Empirical Study and Design of Multimodal Ambient Assisted Comfort Services for Senior Citizens

by

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In partial fulfillment of the requirements for the degree of

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Abstract

The growing size of the aging population is becoming a significant issue for many countries, and the United Nation has proposed "aging-in-place" as a solution, which can be implemented with the help from ambient, assisted living system. Many previous works have focused on the emergency and autonomy services, and lack studies on comfort service. The purpose of this study is to conduct an empirical study of using multimodal interfaces in ambient assisted comfort services for senior citizens targeting participants at their home, with a prototype system that supports both traditional and multimodal interaction methods. Scenarios have been defined that include common tasks such as item finding, communication, media access, and setting calendar events. 15 senior citizens have answered questionnaires and scale rating questions from each performed scenario. The comparison between traditional and multimodal interface were done through a set of evaluation criteria including efficiency (time), pleasantness, fatigue, naturalness, ease of learning, and perceived efficiency. The results showed that all the participants have enjoyed the multimodal interface, and showed better efficiency than traditional interaction method.

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1 Introduction

1.1 Background

The rapidly growing issue of aging population has been widely recognized as a global and national problem. Many researchers have pointed out that in next ten to thirty years, our care facilities will not able to support the amount of aging population, and the global organizations and governments hope the elderly can remain in their house as long as possible [1, 2, 5, 10]. With the advancement of the technologies, our life has been automated and improved by devices like computers and smartphones. While these advances can potentially improve the everyday life of senior citizens, especially those living at home and without the help of care professionals, the senior citizens have more difficulty with, or are simply afraid to adopt, the newest devices and software, mainly due to the factors such as age-specific needs issues (cognitive slowing, limited processing recourses, lake of inhibition, visual perception and processing, hearing, speech, psychomotor abilities, attention, memory, and learning [3]), and product's lack of design considerations for this particular user segment. For example, the modern smartphones would have sleek design, with very small fonts, which makes difficult to read for the seniors, due to the decline of the vision. However, their quality of life would be greatly enhanced, if they could also take advantages of the new technologies in their daily life.

Thus, making the technologies intuitive and less intrusive for senior citizens in a pervasive environment have become a popular research area in the field of Human Computer Interaction (HCI). The mandate of any HCI study is essentially to bridge the human's cognitive model with the computational system's ways of processing users' input and providing proper feedback [11]. A number of Ambient Assisted Living (AAL) systems have been drafted and studied by researchers [9], which have advanced technologies implemented into seniors' home and can be customized to promote wellness for individuals aging in their own home [2].

The concept of ambient assisted living was originally derived from the Weiser's concept of ubiquitous computing [45], where the computing devices are all dissolved into our daily objects and environment, so the user is no longer required to sit in front of a workstation to perform tasks. Instead, the user could interact with the computing system more intuitively, such as using voice, gestures, or via everyday objects with integrated digital informatics. The idea behind this approach is that humans are multimodal by nature (i.e. interact with outside world through various senses), and so a computing device should provide a multimodal interface and adapt to human ways instead of enforcing a limited interaction method. As the results, the Human Computer Interaction model for using such a system will also be different from the traditional way of performing computational tasks. When the users engage with an AAL system through these new interaction methods, they could perform computational tasks anywhere and anytime in their home, and the system would be intelligent to detect and monitor users' conscious commands and unconscious movements via their voice, gesture, or the way how they manipulate certain physical smart objects. Design and development of such AAL systems requires a better understanding of how senior citizens interact with new natural interfaces with different modalities and how these modalities and associated interfaces can be used and combined to provide an effective interaction system when performing typical domestic tasks. The research described here is a step toward such an understanding.

1.2 Problem Statement

The living assistance services have been mainly classified into three categories [9]: emergency treatment services, autonomous enhancement services, and comfort services. The emergency treatment services aim at early prediction and recovery from critical conditions. For example, the system would detect situations such as sudden falls, heart attacks or panics. Autonomy enhancement deals with services that previously had to be given manually by social or medical personnel. For instance, the user with weaker sight would be able to cook alone with modified stove, where audible instruments can notify the users when necessary. Lastly, comfort services generally include services such as finding things, infotainment services, and social contact assistance.

Previous studies have focused on the emergency and autonomous services due to the priority, because the comfort services are perceived as not as important, yet have the same huge social impact comparing to the first two [9]. In contrast, other studies has showed that being socially involved and more achieving as getting older, will be more beneficial to the seniors' well-being [27, 28]. Thus, the comfort services have the same importance and social impact as first two categories. Furthermore, with an AAL environment, the comfort services also requires more cognitive efforts from the users, because most of the emergency and autonomy services are very ubiquitous and require minimal attention from the users. In contrast, if the user wants to use services such as finding an item, creating an appointment, browsing the digital content or engaging in social contacts, they would be in the front line with the technologies. Therefore, the AAL shall provide a seamless, user-friendly, and intuitive user experience, so the elders can adopt to use all the services, actively engage in all the tasks and enjoy the enhanced quality of their life.

Technologies have been advanced in recent years, as numerous commercialized natural interfaces devices and smart objects, so it is possible to use these methods within an AAL environment. Since the interaction mode in an AAL is typically [21], being able to understand how and why the user would use certain modality for certain tasks is essential. Many studies have evaluated these natural interfaces individually, but not yet a system that has integrated all the natural interfaces and smart objects as a multimodal interface for an AAL environment. Thus, many questions are unanswered. For instance, would user prefer to use their voice to activate a video phone call or use a gesture to do so? Maybe the user would still like to use the traditional physical phone-like object to perform such task. How well does our targeted population's perform day to day computational tasks using various modalities within an AAL environment? Our research addresses the problem of how multimodal interfaces can be used for AAL systems to provide comfort services.

1.3 Research Objectives and Methodology

Motivated by the problem stated above, our main objectives have been as follow:

1. To create a multimodal evaluation system that integrates input methods such as gestures, voice, and smart objects

- The evaluation system implements four day to day tasks that the user would use on a daily basis

- The evaluation system would use same interface with traditional input methods using keyboard and mouse, as well as the multimodal interfaces using gestures, voice and smart objects.

2. Conduct a user study with 15 participants, age 55 or greater, at their home to test how well they would use the system

- Using scaled questions to gather feedback from the users
- Using questionnaires to gather additional comments the participants may have

These objectives can be translated into the following research questions:

1. *How do senior citizens react to the use of a multimodal digital interface?*
2. *How do different modalities compare for performing common tasks?*
3. *What modalities are more suitable for these tasks in the context of a smart home?*

To answer these questions, we developed an evaluation system, which includes interconnected applications to mimic an AAL environment. The user can perform domestic tasks, such as item finding, create and view reminders, making video calls, and browsing digital images through this AAL system. All these tasks can be performed by the traditional input methods (i.e. keyboard and mouse), but the user can also use gesture, voice, and touch interfaces on smart phone. We also conducted a user study to evaluate our system and answer the research questions using the criteria including efficiency, ease-of-use, pleasant, naturalness, fatigue and perceived efficiency.

1.4 Contributions

The main contributions of this study are:

1) Comfort services in smart homes:

By reviewing the previous works, we have identified the lack of focuses for the comfort services. And based on the interview we conducted with field professionals, we learned the importance of this category and the impact it has for our target population. This resulted in the study of AAL systems from a novel point of view that focuses on comfort services.

