sensors and DCNN
Yes	Yes	Yes	Jeong, SJ Kang	Self-organizing wearable device platform for assisting and reminding humans in real time
Yes	Yes	Yes	Morita	Smart Monitoring of Population Health Risk Behaviour
Yes	Yes	Yes	M Rantz	Automated health alerts using in-home sensor data for embedded health assessment
Yes	Yes	Yes	Selavo, S Lin, JA Stankovic...	Context-aware wireless sensor networks for assisted living and residential monitoring
Yes	Yes	Yes	Christian, P Petri	Remote Assistance for Elderly to Find Hidden Objects in a Kitchen Asghar
Yes	Yes	Yes	I Iliev, S Tabakov, V Spasova	Multipoint video control and fall detection system applicable in assistance of the elderly and people with disabilities
Yes	Yes	Yes	Navarro, F Alías, M Hervás	homesound: Real-time audio event detection based on high performance computing for behaviour and surveillance remote monitoring
Yes	Yes	Yes	MA Haque	Visual analysis of faces with application in biometrics, forensics and health informatics
Yes	Yes	Yes	L Lin	An Assistive Handwashing System with Emotional Intelligence

Figure B.3: Screenshot of screening process showing part of papers that passed abstract and full text screening

Study title	Objectives	System privacy	Used device(s)	User research	System prototype fidelity	Testing
A smart home platform and hybrid indoor position systems for enabling aging in place	Design a Smart Home platform and two indoor positioning systems and a fall prediction system for older adults	non-intrusive	Motion sensor, bluetooth low energy, rader sensor, RFID tags, RFID reader and IR sensor	no user research study was conducted	hi-fi with lab deployment	Accuracy, cost, implementation ease and scalability
Habit Representation Based on Activity Recognition	a recognition system tracks the user's activities of daily living by collecting data from multiple object sensors and ambient sensors that are distributed within the environment	non-intrusive	motion sensor, pressure sensor, RFID tags, RFID reader, current sensor	no user research study was conducted	hi-fi with lab deployment	Accuracy
RiSH: A robot-integrated smart home for elderly care.	This article presents the development of a robot-integrated smart home (RiSH) which can be used forresearch in assistive technologies for elderly care. The RiSH integrates a home service robot, a home sensor network, a body sensor network, a mobile device, cloud servers, and remote caregivers	intrusive	motion sensor, wearable e-health kit, smart watch, robot sensors; depth camera, microphones, motion sensors	no user research study was conducted	hi-fi with lab deployment	Accuracy
Behavioral telemonitoring of the elderly at home: Detection of nycthemeral rhythms drifts from location data.	This paper proposes a method for Telemonitoring to detect abnormal changes in behavior which may lead to an early entrance in dependency.	non-intrusive	motion sensor	no user research study was conducted	hi-fi with field deployment	Usability testing, Accuracy in real-world
Assessment and Care System Based on People Detection for Elderly Suffering From Dementia	This paper presents a novel AAL (Ambient Assisted Living) concept related to the care of people suffering from dementia	intrusive	camera and microphone	no user research study was conducted	low-fi	Accuracy

Figure B.4: Screenshot of the included papers showing the extracted attributes in each paper such as used devices, privacy, prototype fidelity, etc.

B.5 Selected papers based on data source

Table B.1: Final number of included papers based on their source

Data source	Number of papers
Google Scholar	33
ACM Digital Library search tool	5
IEEE Explore search tool	8
Total	**46**

Appendix C

Requirements Elicitation study Appendix

C.1 Overview

This appendix presents important documents used during the requirements elicitation study presented in Chapter Five including the research ethics approval and consent form. According to our research ethics protocol, we are required to secure the research data in a protected folder for a maximum of five years or until the research is completed (whichever comes first). Therefore, we are unable to share the data publicly. We will include screenshots of script samples and the qualitative data analysis process from NVivo.

C.2 Certificate research ethics and consent form

UNIVERSITY OF CALGARY

Conjoint Faculties Research Ethics Board
Research Services Office
2500 University Drive, NW
Calgary AB T2N 1N4
Telephone: (403) 220-4283/6289
cfreb@ucalgary.ca

CERTIFICATION OF INSTITUTIONAL ETHICS APPROVAL

Ethics approval for the following research has been renewed by the Conjoint Faculties Research Ethics Board (CFREB) at the University of Calgary. The CFREB is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS 2).

Ethics ID:	REB13-0951_REN5
Principal Investigator:	Frank Maurer
Co-Investigator(s):	Richard Levy
Student Co-Investigator(s):	Lorans Alabood Shreya Chopra Fatemeh Hendijani Fard Angela Rout Alemayehu Seyed Steven Vi
Study Title:	Requirements Elicitation
Sponsor:	Natural Sciences and Engineering Research Council Natural Sciences and Engineering Research Council World of 21st Century (W21C) Natural Sciences and Engineering Research Council Natural Sciences and Engineering Research Council

Effective: January 31, 2019 **Expires:** January 31, 2020

Restrictions:

This Certification is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to the CFREB for approval.
3. An annual application for renewal of ethics certification must be submitted and approved by the above expiry date.
4. A closure request must be sent to the CFREB when the research is complete or terminated.

Approved By: John H. Ellard, PhD, Chair , CFREB

Date: January 10, 2019

Figure C.1: Latest certificate of the research ethics protocol that was used to conduct the requirements elicitation study

Researcher: Lorans Alabood, Computational Media Design, Faculty of Science.

Researcher: Dr. Frank Maurer, Department of Computer Science. Dr. Richard Levy, Faculty of Environmental Design.

Title of Project:

Requirements Elicitation for Smart Home Systems to Support Aging in Place for Older Persons with Minor/Major Neurocognitive Disorders.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study.

Purpose of the Study

The purpose of this study is a requirement elicitation to design a smart home system that can support aging in place for seniors with minor or major neurocognitive disorders MMNCD (dementia, Alzheimer's and MCI). The first part of this study is aimed to determine which population can benefit from the suggested technology the most. While the second part will only focus on the need of only one population category: persons with either early-mild dementia, early-mild Alzheimer's or MCI. The results of this study will help us to better understand the special needs for seniors with MMNCD in order to design implementable and applicable technological solution.

What Will I Be Asked To Do?

In this study, you will be asked to participate in an interview/ focus group that will discuss two main topics. Firstly, what are the special needs of seniors with MMNCD who are living in their own home. Secondly, how smart home technology can support aging in place for those seniors. Then, we will present our concepts of a smart home system that we believe it might help seniors with MMNCD to age in place. You are expected to disuses the applicability of our concept and to provide feedback. In addition, we may ask you to participate in a small exercise that includes dealing with small paper cards only (a presentation will be given prior to the exercise).

What Type of Personal Information Will Be Collected?

Should you agree to participate, we ask to videotape you in an interview or focus group, and to audiotape your comments during a post-study interview. Other than these video and audio recordings, no other personal identifying information (such as your name) will be collected. By default, in all written publications and presentations based on this research, you will remain anonymous and your comments from the interviews will be referred to with either a participant number or a pseudonym.

In order to better communicate the results of this research in written publications and presentations, it may be helpful to share video (or still photographs from the video) of you in an interview or focus group. If you grant us permission to share video (or still photographs from the video) of yourself in an interview or focus group, in written publications or presentations of this research, there is a chance that you may be recognized and so we cannot

Figure C.2: The consent form used this study

guarantee your anonymity. We will never, however, reveal your name in association with your image.

Please note that, where intended reporting of photographed or videotaped images includes public display, the researchers will have no control over any future use by others who may copy the images and repost them in different formats or contexts, including online

Please indicate your preference to the following statements:

I grant permission to be videotaped: Yes: ___ No: ___

I grant permission for video (or still photos from the video) of me to be shared in publications or presentations of this research: Yes: ___ No: ___

Are there Risks or Benefits if I Participate?

There is no known harms or risks associated to the participation in this study. There is also no cost associated with your participation in this study.

What Happens to the Information I Provide?

Participation in this research is completely voluntary and confidential. You are free to discontinue participation at any time during the study. Any information you contribute up to the point at which you choose to discontinue your participation will be removed. No one except the researchers will be allowed to see or hear any personally-identifiable information unless you have given permission for us to share video or photographs of you in our interview or focus group, in publications or presentations of this research. The audio/video tapes and interview data will be kept on password-protected university computers or in a locked cabinet only accessible by the researchers. The data will be stored for five years, after which it will be permanently erased.

Signatures (written consent)

Your signature on this form indicates that you 1) understand to your satisfaction the information provided to you about your participation in this research project, and 2) agree to participate as a research subject.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) ____

Participant's Signature ____Date: _______________

Researcher's Name: (please print) ____

Researcher's Signature: ____Date: ________________

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Dr. Frank Maurer
Department of Computer Science
E-mail: fmaurer@ucalgary.ca

Figure C.3: The consent form used this study

Dr. Richard Levy
Faculty of Environmental Design
E-mail: rmlevy@ucalgary.ca

Lorans Alabood, MSc, BArch.Eng
Computational Media Design, Faculty of Science.
E-mail: lorans.alabood@ucalgary.ca

If you have any concerns about the way you've been treated as a participant, please contact the Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-4283 / (403) 220-6289; email cfreb@ucalgary.ca.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

Figure C.4: The consent form used this study

C.3 Interview script sample and data analysis

Interview script

Interviewer name: Lorans Alabood
Interviewee name: P4
Relationship to the senior: formal caregiver
Date: Calgary, Canada
Subject code: S4
Diagnoses: Alzheimer - Dementia

Speaker	Script
Lorans	**Lorans introduce the study and explain the purpose of the study.**
Lorans	**Could you please tell me about your experience in cared for seniors with Alzheimer's or dementia and for how long?**
P4	I have been in the nursing profession for about 35 years, hospital or private care settings. Two patients, Parkinson's, Alzheimer's with dementia.
Lorans	**I am interested to know about their cases, condition, needs they currently have and how you are helping them**
P4	Parkinsons and dementia, about 2 years ago, he didn't have much difficulty, used a walker sometimes and now he's full time wheelchair and rapid decent into almost flat out confusion at this time. 9-10 months ago, we can have conversations and he could follow along and recite some limericks that he's known his whole life and he's an anesthesiologist doctor. He was able to manage cognitively until about a year ago. Surprising how quick the decent is, 6 months ago, with prompts couldn't bring out the entire limerick. Mostly knew where he was and able to relate to those surrounding around him, didn't know date and time but knew it was spring. When I arrived, he knew who everyone was, and what to expect. We would go on long walks and I would give him care. Cognitively, during long walks he would look forward to it and would be thrilled 4 months ago vacant look into his eyes and open mouth gaping look. Talk to him, he was very aware. Until about a month ago he kept going down and didn't know his wife, but he did know my name. so far, he is reoriented to who his wife is with some prompting.

Figure C.5: Screenshot of an interview script as raw can't be available publicly due to research ethics requirements

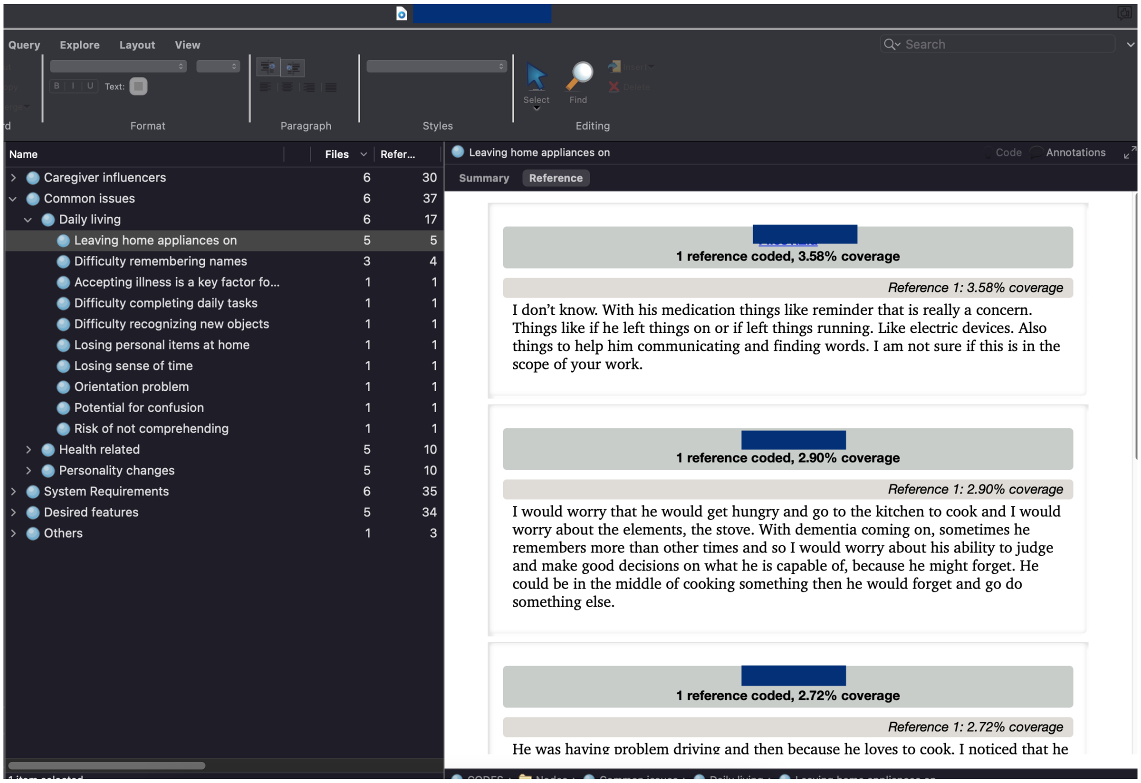


Figure C.6: Screenshot the NVivo software after completing the thematic analysis. The screenshot shows the main themes, sub-themes, codes and script quotations