2) Multimodal interface for common everyday tasks

Through existing studies, we have selected four tasks that are important and essential for senior citizen's daily life. We developed a multimodal system that provides different options for performing these tasks.

3) User study on gesture and voice based interfaces

We conducted a novel user study that provides data from the senior citizens, who performed all the tasks at their home. This is an important factor, because the participants are completely relaxed and most of them have also enjoyed the study. Based on the first hand data we gathered from the participants, the experiences the user had are evaluated from ratings and comments.

1.5 Thesis Outline

In the following text, the complete process of creation of the evaluation system, the user study and the results will be discussed. In the chapter 2, a review of the key literature in the field of multimodal and natural interface, the smart home environment, and the ambient assisted living for senior citizens will be provided. In chapter 3, our research approach will be explained. This includes the choice of tasks, modalities, and interface design and user study method. Chapters 4 and 5 will address the detailed design and development of our evaluation system and the user studies. Chapter 6 will present the findings and results from the user studies, plus some discussions and design guidelines. Finally some concluding remarks and directions for future research are the subjects of chapter 7. Other additional documents used during this research will be included in the appendixes.

2 Related Work

In this chapter, the reviewed literatures are categorized into three categories:

1. *Ambient Assisted Living*, the state of art for AAL. This category will focus on the existing and on-going projects and studies on this topic.
2. *Multimodal interfaces*, mostly in the context of the elders. The studies on how unimodal and multimodal natural interfaces would affect the user experiences and performance.
3. *Related User Studies* will take a closer look at the research, which have conducted extensive user studies with seniors in a real or pseudo AAL environment with unimodal or multimodal user interfaces. It will also discuss how aging related problems can affect the design of a gesture-based application.

2.1 Ambient Assistive Living

As Sadri's survey paper indicated, supporting independent living for the elderly is one of the main applications for ambient intelligence. In next 5 to 10 years, the percentage of the senior citizen will be higher than the youth. The predicted expenses on health care or chronic diseases will no longer be affordable to many governments. A survey paper has reviewed a few pioneering AAL projects, such as Robocare [42], AHRI [43], and MINAml [44], and these projects have created a good foundation in the field of AAL. A few newer projects and system will be reviewed in the course of this chapter [41].

As previously mentioned, studies on creating pervasive living assistance systems, and have categorized assist-living systems into three categories, emergency treatment services, autonomy enhancement services and comfort services [4, 9]. While they believed these three categories are equally important and critical for the older adults, but they have given more attention to the first two categories.

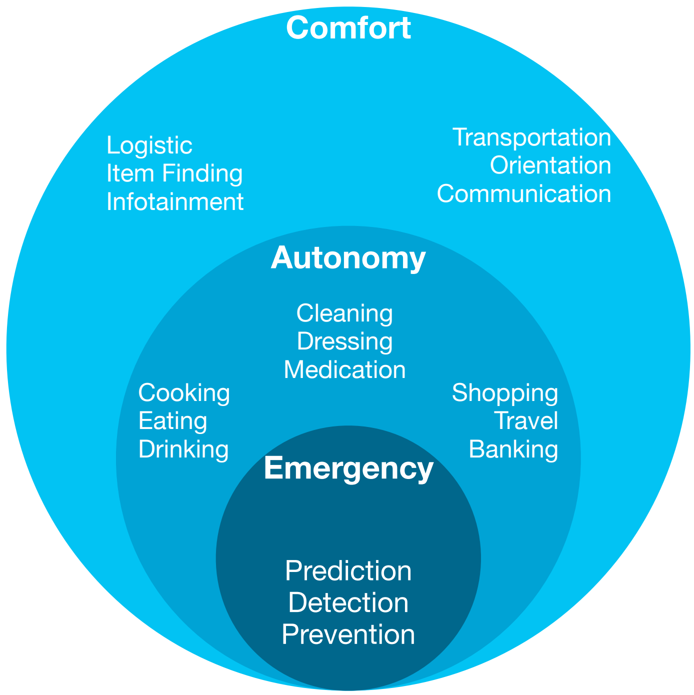

Figure 1. The classification scheme for the living assistance domain

Moreover, researchers have generally agreed that an AAL should have following characteristics [9, 16, 18]:

- Invisible
- mobile
- context aware
- anticipatory
- communicating naturally

- adaptive

Before introducing the interaction methods within the AAL, we will first take a look at the infrastructure of the AAL, since it is a complex and intelligent system and it is worth investigating how it works in order to have attributes mentioned above. Nick and Becker [19]. Have worked on a monitoring and assistance component including a hybrid processing/executing unit, which uses case-based and situation-recognition-based approaches to monitor and adapt the planned and running treatments. So the system is context aware of the users and able to anticipate the upcoming commands and execute them accordingly. Similar work has been done by Storf et al. [22], who proposed a multi-agent, and event-driven approach for recognizing emergency situations or unusual behaviors. Based on the results of tested scenarios:"toilet usage", "personal hygiene", and "preparing meals", their proposed system showed that the percentage of correctly detected scenarios out of all scenarios is more than 80%. Lezoray et al.'s dynamic adaptation approach [7] is also being used in an Ambient Assistive Living environment. The main contributions of this work are (1) the use of a specific development method, based on the concept of medium, to specify an adaptive architecture for pervasive AAL systems, and (2) the identification of the improvements of this method to make it more fitted to that specific domain.

In additional to the underlying technologies and approaches, other researchers have focused on the interface of their system. For instance, D'Andrea et al. [21] have proposed a multimodal pervasive framework for ambient assisted living environment, which divides the framework into four levels, the acquisition/presentation level, the analysis level, the planning level, and the activation level. Their study has also outlined the kinds of support that the framework could accommodate for the elderly population, such as cognitive support, socialization support, and care support, (which roughly aligns with the three services categories). An interview-based user study was conducted, and the users showed overall positive experiences. Similarly, Kernchen et al. [34] created a conceptual framework integrating a multimodal user interfaces and ubiquitous sensorised environments in order to provide better user experiences. They illustrated how user modality sensors/actuators and mobile/embedded sensors/actuators can be processed and fused during the user input phase, recognized by the situation aware component and provide semantically controlled output. However, their study was theoretical, and did not provide any practical details, such as the kind of modalities and interaction methods that would be involved, and the type of tasks the users would perform within their system.

Above all, these studies have paid great deal of attention on the mechanics of how an AAL would work within a senior's home. Although, some of them have adopted some level of multi-modal user interfaces and have explored the ways to fuse all different input/output modalities to behave as one unified system, these studies are still at a conceptual and theoretical level, and thus, our study would build on their theories and to create such a system, which implements the features to be evaluated with the real users. Next, we will review studies that have paid more attention on the interaction between the system and the users.

2.2 Multimodal Interfaces

The use of voice, gestures (body movement, arm movement, and hand movement) and tangible digital objects as new form of interfaces has became more popular and investigated comprehensively. These new interaction methods are believed to be more natural and pleasant compared to the traditional methods (keyboard/mouse). Integrating these “natural” methods into a multimodal interface can potentially be very beneficial for senior citizens.