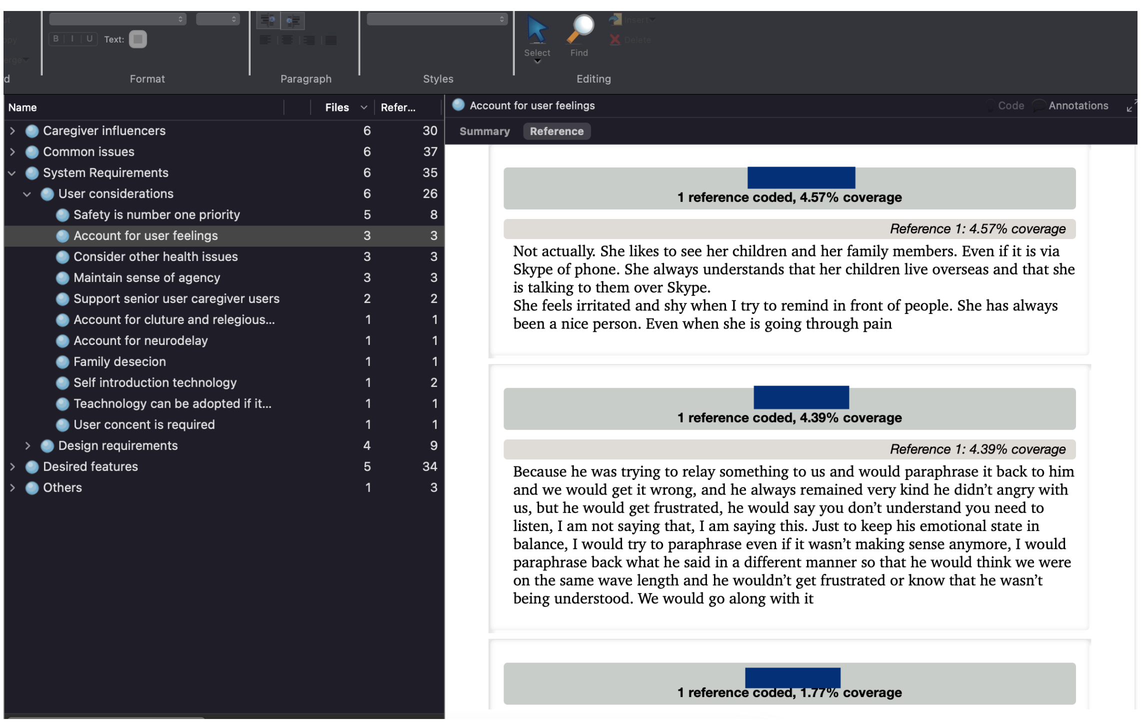


Figure C.7: Screenshot the NVivo software after completing the thematic analysis. The screenshot shows the main themes, sub-themes, codes and script quotations

Appendix D

Design Critique evaluation appendix

D.1 Overview

This appendix presents supplementary material related to the Design Critique study in Chapters Seven and Eight. Important documents including the certificate of ethics approval and consent forms are presented. A sample of DC sessions questions, screenshots of session script sample and screenshots of the data analysis via NVivo.

D.2 Sample of session questions

- Do you relate to the scenario in the short video? If yes, how accurate is this scenario? What should we change to make it more realistic?

- As you saw in the video, the system notifies the user multiple times. When the user ignores the reminders, the system will proceed to a higher notification level and eventually will intervene to keep the user safe. What are your thoughts on the notification style and intervention levels? How appropriate is chronological order of the intervention scheme in our prototype design?

- One of the benefits of using mixed reality technology is that the user can interact with the system and receive notifications privately in an immersive way. User interface elements can be flexible in their design to make them easily and naturally understandable. Based on the videos that you watched, do you think the users can understand the notifications and memory prompts easily without the need to learn new skills? And why?

- If you were to change three things about the user interface design, what would they be? And what would you do instead?

- In addition to providing users with notifications and memory prompts, our system prototype allows the user to interact with some devices within the smart home environment. Users can interact with the user interface by either using hand gestures or voice commands. Which interaction method do you think is more suitable? And why?

- Overall, despite the size and weight of current mixed reality headsets, do you think it is realistic that seniors can use such technology to interact with the smart home system? Why or why not?

- Do you think it is realistic that by using such technology we can increase the sense of independence and agency for seniors who are at an early stage of cognitive impairments? Why or why not?

- Do you think that by using mixed reality and smart home technologies we can further support aging in place for seniors at an early stage of cognitive impairments? Why or why not?

- Do you have any additional feedback that you would like to share with us?

D.3 Certificate of research ethics and consent form

UNIVERSITY OF CALGARY

Conjoint Faculties Research Ethics Board
Research Services Office
2500 University Drive, NW
Calgary AB T2N 1N4
Telephone: (403) 220-4283/6289
cfreb@ucalgary.ca

CERTIFICATION OF INSTITUTIONAL ETHICS REVIEW

The Conjoint Faculties Research Ethics Board (CFREB), University of Calgary has reviewed and approved the below research. The CFREB is constituted and operates in accordance with the current version of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS).

Ethics ID:	REB20-1634
Principal Investigator:	Frank Maurer
Co-Investigator(s):	Fabian Neuhaus
Student Co-Investigator(s):	Lorans Alabood
Study Title:	The application of the design critique method in the context of user-centered design for smart home system prototype evaluation.
Sponsor:	

Effective: 4-Jan-2021 **Expires:** 3-Jan-2022

Restrictions:

This Certification is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to the CFREB for approval.
3. An annual application for renewal of ethics certification must be submitted and approved by the above expiry date.
4. A closure request must be sent to the CFREB when the research is complete or terminated.

Approval by the REB does not necessarily constitute authorization to initiate the conduct of this research. The Principal Investigator is responsible for ensuring required approvals from other involved organizations (e.g., Alberta Health Services, community organizations, school boards) are obtained.

Figure D.1: Latest certificate of the research ethics protocol that was used to conduct the DC study

UNIVERSITY OF CALGARY

The University of Calgary Conjoint Faculties Research Ethics Board has approved this study (REB20-1634)

Researcher: Lorans Alabood, Computational Media Design, Faculty of Science.

Researcher: Dr. Frank Maurer, Department of Computer Science.

Researcher: Dr. Fabian Neuhaus, School of Architecture, Planning and Landscape.

Title of Project:

The application of the design critique method in the context of user-centered design for smart home system prototype evaluation.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of the Study:

According to Statistics Canada, the number of senior citizens has been increasing steady over the past 40 years. This increment puts the healthcare system at high pressure. A model of home healthcare that allows seniors to live in their own home safely is known as Aging in Place, was suggested as response to the increasing aging population problem. Many recent studies suggested utilizing smart home system technology to support aging in place for senior citizens. However, setting up and using most smart home systems require certain technical skills that may be difficult for seniors and their caregivers, particularly those seniors who suffer from an early cognitive impairment. In our research, we suggest a novel user-system interaction method that relies on the Mixed Reality technology. We believe that by using a Microsoft HoloLens application, we can provide the senior users with a unique user experience that allows them to use previously learned skills to interact with the smart home system that is designed specifically to meet their needs. Users will receive notifications, reminders and memory prompts in the form of a hologram that will be projected virtually on certain surfaces in the real-world (wall, table, floor, etc.). Since the HoloLens headset can track hand gesture, users can use natural hand gestures to interact with the system interface easily. We used a user-centered design approach to develop our system prototype. At this stage of our research, we are planning on conducting online sessions with a sample of potential stakeholders to present videos of our system prototype. The purpose of these sessions to is collect feedback that can help us in improving our prototype design.

Figure D.2: The consent form used this study

What Will I Be Asked To Do?

In this study, you will be asked to join a one-on-one online meeting with us, where we will be playing 3-6-minute videos presenting the design of our system prototype. After watching each video, you will participate in a short interview of a few questions about the video prototype that you have watched. Thereafter, you will be given the chance to provide any additional feedback.

What Type of Personal Information Will Be Collected?

Should you agree to participate, we ask to video record you in an online interview or focus group, and to audiotape your comments during a post-study interview. Other than these video and audio recordings, no other personal identifying information (such as your name) will be collected. By default, in all written publications and presentations based on this research, you will remain anonymous and your comments from the interviews will be referred to with either a participant number or a pseudonym.

In order to better communicate the results of this research in written publications and presentations, it may be helpful to share video (or still photographs from the video) of you in an interview. If you grant us permission to share video (or still photographs from the video) of yourself in an interview or focus group, in written publications or presentations of this research, there is a chance that you may be recognized and so we cannot guarantee your anonymity. We will never, however, reveal your name in association with your image.

Please note that, where intended reporting of photographed or videotaped images includes public display, the researchers will have no control over any future use by others who may copy the images and repost them in different formats or contexts, including online

Please indicate your preference to the following statements:

I grant permission to video record this session: Yes: ___ No: ___

I grant permission to audio record this session: Yes: ___ No: ___

I grant permission for video (or still photos from the video) of me to be shared in publications or presentations of this research: Yes: ___ No: ___

The voluntary nature of this study

I understand that my participation in this study is voluntary initial:_______

I am not participating in this study against my will initial:_______

I am not under any influence at the time of signing this form initial:_______

Figure D.3: The consent form used this study

Are there Risks or Benefits if I Participate?

There is no known harms or risks associated to the participation in this study. There is also no cost associated with your participation in this study.

What Happens to the Information I Provide?

Participation in this research is completely voluntary and confidential. You are free to discontinue participation at any time during the study. Any information you contribute up to the point at which you choose to discontinue your participation will be removed. You still can withdraw from the study up to one month from the date you sign this form. No one except the researchers will be allowed to see or hear any personally identifiable information unless you have given permission for us to share video or photographs of you in our interview, in publications or presentations of this research. The audio/video tapes and interview data will be kept on a secure university server only accessible by the researchers. The data will be encrypted and stored for five years, after that it will be permanently erased.

Signatures (written consent)

Your signature on this form indicates that you 1) understand to your satisfaction the information provided to you about your participation in this research project, and 2) agree to participate as a research subject.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) ____

Participant's Signature __________________________________ Date: ______________

Researcher's Name: (please print) ____

Researcher's Signature: ________________________________ Date: ____________

Figure D.4: The consent form used this study

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Dr. Frank Maurer
Department of Computer Science
E-mail: fmaurer@ucalgary.ca

Dr. Fabian Neuhaus
School of Architecture, Planning and Landscape
E-mail: fabian.neuhaus@ucalgary.ca

Lorans Alabood
Computational Media Design, Faculty of Science.
E-mail: lorans.alabood@ucalgary.ca

If you have any concerns about the way you've been treated as a participant, please contact the Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-4283 / (403) 220-6289; email cfreb@ucalgary.ca.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

Figure D.5: The consent form used this study

D.4 Transcript and qualitative data analysis samples

Design Critique session transcript
Participant code:
Participant location: Louisville, USA
Participant category: SwNCDs

Scenario one: medication support

Lorans Alabood: I want to ask you a couple of pre interview questions. The first question is how are you involved in supporting and/or living an aging in place, are you a senior yourself living in place, or are you supporting someone who lives at home?

Participant: um I actually live at home, and I have dementia and my brother lives with us, he has dementia and my husband cares for both of us. So we are still in the home, our home.

Lorans Alabood: Okay, would you mind letting me know when you actually were diagnosed with dementia.

Participant: It was November of 2015.

Lorans Alabood: Is your dementia mild? Do you guys rely on any smart devices at home for your support and care?

Participant: Yes and yes.

Lorans Alabood: Good, what do you have?

Participant: Beside the tablet my husband has a laptop and I usually just use my phone.

Lorans Alabood: Okay, do you have any security equipment at home for the stove, just to prevent a burn or fire in your home?

Participant: I can't cook anymore, because I was doing dangerous things and my neurologist told my husband not to let me cook anymore. We don't have any type of alarm system known for the doors, because so far we haven't tried to get out, like at night.

Participant: Okay.

Lorans Alabood: So, what happened here, the notification was ignored twice, and the person did not take the medication. The third notification is a video, recorded by a familiar person such as a spouse or child. The video would say: "hey dad, we bought you this medical dispenser which is on the piano" just to remind them.

Participant: For me, I think the best would be to see an actual family member.

Figure D.6: A transcript of a DC session with a SwNCDs. The screenshot shows the first part of the session where discussing the first use case (medication support) takes place

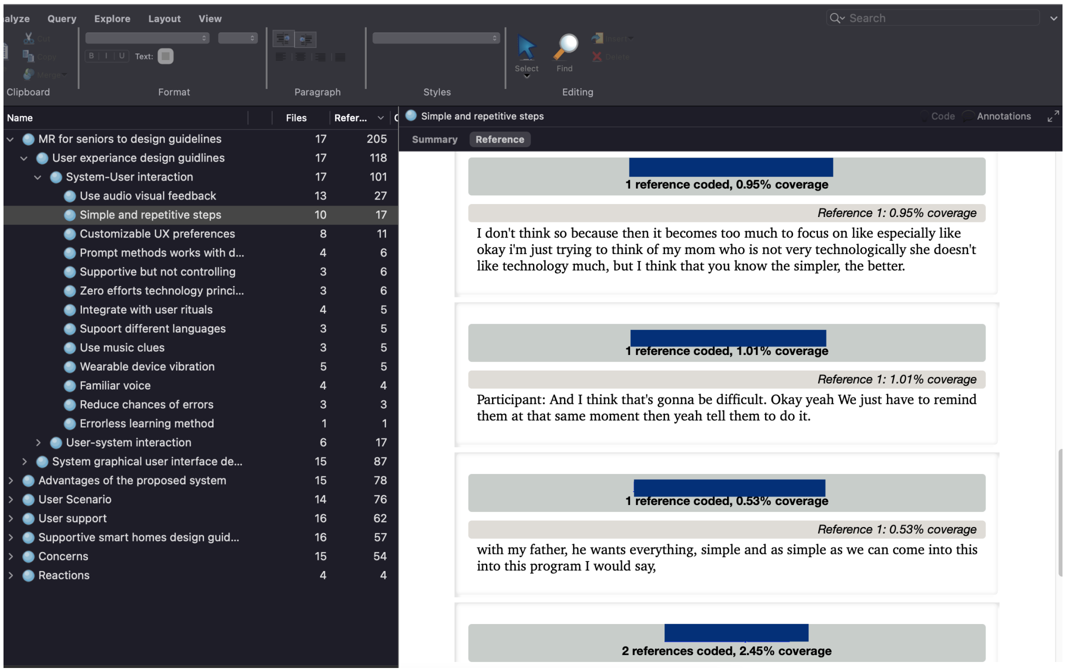


Figure D.7: A screenshot showing the thematic analysis with quotation samples using NVivo software