Many researchers have used voice as input method as part of the AAL system. Goetze [30] created an assistive robot platform utilizing speech, visual, haptic modalities with brain computer interface. The system currently provides feedback to the user by a graphic user interface and a speech synthesis system. The user could use the voice recognition in an assisted living environment along with mouse and keyboard. Also, Becker et al. [20] have worked on a voice recognition-enabled event-based system for ambient assistive living environment. Their system uses wireless sensors which can be rapidly deployed and avoid unwanted intrusion to the users' life. The user can use voice to give commands, which would be processed by the dialog management system. Lastly, Callejas and López-Cózar’s project [38] utilizes the user centered design approach to design a smart home interface for elderly people. According to their survey results in the planning phase of their work, the participants had high acceptance for features such as using spoken commands to control window blinds and television. The participants also appreciated the proactivity of the system, which is always ready, and providing proper prompts, but they did not like the animated agent.

Even though most of studies have found the voice input is a suitable and efficient interaction method, Turunen et al. [33] have created a multimodal interaction system for a media center application. Their multimodal system includes device gesture, voice and touch input methods. Their experiment results show that physical touch and gesture interfaces were successful for this application, whereas the speech input did not satisfy their participants, which was considered not robust due to the technical and hardware limitations.

Moreover, Anastasiou et al [32] have conducted a user study in their Ambient Assisted Living Lab at Bremen University, which collected speech and gesture empirical data when the participants were using their voice to control a robot wheelchair to navigate around in the lab. The study has observed that the participants would gesture accompanying certain voice commands. This would be valuable for researchers to integrate the gesture-based interaction into an AAL system.

Currently, despite the fact that depth sensors such as Microsoft Kinect are easily accessible to anyone in the market, studies have not conducted for using such device to perform ordinary computing tasks, nor anything has been done specifically for senior citizen. One reason is because the device was originally designed for gaming purpose, where we were able to find studies for seniors.

Ganesan and Anthony [31] have created a Kinect based prototype game to promote and help seniors to do physical exercises. Some preliminary findings with their limited focus study group suggest elderly enjoyed the activity and saw it as pleasurable, and they found the body gesture-based game was amusing, exciting and fun. They also thought being able to socialize with others is a motivator for them to exercise. The initial results were promising, but the question is still unanswered: how about performing day to day tasks such as the services from AAL domains, such as emergency, autonomy, and comfort?

Some studies regarding gesture-based computational tasks on younger generation have been done. For example, Farhadi-Niaki's [39] research has developed a vision based HCI prototype, for a comprehensive usability study on using arm and hand gestures for interaction for computational tasks, such as opening/closing a file, selecting files etc. The user study compared the gesture-based interaction method with the traditional mouse and keyboard inputs for criteria, such as precision, efficiency, ease-of-use, fun-to-use, fatigue, naturalness, and perceived efficiency. The results showed that gesture-based is superior to mouse/keyboard when using big screen, and the finger-based gesture input is superior to arm-based in the long term of use. Also, the participants from this study also indicated that the gesture-based input are more natural and pleasant than mouse/keyboard, but the arm based gesture would cause more fatigue than mouse. However, the setup in this study was still measuring people performing tasks in front of a stationary workstation, and did not concern much regarding the ubiquity of the potential user scenarios in an AAL environment. For example, in a smart home, how would user know where they can use their gesture to control the assistive system, and how the environmental factors could affect the accuracy of the gesture capturing?

Besides the study of how the users would send command to the system, there are studies concentrating on the effectiveness of the multimodal feedbacks. The study results demonstrated that the output modalities, such as audio, visual and multimodal, would not affect the seniors' performance, and the multimodal and visual interfaces give better feedback than the audio interfaces [12, 18]. Warnock et al.'s study [13, 14] examined senior participants with a card matching game to see how different modalities affected the performance and how effective the different modalities were at delivering information. They found out how seniors negatively perceived the olfactory information.

The way they receive the notifications from different modalities demonstrated similar performance as the younger people, which confirms their hypothesis that neither notification function nor modality have an effect on the error rate in the card game they used, and the notification function and modality do not have interaction effect. However, Singh et al. [40], used a virtual assistant for website control and navigation, which provides an animated human avatar with voice and text based step-by-step instructions for senior users. The users would use the mouse and keyboard to input the information. According to the results, the participants performed better with the multi-modal instructions than the traditional graphical interface.

As the studies have been conducted either for voice or gesture, it is rare for researchers to combine both input method into one evaluation system, even though they agree that certain modalities are more suitable for certain tasks [13]. It would be valuable to have a robust system with as many interaction modalities possible to the users.

2.3 Related User Studies

In this section, a number of on-going multimodal and AAL related user studies will be reviewed. To begin with, Krahnstoever et al. [35] presented a framework for creating a voice and gesture based multimodal interaction system with large screen displays. The system is capable of fusing the voice and gesture data and providing the feedback via a large display. Informal studies indicated that the system was robust and the users have high acceptance of the systems.

Vacher et al. [36] conducted a study for Sweet-Home project in Grenoble, France with three important aspects of the speech interaction in smart home: voice orders, communication with outside world, and home automation system interrupting a person's activity. The methods they used are Wizard of Oz [47] experiment and interview. The Wizard of Oz is a method that the researchers are controlling partial of their evaluation system for their participants to operate, whereas a real computational system shall always be automated. The results showed that the seniors and their relatives preferred mostly the voice commands, the system interventions regarding the safety issues and the video-conferencing. Their results also showed the "key-word" (e.g. closing the door or using the vacuum) form for commands is highly accepted (rather than natural sentence commands). Further, they also studied the adaptation of speech recognition technologies for senior people by recording two specific speech corpora to find out aged-voice characteristics. The results show that some phonemes are more affected by age than others.

The further experiment in the Sweet-Home project by Portet et al. [37] have shown that the voice interface appeared to have a great potential to ease daily living for elderly, and they also stated that the users would like to have the ability to control their daily life rather than putting them away by the caregiver or the automated programs. In another word, the seniors prefer to have the same life style as they were young and only with necessary support, but ubiquitous helps and supports from the AAL system. This is similar to the informal interview we had with the Glebe Senior Centre, who stated that they organize all kinds of activities and encourage their resident to be more active and keep them busy to avoid the fear of the aging.

Researchers [7, 23, 25, 26] have reviewed a few known projects from their AAL living lab in Schwechat, Germany. The establishments of living lab can be seen in several studies, as an emerging research method, which allows, "sensing, validating and refining complex solutions in multiple and evolving real life contexts". The projects they are currently working on in the lab are "e-Home", a minimal intrusive wireless monitoring and guidance system, which increases the safety and autonomy of independent living for seniors. Based on user-centered development method, this project equips sensors, and targets to detect falls, and generates the alarms up on emergency; "e-Shoe": a wearable system integrated in a shoe or shoe sole, which equips with sensors to measure human ambulation, and to evaluate and gait characteristics to recognize and prevent falls; "interactive picture frame": based on participatory design approach, which allows seniors to touch a picture frame to make a voice and video phone call; "Long Lasting Memories": a platform that will deliver an effective countermeasure against age-related cognitive decline, by simultaneously inducing neural and corporal stimulation in a safe and controlled environment; "Demo-apartment for seniors": an apartment at a local senior center which serves the purpose of an "AAL showroom", so the elder can experience the newly developed project, and learn to use them quickly.