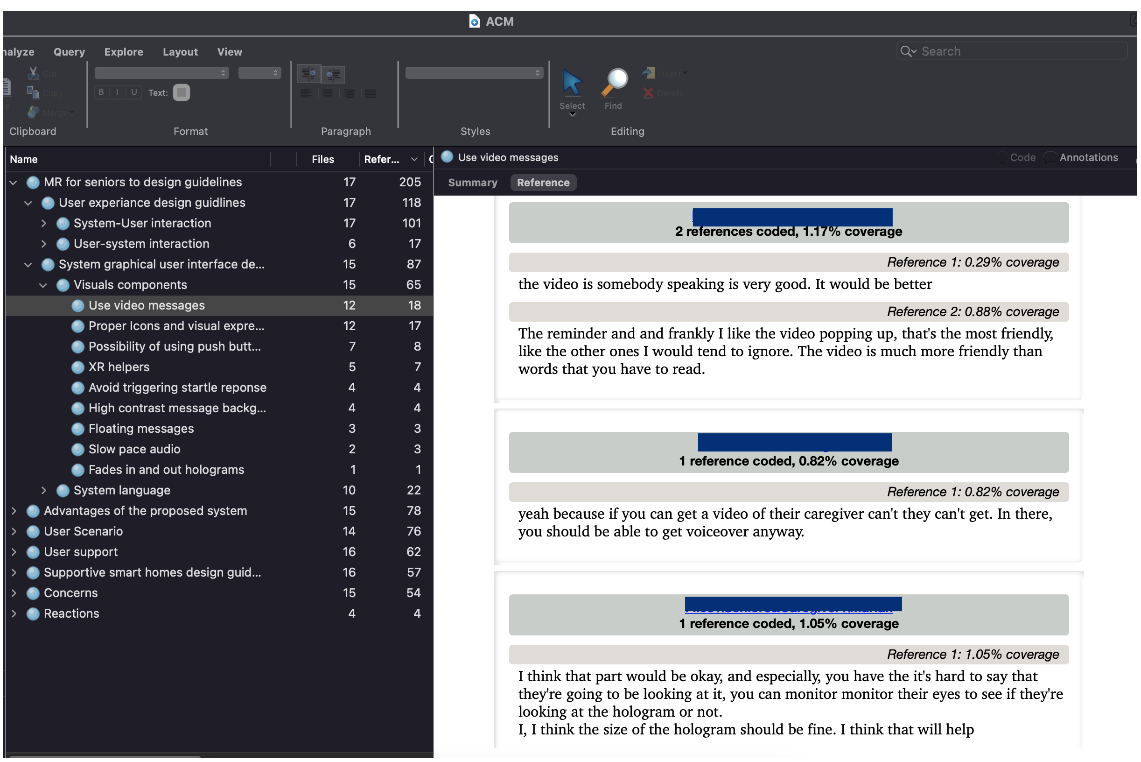
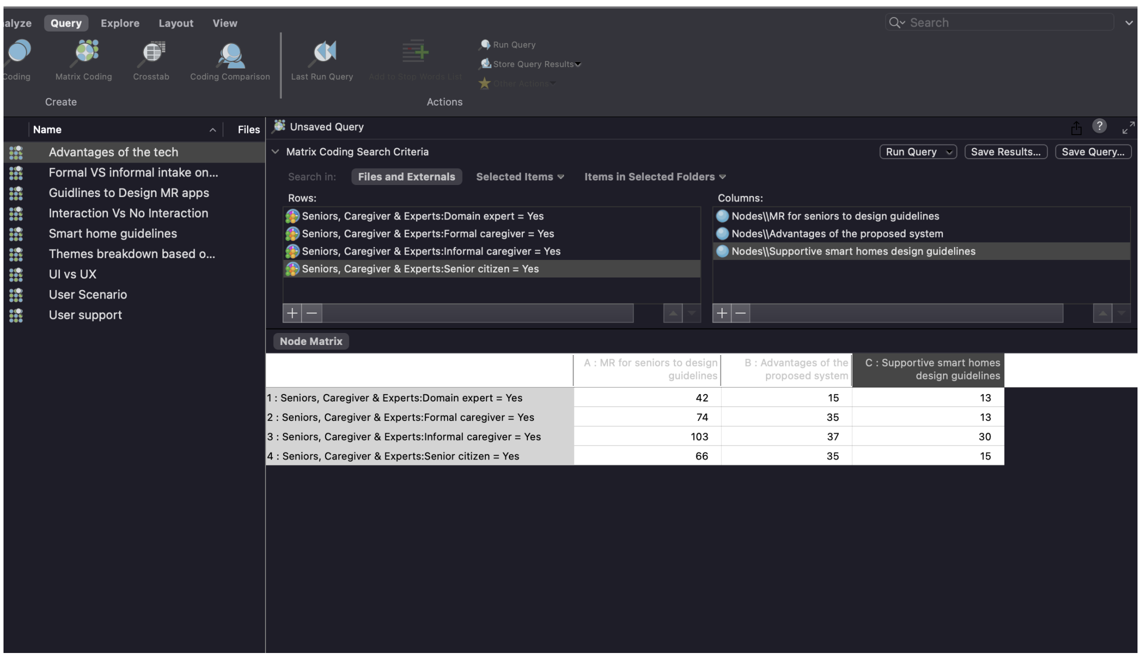


Figure D.8: A screenshot showing the thematic analysis with quotation samples using NVivo software



	A : MR for seniors to design guidelines	B : Advantages of the proposed system	C : Supportive smart homes design guidelines
1 : Seniors, Caregiver & Experts:Domain expert = Yes	42	15	13
2 : Seniors, Caregiver & Experts:Formal caregiver = Yes	74	35	13
3 : Seniors, Caregiver & Experts:Informal caregiver = Yes	103	37	30
4 : Seniors, Caregiver & Experts:Senior citizen = Yes	66	35	15

Figure D.9: A screenshot showing a Cross-Matrix query using NVivo. The query checks the number of references of three different themes against all participant category

Appendix E

Hi-Fi Prototype appendix

E.1 Overview

In Chapter Nine, we a briefly described the final Hi-Fi system prototype along with selected screenshots. In this appendix, we provide a detailed description of all user tasks for both user modes. User flow diagrams are presented as well. At the end of appendix, we include screenshots of the cognitive walkthrough survey raw data.

E.2 Senior user mode details

E.2.1 Medication reminder

Figure E.1 presents the user flow for the medication reminder use case. As seen in the figure, the system will use the attention/action model to deliver the first reminder to the user to take their medication; this is the default sequence of events. Figure E.3 shows how the reminder message is displayed above the wrist and other screenshots of the UI as seen from the senior user perspective. This message's design is minimal, while the content is picked carefully to avoid any sensitive words such as 'remember to' or 'don't forget to'. In addition, the text is displayed in prominent and readable font with only two simple words. Furthermore, the reminder message accounts for users with less motivation to read; therefore, we included two virtual medical pills floating around the message to give the user a visual cue. Finally, the same reminder message is displayed again in the second reminder with a short music cue. The system requires the caregiver to set at least one memory prompt; additional prompts are optional. Failure, at completing the task results in notifying the caregiver.

E.2.2 Cooking safety

Scenario A) The user is awake and withing the safety range

Depending on the pre-set cooking time by the caregiver, the system will send the first and the second reminders in the same fashion as the medication reminder scenario (long vibration signal then a message). In this messages says 'the stove is on', and it displays a 3d model of a pot and a pan flouting around the message to give the user a visual cue if they don't read the message. Figure E.2 illustrates the user flow for the cooking support case for the senior use.

If the user doesn't respond to any of these prompts, then a big message will be displayed in front of the user with a clickable button to turn off the stove remotely. The rationale behind this design choice is to give the user multiple chances to intervene while maintaining their sense of agency by not escalating to the caregiver immediately. If the user fails at turning off the stove manually or using the virtual button, the system will notify the caregiver and wait for 5 minutes; if the stove is still running, the system will shut it down automatically. These 5 minutes give the caregiver the time to either call home and ask the senior to check on the stove or they can simply turn the stove off remotely using their HomeAssistant mobile application.