Doyle et al. [27] have created a touch screen based communication device and deployed in 9 seniors' home for a 7-9 weeks evaluation period. The finding has summarized the following:

> Perceived usefulness: who is it for? For example, some participants are happy with their current communication methods, but others who are geographically isolated, bed-bound, house-bound or chair-bound may need it.
>
> Attitudes towards communication: the participants have preferences regarding whether they would like to be monitored, contacted, or when to turn on or off the device for other events of their life. For instance, they would not

want to be bothered when they are watching TV shows.

Making friendships: the importance of common interests, the participants has expressed how they would like to contact to people who have common interests on certain subjects.

Another project by Doyle et al. [28] has suggested the emotional wellbeing is normally overlooked in the area of technology design for assisted living. They developed an application to monitor and promote seniors' emotional well-being. To design the application, they held three focus groups, and all the groups indicated that the social interaction is the most important aspects as they age. The application consists of a daily survey for the user to fill and view the feedback from a clinician, based on their survey. It is an interesting study to measure the senior' emotional state, and proofs the importance of the emotional well-being can also greatly affect seniors' quality of life.

Gerling et al. [29] have summarized some aging related changes and impairments, such as having an impact on the ability to engage in gesture-based interaction. Certain age-related diseases may also affect their physical abilities and capacity to use the traditional paradigms of Human Computer Interaction. Based on their findings and consultations from a physical therapy expert, they suggested a basic gesture set they used for older adults to engage full-body interaction. Their results suggested that the participants' have different abilities causing different results in response to the gesture set, such as limitation in range of motion, strength affecting the ability of holding and repeating a gesture, and overall movement speed.

The projects reviewed above have illustrated many important aspects of AAL, however, majority of the studies were taken place in a fixed lab environment, even though some of the living labs were setup as a home environment. The participants may not able to completely imagine the experience they may have if they were performing tasks at their home. Secondly, the lack of arm/hand movement gesture based study for senior citizen is an area worth to explore more. Arm/hand gestures may not be as intuitive as voice commands, but the users can still interact with the system in a more flexible way than sitting in front of their computers, especially for simple interactions, such as swipe hand to go to next television channel or next image. Thirdly, some projects have attempted to integrate digital informatics into traditional objects, such as interactive picture frame, rather than using it as part of an AAL eco-system, these objects normally work as an individual piece of technology. It would be worthwhile to investigate how the target audience would use it under a unified AAL system. Above all, it will be very beneficial to test how users would perform different daily tasks with different interaction methods, and what kind of user experiences they would have.

3 Research Overview

3.1 Background

By reviewing previous works, we have studied the state of art in fields of Ambient Assisted Living environment, natural interfaces, multimodal interface, and the rapid-increasing aging population. A gap was identified from the previous chapter between the fundamental technologies of AAL and the interaction design for the targeted audience. In another word, the studies are either too general or too specific for a particular area of the AAL, but the exploration of how users would reflect on a functional multimodal user interface for their day-to-day tasks is still lacking.

3.2 Objective

The objective of this study is to create and evaluate a multi-modal based system-integrating tasks from the comfort services category within a smart environment to help aging population to maintain same life quality as their abilities decline. According to Kowtko [6] and Dishman's [2], the needs for providing aging population technologies that are ubiquitous, proactive in everyday life are identified. Thus, the elderly can still have the controls for different aspects of their life. Moreover, in an interview with the facilitator at a local caring home, Lee claims that it is a good way to make elderly people feeling achieve something by helping them access to more resources, such as technologies. This proactive approach would also reduce the increasing expenses from the health-care system's diseases-oriented approach [2].

Figure 2. Implemented tasks

After some informal interviews with experts such as professionals working at Glebe Senior Centre in Ottawa, four tasks were identified as good examples of common domestic activities. These tasks are shown in Figure 2. These tasks all fall into the comfort services category within the AAL classification showed earlier. Further, these tasks would all require some degree of cognitive abilities, such as memory encoding and retrieval, problem solving and reasoning, discourse comprehension, attention process and working memory, which will decline with age [4]. For instance, people would recognize an item presented in front of them, but they would normally have difficulties to remember where was it stored [46]. As the results [3], such cognitive changes would also affect computer use. Therefore, the interaction methods which are suitable for young users may not be suitable for older users. It is necessary to see what other interaction options are by creating multimodal interfaces with these essential tasks.

Moreover, one of these four tasks may have been studied in one of the previous studies to test certain functionality of a technology and may have accompanied with a user study. Nevertheless, not many studies have implemented all these tasks into one application with the proposed interaction modalities, such as gesture, voice and smart objects [9, 33, 34]. Other studies may have tested many scenarios with more than one tasks, but they may only implemented using one interaction modality, such as speech [36, 37] or gesture [31]. Our study aims to utilize use body movement based gesture input, voice input, and handheld devices with smart objects to form a multimodal evaluation system with all the tasks mentioned above.

3.3 Research Approach

This study aims to use human centered design techniques, such as incorporating day-to-day tasks scenarios, use cases, work flows, with the implementation of ambient technologies and multimodal interfaces to create an evaluation system for conducting user study. The user study uses rating scale and questionnaires to gather subjects' experiences to answer the research questions, which would be more worthwhile than simply using scientific tools to measure the performance.

3.3.1 User interface Design

The basic user interface (UI) in the evaluation system is created based on the Metro interface [11], which is optimized to handle both pointing devices such as mouse and touch interfaces. The main difference between the traditional WIMP (windows, icons, menus and points) interface and Metro interface is that the Metro interface focuses on the content rather than the graphics [11]. The Metro interface was used not only on the newest desktop operating system, but also used Microsoft's tablet and smart phone's operating system. It provides a consistent user experience across different devices, and this consistency can help the user to focus on the tasks.

3.3.2 Gesture Selection and Detection

The gestures used in the evaluation system were either using the left or right hand to swipe left and right, or draw circle clock-wise. The system would understand whether the participant was using their left or right hand. The command that the gesture would trigger was also consistent across all the tasks. Both algorithm-based and template-based methods were used for gesture recognition. The device used for detecting gestures was the Microsoft Kinect (http://www.microsoft.com/en-us/kinectforwindows/) and the application-programming interface was Microsoft Kinect software development kit.

3.3.3 Voice Recognition

The evaluation system used the Microsoft's speech software development kit. Based on the content of the different tasks, voice commands were hard coded into the evaluation system. The Kinect's multi-array microphone system was used to gather voice from the users.

3.3.4 Smart Objects

The evaluation system includes two smart objects, the first one is used in the item finding task and the second one is used in the communication task. The first one is a bluetooth-based chip produced by ACE sensors and placed in a RUM foam model, which can be attached to items such as keys or glasses. The second smart object uses a Windows phone to run a wireless connected mobile application to initialize video phone calls with the main application.