Scenario B) The user is awake but left the safety range

If the user leaves the range set by the caregiver while the stove is on, the system would send them a reminder message above the wrist every 2 minutes. After a total of 6 minutes, if the user does not return to the attend the stove, the system will notify the caregiver and

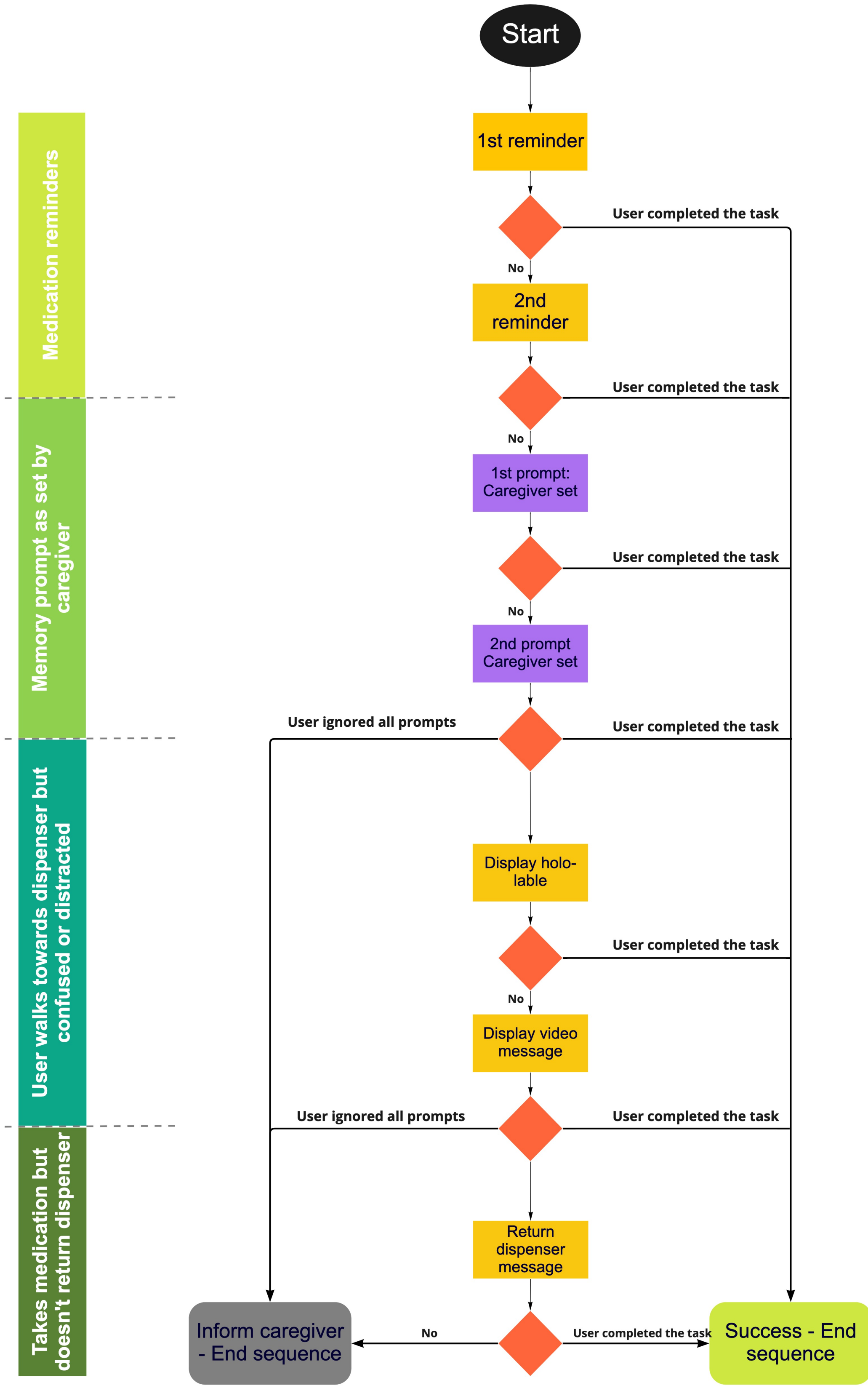


Figure E.1: User flow diagram presenting all senior user tasks for the mediation reminder support. Yellow coloured tasks are required while purple coloured tasks are optional

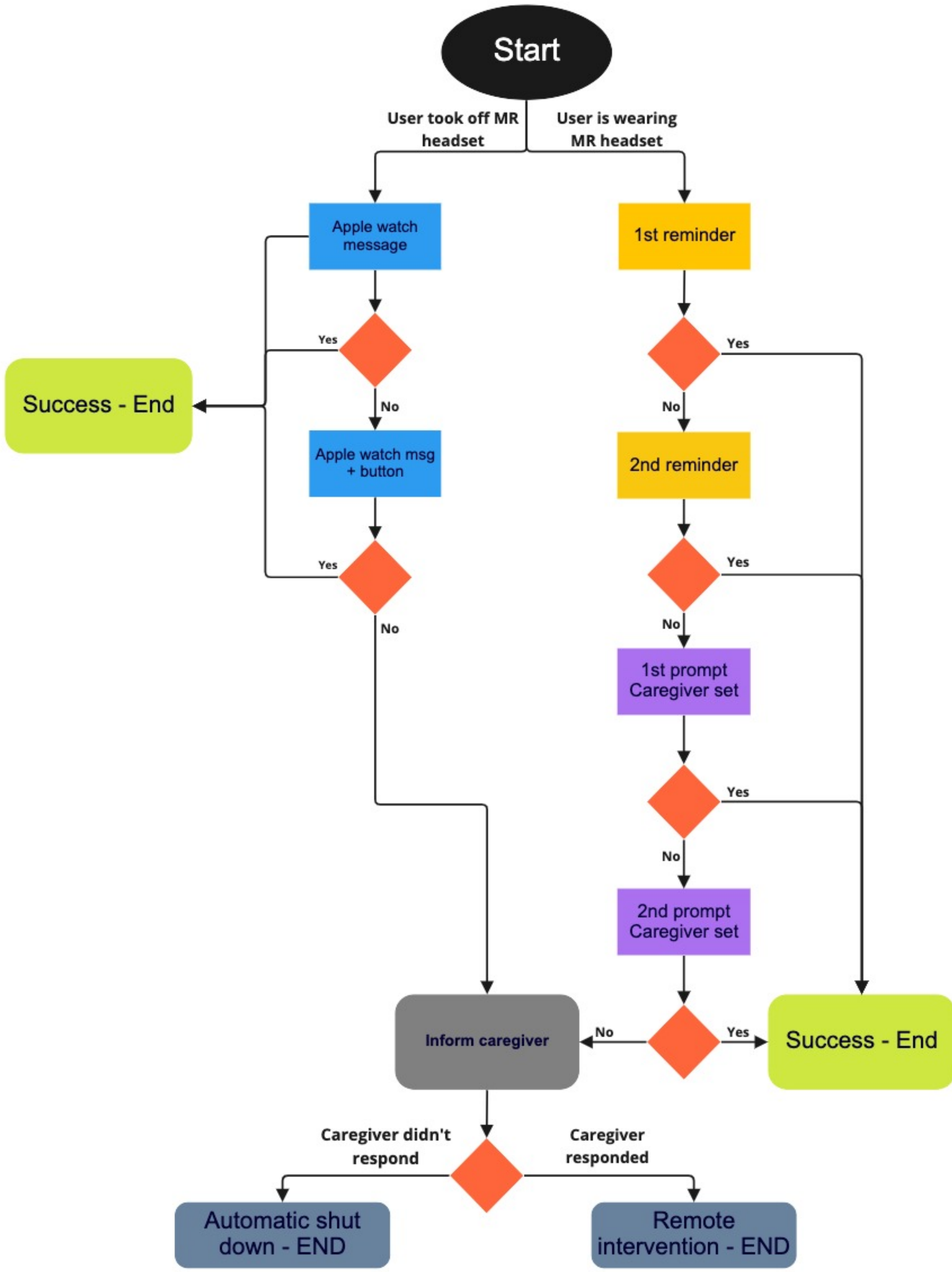


Figure E.2: User flow diagram presenting all senior user tasks for the cooking support. Yellow coloured tasks are required while blue coloured tasks are optional