3.3.5 User Experiment

Our experiment invited 15 senior citizens from three different senior homes, and all the experiments were conducted at their comfort of home. During the user experiment, which normally lasts around 60 minutes, this study has focused on daily tasks that belongs to AAL's comfort services, which includes item finding, create and view reminders, communication, and infotainment. These tasks are organized by as four scenarios. For each scenario, it is further divided into two different parts, as one requires participant to use mouse and keyboard, and the seniors would use natural interfaces such as gesture, voice and smart object to perform the second part. Two pilot studies were also conducted prior to the user experiment, which corrected a few bugs based on the comments from the participants. During the experiment, the users were given a short tutorial, so they were familiar with the equipment used in the study, such as mouse, keyboard, smart phones, smart objects, and available gestures and voice commands. Three different sections of questions were answered, which were

1. Pre-study questions
2. Scale ratings for evaluating criteria
    i) Pleasantness
    ii) Fatigue
    iii) Ease of learning
    iv) Naturalness
    v) If it is better than their current solution
3. Post study questions,

Furthermore, in order to help the participants to recall all the tasks they have performed, each task is named with a color name. So a table for mapping the task names and the color names are presented as following in Table 1.

Task Name	Color Name
Item Finder Traditional	Blue
Item Finder Multimodal	Purple
Reminder Traditional	Orange
Reminder Multimodal	Red
Video Call Traditional	Green
Video Call Multimodal	Yellow
Media Traditional	Grey
Media Multimodal	Black

Table 1. Task names and color names mapping table

4 System Design

4.1 Software

In order to fulfill the requirements to create a capable AAL system (e.g. communicating naturally) as described from the previous chapter, an evaluation system has been drafted and included applications that were developed specifically for the user study (as illustrated in Figure 3):

1. The Main application (Main app): for interacting between the user and the entire system
2. The Kinect Server application (Kinect app): for receiving from Natural User Interface (NUI) commands, and transmitting to the UI app via WinSocket.
3. The Phone application (Contacts Phone app) captures input and transmits command to the Main app

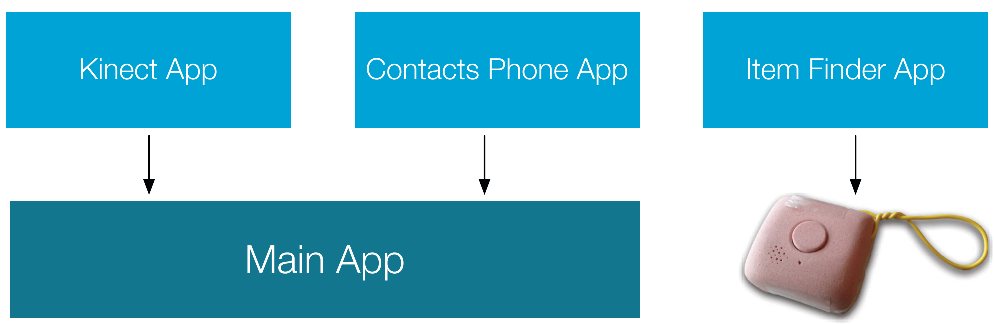

Figure 3. The structure of the prototype system

In addition to the applications developed during this study, a few third party software and libraries are also integrated into our evaluation system:

1. Skype: used to initialize the video call between the researcher and participants

2. Smart Finder: an iOS app to work with the Smart Objects
3. Syncfusion WinRT XAML control kit: an WinRT runtime based user interface programming extension kit, it includes components such as the calendar, and date/time picker

4.1.1 Main Application

The Main app is the hub for hosting all the scenarios and their tasks, and it is also responsible for communicating with the Server application for receiving NUI inputs, and the Contacts Phone app for getting command from the user's selection. The Main app was a C# written app and built based on the Windows Runtime framework, which is the underlying technologies in the newest Microsoft operating system, such as Windows 8, and Windows Phone 8.

The features that developed within the Main app is listed as following:

- Navigate through "Item Finder", "Reminder", "Communication", and "Media" tasks

Figure 4. The main navigation menu

- Browse through and look up each item in detail for the Item Finder task (Blue Task only, See Figures 5 and 6)

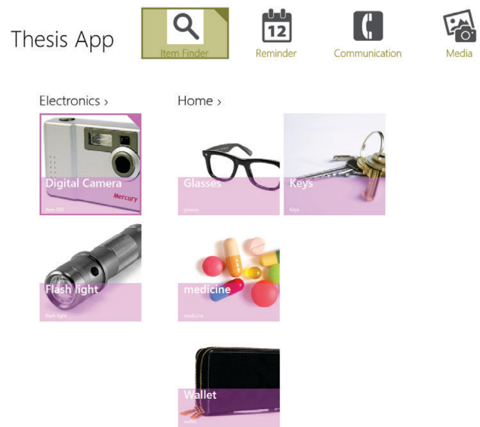

Figure 5. The item finder task home page

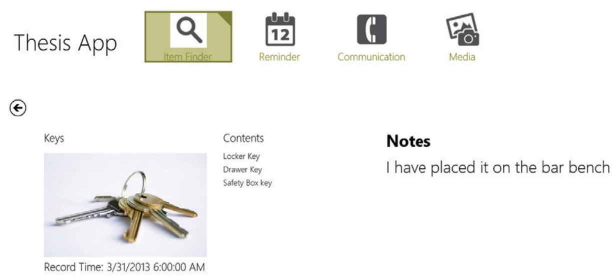

Figure 6. The item finder task detail page

- Create a new reminder and browse calendar for the future events (Orange/Red Task, see Figures 7 and 8)

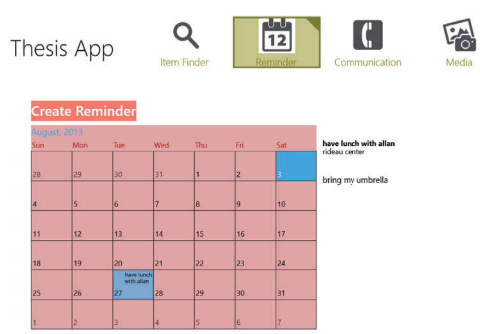

Figure 7. The reminder task calendar page

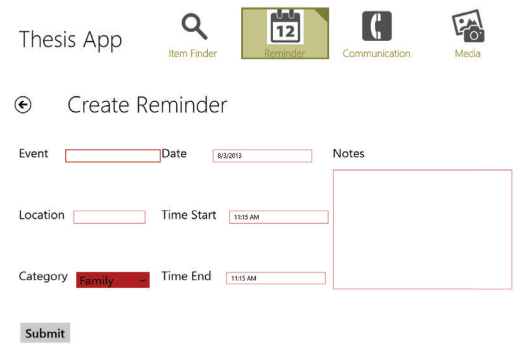

Figure 8. The reminder task create reminder page

- Select the desired contact they wish to make a video chat with (Green Task only, see Figure 9)

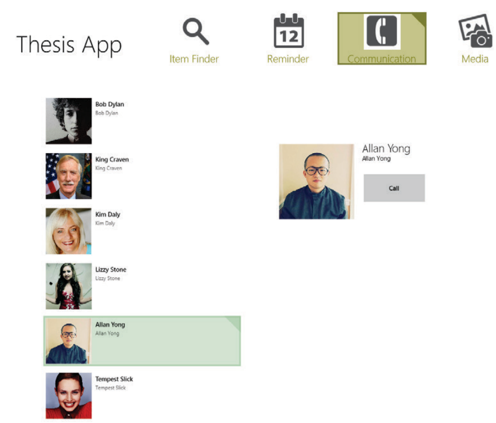

Figure 9. The video call task page

- Browse through and view each media file for the Media task (Black/Grey Task, see Figure 9 and 10)

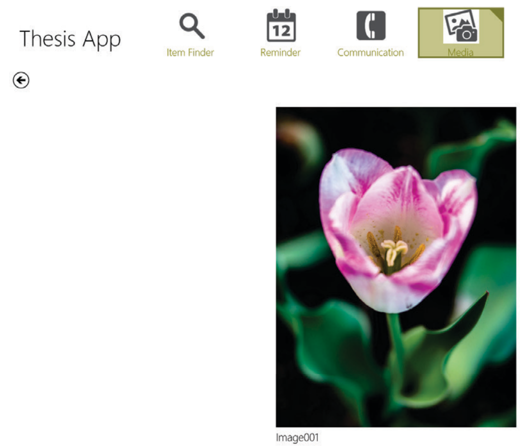

Figure 10. The media task home page

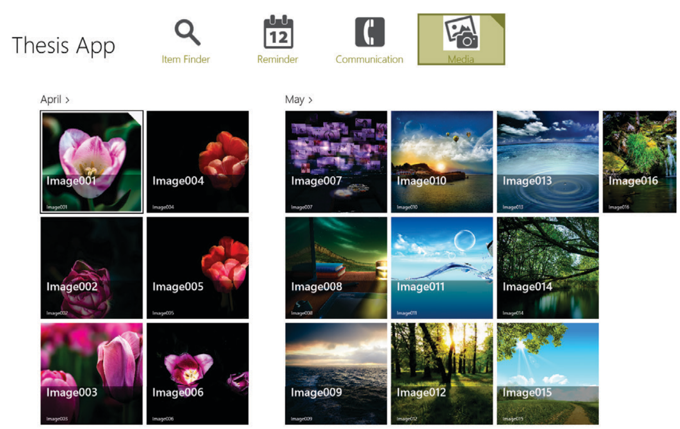

Figure 11. The media task detail page

- Controls for establishing connection with the Kinect app and Contacts Phone app and debugging the application (see Figure 12)

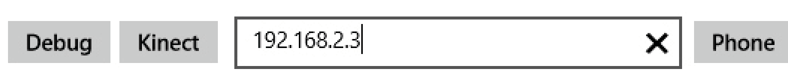

Figure 12. The connection and debug control area

- Receive commands from the Kinect app and Contacts Phone app via WinSocket protocol.

4.1.2 Kinect app for Natural Interface Input

Since Kinect sensor has not been supported by the Windows Runtime Library yet, as one of the biggest challenges during the development process, the Kinect app was developed as a middleware for the Kinect sensor and the Main app to communicate with each other via WinSocket. The Kinect app was developed in C# based on the Windows Presentation Foundation (WPF) framework. Besides the gesture and voice recognition feature, the Kinect app also has network functionality, which can send converted gestures and voices as commands to the Main app.

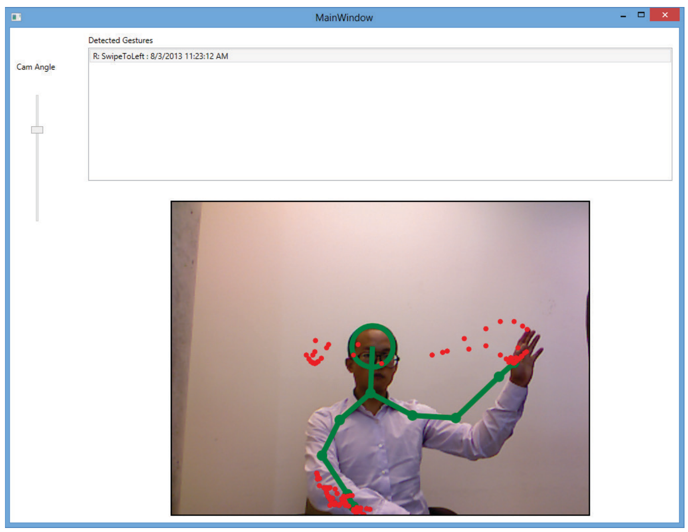

Figure 13. The Kinect app interface

By using the Kinect ToolBox toolkit (http://kinecttoolbox.codeplex.com), the Kinect app is able to recognize gestures such as, swipe left /right, and clock-wise circle from each hand separately. The swipe left and right gestures used the algorithmic method, whereas the circle drawing was template based. The algorithm method calculates the distance, direction, and duration of each hand joint. The template based method uses the Hidden Markov Model, so a particular gesture has been recorded as a binary file and would be used for detecting the gesture input. Since the purpose of using gesture in this study is to show how the senior citizen would react to such new input method, and understand the experiences of the usage. The gestures that have been implemented are not extensive, but these gestures are capable of dealing with most of the tasks, thanks to the Metro UI, which simplified the traditional WIMP method, and allows the user to just concentrate on the content.

Microsoft speech platform SDK was used for recognizing the voice commands from the user. By using the experiment method Wizard of Oz, the researcher has created a set of commands, which are used in the evaluation system, so the user can use these commands to control the system smoothly. A set of grammars, such as the commands (e.g. “next”, “previous”) and contents (e.g. “bring my umbrella”, “August 27th, 2013”), was implemented in the application. Table 2 shows the mapping of gestures and voice commands for the Kinect app.

[1]

GESTURES	VOICE	KEYBOARD	FEATURE
LeftHand Swipe Left	“Previous”	Arrow Key: Left	Go to Previous Item/Viewing Item
LeftHand Swipe Right	“Next”	Arrow Key: Right	Go to Next Item/Viewing Item
LeftHand Circle	“Back”	ESC/Backspace*	Go back to previous level of page if exists
RightHand Swipe left	“Item Finder”, “Reminder”, “Communication”, “Media”	Tab Key	Tab Navigation in Top Menu
RightHand Swipe Right	“Item Finder”, “Reminder”, “Communication”, “Media”	Tab Key	Tab Navigation in Top Menu
RightHand Circle	“Okay”, “Submit”, “Go”	Enter	Select, confirm a selection

Table 2. Map of gesture, voice, keyboard and feature table

[1] *In certain conditions, e.g. when the current page can go back to previous page.

4.1.3 Contacts Phone app

The application developed and deployed to the smart phone is based on Windows Phone 8 SDK. The application is written in C# and main function of the application is to display the frequent contacts for making video calls. A large contact image and contact's name are displayed as a list. The Contacts Phone app also has a network functionality (via WinSocket) to send user's selection to the Main app (See Figure 14).

4.1.4 Third-Party Software

For item finding task Purple, the smart object, an iOS application Smart Finder, was used for user to perform item finding task in the study (http://acesensor.com). Skype was used for making video chat, and the prototype software used SkypeUrl to initialize the phone calls to the Skype (http://www.skype.com). An evaluation version of Syncfusion WinRT XAML control kit was used to create Calendar, date and time picker for Reminder task (Orange/Red Task) (http://www.syncfusion.com/products/winrt).