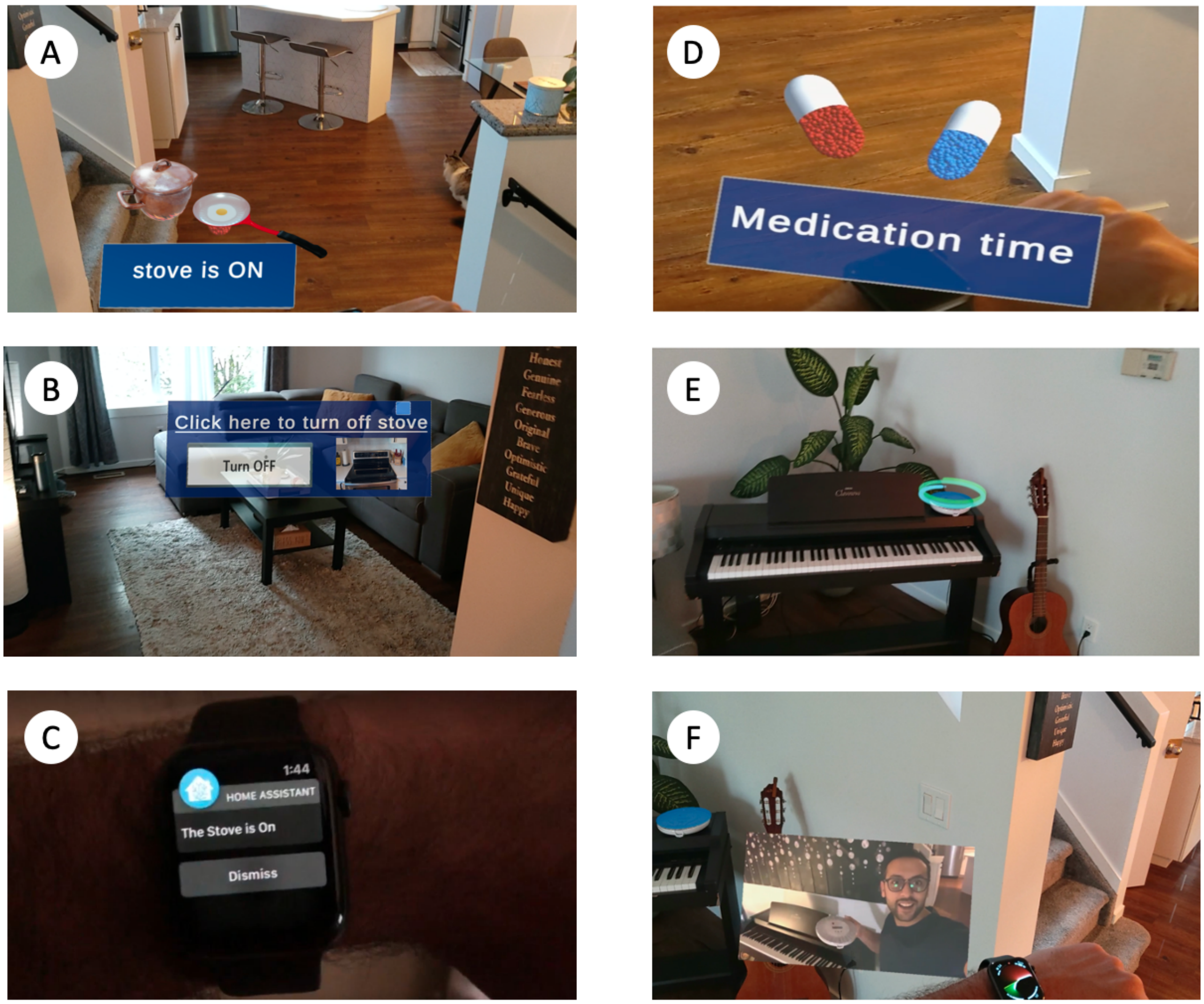


Figure E.3: Sample of the senior user mode user interface screenshots presenting reminders and selected memory prompts. A) The user receives a holograph reminder above the wrist about the stove. B) A virtual button to turn off the stove remotely. C) The user took off the headset while the stove was running, D) Augmentation reminder to take medication. E) visual cue around the dispenser to attract the user's attention. F) video message as seen by the senior user

Figure E.4: Sample of the caregiver mode user interface screenshots. A) shows the caregiver aligning the virtual object with the stove. B) the caregiver is adding a new prompt. C) modifying existing prompts, D) customizing a prompt. E) setting cooking safety range. F) selecting a function follow the same safety sequence that we discussed above.

Scenario C) The user took off the headset

If the user takes off the headset or falls asleep, the system will check if they are still wearing their Apple Watch. If yes, they will receive a short notification message on the watch saying 'the stove is on'. If they don't respond within 5 minutes, the system will trigger the Apple Watch to vibrate longer and display a single big button on the watch to turn off the stove remotely. If the stove is still running after that, the system will trigger the safety sequence and notify the caregiver. The timings are completely re-configurable.

E.3 Caregiver mode details

The purpose of the caregiver mode is to set up the system when it runs for the first, and to customize preferences when needed. Accounting for caregivers with different technology skills was an essential consideration throughout the design process. We have made a number of important design decisions to simplify the caregiver mode as much as possible. The user experience flow is set to have a linear flow with a beginning an end of each user task while allowing for easy error-recovery. In the efforts to avoid using technical language, we selected terms relate to caregiving such as: 'set a memory prompt' or 'set a cooking safety range'. Figure E.5 presents screenshots of the caregiver mode UI as seen from the Hololens device.

When the application runs for the first time, caregivers will be presented with a simple window with two buttons only; medication support and cooking support. Upon clicking one of these options, setting up the selected feature will start.