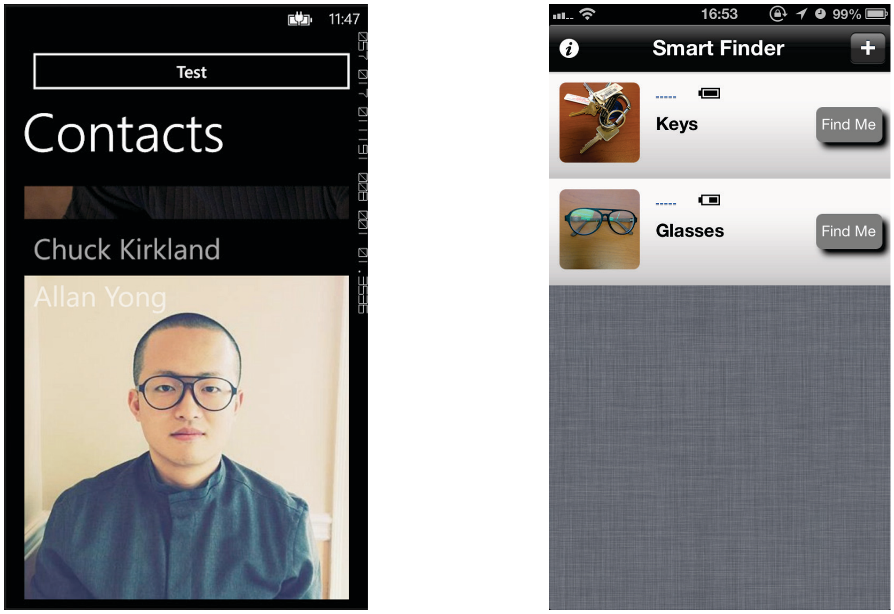

Figure 14. The Contacts Phone app interfaces and Smart Finder Interface

4.2 Hardware

4.2.1 Fabrication

A prototype model casing (see Figures 15 and 16) was designed and made by researchers for the PCB board produced by Ace Sensor for Item Finder Task (Task Purple). The sensor integrates a Bluetooth LE chip from Texas Instrument which can run on a coin battery for almost two years. As writing this thesis, multiple companies have started offer this type of products with the same Bluetooth technologies, including Pally (http:// acesensor.com), Button Tracker (http://www.button-trackr.com), and Tile (http://www.thetileapp.com).

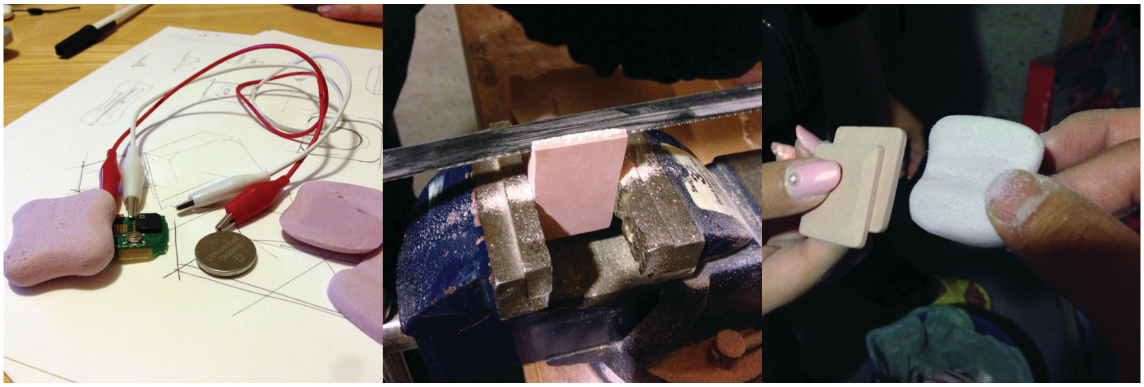

Figure 15. The design of the Item Finder physical model

Figure 16. The inside view, back view and top view of Item Finder model

4.2.2 Equipment used for the study

Following are the devices that have been used for this study.

- A laptop computer running Microsoft Windows 8 operating system

- A Microsoft Kinect for Windows depth sensor

- An Apple iPhone 5 smartphone

- A Nokia Lumia 920 smartphone

- A ViewSonic projector

4.3 User Experience Considerations

Measuring the overall experiences of different interaction modalities is one of the major criteria for this study. For the target users, age-related concerns have been considered throughout the design processes. To begin with, the menu for the four tasks is placed on the top of the screen, so the participant will always be able to navigate through them, without worrying about getting lost in the application. Secondly, all the font size and controls in the application are intentionally enlarged to assist weaker sights. Thirdly, the color scheme for each scenario is matched with the name of each task's color coding (e.g. the color used in item finding interface would be the combination of blue and purple as the name of the tasks were blue and purple), which hopefully will let the participants be more confident and get familiar with the system easier. As mentioned earlier, there are very few gestures and voice commands, so the participants will be able to remember these controls effortlessly. In addition, the questionnaire booklet is also designed with the color coding, and always labeled the gesture and voice command in bold font weight, so the participants would be able to recall all the gestures and voice command if they forgot.

5 User Study

5.1 Introduction

The purpose of this user study is to evaluate the prototype multimodal system using these criteria: pleasantness, ease of learning, easy-of-use, efficiency (time), fatigue, naturalness and perceived efficiency. The user study consists of four different scenarios based on the tasks we selected in Chapter 3. Each scenario includes two parts performing the same task but compares the traditional input methods (e.g. mouse and keyboard) versus the natural user interfaces (e.g. voice, gesture, and tangible interface). As mentioned above, the user could use either voice or gesture to perform most of the navigational tasks, such as going next, previous, navigating between scenarios, or performing a mouse click action.

A stopwatch was used to measure the time took for participants to complete each task. All participants were healthy seniors, and based on their age, they tend to have normal aging symptoms, such as declined cognitive level, and weaker motor skills. The reason we did not recruit any seniors with aging diseases is that the main purpose of this user study is to evaluate the experience and get the initial feedback from the participants, and the system already has many variables that could create diverse outcomes. The system itself has already considered the decline in abilities of the senior subjects, and future investigation may branch out from this study to explore and evaluate the system's efficiency, usability and overall experience for seniors at different levels of physical and mental health.

The survey questions were grouped into three parts:

1. Pre-study qualitative questionnaire
2. Post-study qualitative questionnaire
3. Numeric questions to evaluate each task using our criteria based on a 1-5 scale

A sample questionnaire can be found in Appendixes A. The purpose of this questionnaire is to understand the following:

1. Demographic information (e.g. age, gender)
2. The comfort level of using technology.
3. The knowledge of technology they have.
4. How do they perform the tasks in this study with or without current technology
5. Do they have any problem with existing technologies
6. What are their daily routines, e.g. what do they do everyday
7. What was their favorite natural interface
8. Did they enjoy performing these tasks
9. If they found any of the tasks is pleasant, easy to use, tiring, and natural. How much do they feel so
10. Their overall experiences and efficiency from performing these tasks.

The Research Ethics Board at Carleton University, Ontario, Canada, has approved this study. Two colleagues participated in the pilot studies and a few software bugs were fixed and some design improvements were made.

5.2 Scenarios

In order to reduce the use of the complex technical terms, such as keyboard and mouse task, or swipe gesture task, all the tasks under the scenarios are given a color name. Each scenario would have a set of tertiary colors, such as blue and purple, orange and red, green and yellow, and grey and black.