E.3.1 Setting up medication support for first time

The setup process follows these steps:

1. **Drag and drop virtual object:** The first step is to introduce real-world IoT devices to the application. Each IoT device is represented by one virtual object. In order to

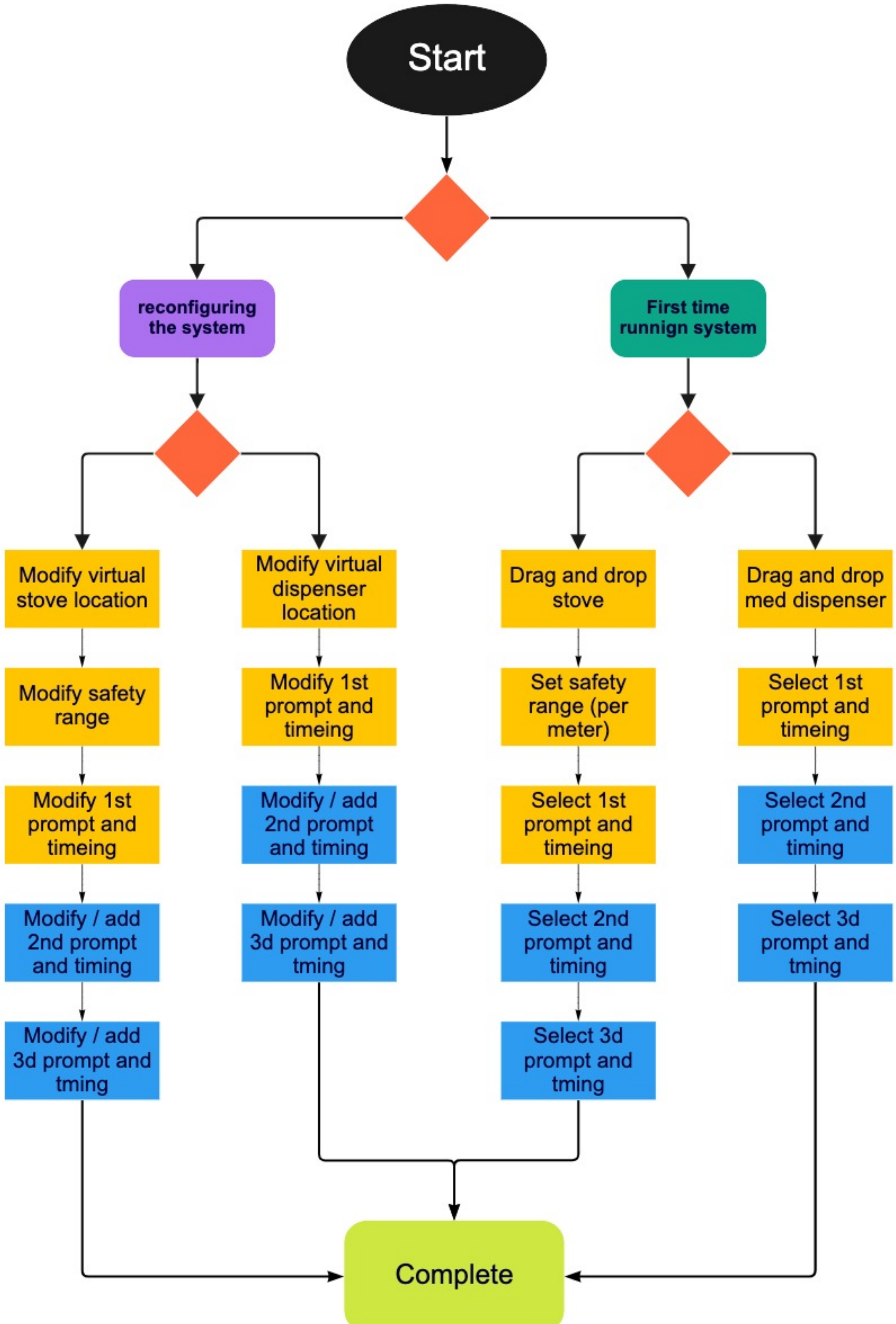


Figure E.5: Caregiver user flow diagram presenting all user tasks for setting up the system first time and for reconfiguring. Yellow coloured tasks are required while blue coloured tasks are optional assist the user, the system displays animated hand gestures illustrating how to interact with the virtual object (MRTK Hand Coach prefab). Using 'grabbing' and 'dropping' interactions, the caregiver can move the virtual object and align it with the real-world IoT dispenser. After that, double tapping on the virtual object is required to complete this task.

2. **Add first memory prompt:** Upon confirming the location of the medical dispenser, the application will present the user with an 'add memory prompt' window. Figure E.4 shows a screenshot of the UI as seen by the caregiver. On the right side of the window, users can select from the six built-in memory prompts (please refer to the next section for a detailed description of these prompts). Caregivers can choose to activate one or multiple prompts, which will get fired if the senior doesn't take their medication after the first reminder. The time between the reminder and the first prompt can be set using the slider of the left side. The window displays selected prompts in yellow on the upper left side of the window.

3. **Adding additional prompts:** Pushing the 'add more prompts' button will save the changes and move to add a second prompt. The prompt will be fired if the user did not respond to the first prompt. Caregivers can add as many prompts as they want with different variations.

4. **Summary:** Pushing the 'complete' button will display a summary window listing all memory prompts, their sequence and timing. Save all changes and go back to the main menu.

5. **Completing the setup:** Pushing the complete button will display a final confirmation message, save the changes and end the task.

E.3.2 Setting up cooking support for the first time

1. **Drag and drop virtual object:** This step is similar to the first step in the medication reminder feature.

2. **Set cooking safety range:** The system will measure the distance between the user (the Hololens device) and the stove. If the stove is turned on and the user is far from the stove, the application will prompt the user to attend to the stove. This range can be set using the slider on the 'set cooking safety range' window'. The default range is 8 feet. If the user wants to change it, they can move the slider, push the 'set range button', then complete the task.

3. **Add new prompt:** This step and all following steps are similar to the medication reminder feature steps 2-4. therefore, we won't list them again in this section.

E.3.3 Reconfiguring the system: modify existing settings

1. **Select system feature:** When a caregiver triggers the caregiver mode using the verbal password, they will be presented with a two buttons window asking to select a system feature to modify.

2. **Select a prompt to modify:** After selecting the system feature, the application will display a list of current prompts. The caregiver can use the checkbox to select an option and then push the modify button, which will display all that prompts' parameters.

3. **Confirm or dismiss changes:** Pushing the complete or the cancel buttons will trigger the system to ask for final confirmation before saving or dismissing the changes.

E.3.4 Reconfiguring the system: adding new prompt(s)

1. **Add new prompt:** Similarly, the application would display a list of current prompts. If the caregiver pushes the 'add new prompt' button, they will be presented with a

standard window for adding new prompts that we discussed previously. The sequence of this newly added prompt is based on the time set by the caregiver.

2. **Add more prompts:** On the same window, users can -simply- push the 'add more prompts' button instead of the 'complete' button, which will save the changes and take the user an empty 'add new prompt' window.

3. **Confirm or dismiss changes:** Similarly, pushing the complete or the cancel buttons will trigger the system to ask for final confirmation before saving or dismissing the changes.

E.3.5 Caregiver mobile application

Besides the caregiver mode on the MR application, caregivers can always use their HomeAssistant mobile application to monitor medication intake and stove usage. Additionally, they can turn off the stove remotely when needed. The mobile application's home page displays only a 2D map of the senior's house with two icons representing the dispenser and the stove. Clicking on either of these icons will display more information, such as device status and usage history for the past 24 hours.

E.4 Cognitive walkthrough questionnaire samples

Figure E.6: A screenshot of the cognitive walkthrough row data as exported from Qualtrics. The screenshot is taken from caregiver user mode evaluation. As shown, each system event is inspected using five questions. Evaluators answered the same set of questions for all user tasks / system events

Figure E.7: A screenshot of the cognitive walkthrough row data as exported from Qualtrics. The screenshot is taken from senior user mode evaluation. As shown, each system event is inspected using four questions. Evaluators answered the same set of questions for all user tasks / system events