5.2.1 Scenario One: Item Seeking

Task blue: the researcher would place the physical item somewhere in participant's home, and update the "notes" content for this "missing" item. Participants used the Keyboard and Mouse to find a pre-recorded item from the Main app, and then they will need to locate the item physically (e.g. keys) according to the "note" associated with the item. Task purple: the researcher would attach the smart object with the item the participant needed to find. The participants used the application from the handheld device to locate a pre-recorded item and they would need to locate the item physically by listening to the audible indication from the attached smart object. The modality used in this task was the smart object.

5.2.2 Scenario Two: Creating Reminder

Task orange: the participant would use the Mouse and Keyboard to create a reminder following the instructions from the booklet.

Task red: the participant could use either voice commands or gestures to create a reminder by following the instructions from the booklet. Participants would use the combination of voice and gestures modalities in this task, and most of them only used the voice commands.

5.2.3 Scenario Three: Communication

Task green: the participant would use the Mouse and Keyboard to select a person from the contact list, and initialize the video chat via Skype.

Task yellow: the participant would use the handheld device to swipe through a number of the contacts and tap on one of the contact to initialize the video chat via Skype. The modality used in this task was the smart object.

Figure 17. The experiment setup

5.2.4 Scenario Four: Media

Task grey: the participant would use the Mouse and Keyboard to access to a photo album from a particular month according to the instructions from the booklet.

Task black: the participants would use either gestures or voice commands. The participants would firstly use the gesture modality, but if did not work well, they would use the voice instead.

5.3 Study Details

For each experiment, the researcher would follow following steps to setup, conduct and interact with the participants.

5.3.1 Preparation

1. Finds a solid surface to project the display on and setup the computer, depth sensor, and projectors.
2. Join the local wireless network, and the main application is connected with the Kinect app and the Contacts Phone app. In some experiments, a personal network is created via researcher's smart phone, so all other devices can join this network.
3. Check the battery of the smart object, and make sure it can be triggered for audible feedback.
4. The participant would read and fill in the consent form and pre-study questionnaire booklet using the pen.
5. The researcher would brief the intent and the agenda for the study.
6. A short training would be given to the participant so they got familiar with all the gestures, voice and the user interface gadgets (e.g. changing dates and times for Reminder task)

5.3.2 During the Study

The user would be asked to perform the each scenario, and the researcher would record the time that spent for each task. After each scenario, the participant would be asked to fill in the scaling questions for the tasks they have just performed.

5.3.3 After the Study

The participants will be asked to fill in the post-study questionnaire by hand and will be debriefed. A $10 coffee shop gift card is given to the participant as our appreciation for their time. The expected time to perform entire study is approximately 60 - 80 minutes.

6 Experimental Results and Discussions

6.1 Results

15 healthy participants (5 male, 10 female) were recruited for this study from three local senior centers, whose ages were between 55 and 75. The reason of this age group was selected for this study is because we want people who are close to retire, and have some exposure to the computer systems, and this research would essentially being adopted when they are older and in need for such a system. Most of the experiments were taken place at participants' home, with one exception where the tasks were performed in a boardroom, but it had been setup as a home-like environment. All the data gathered from the experiments are analyzed and will be discussed in the following sections. All the questions can be found in Appendix A.

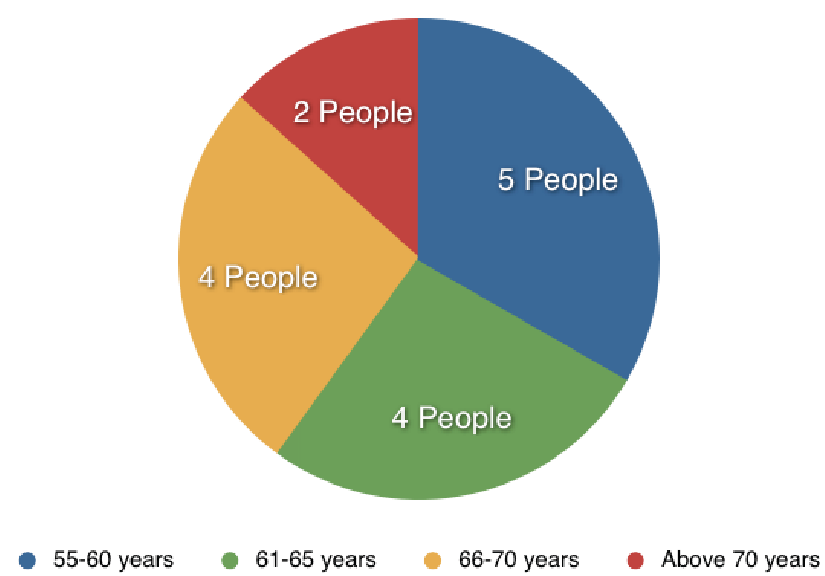

Figure 18. The age distribution

6.1.1 Pre-Study Questions

The intention of the pre-study questions was to understand the general demographic information, the participants' daily life routine, their comfort level with technology, and their current methods of performing the tasks in the experiment. Similar to the post-study questionnaire, all the handwritten answers were recorded into the computer after each experiment. Due to the natural of the questionnaire, all the answers were short, and somehow similar. The researcher have categorized all the high appearing keywords and organized the results accordingly.

Q1	Q2	Q3	Q4a	Q4b
Read (8/13)	Yes (10/13)	Email (10/13)	2 to 6 (7/13)	No (12/13)
Exercise (7/13)	Yes, but rarely (2/13)	Internet (8/13)	2 hrs or less (4/13)	Yes, not use (1/13)
Work (7/13)	No (1/13)	Media (7/13)	6 hrs or more (2/13)	
Computer (7/13)		Games (5/13)		
Housework (5/13)				
Entertainment (5/13)				

Table 3. Pre-Study questionnaire answers group 1

The following questions are related to their daily life routine, and comfort level with technology:

1. What do you normally do in a normal week or in a day?
2. Do you have a computer at home, and how often do you use it?
3. What do you normally do with your computer, e.g. surfing the Internet, checking emails, and watching videos?
4. How many hours do you spend on your TV? Do you have any gaming console, such as XBOX, Playstation or Wii?

Table 3 shows the most common answers among participants. In summary, read (61%), exercise (53%), work (53%), and using computer (53%) are the most common activities that are mentioned specifically for the participants' daily life. Majority of participants (92%) own one or more computing devices at home or work, and most of them (76%) use it fairly frequently. Email (76%), surfing Internet (61%), consuming digital media (53%), and playing games (38%) were the most common activities they do with their computer. Furthermore, only one participant stated that she owns game consoles at home, but she does not use them. 7 participants (53%) spend two to six hours on the television daily, while 4 participant (30%) watch less than 2 hours and 2 participants (15%) watch more than six hours a day.

To find out the senior citizens' current way of performing certain tasks, following questions were asked in pre-study questionnaire:

5. Have you ever had a video chat via your computer with your friends?
6. How do you keep your address book? on a small notebook, mobile phone or computer?
7. How do you keep track of your personal belongings inside your home, what would you do to prevent from forgetting where they were placed?
8. How often do you found yourself seeking something but unsuccessfully?
9. Do you use computer software to keep track of your personal belongings?
10. How do you save your pictures from the past?
11. Do you have any photos on your digital devices, e.g. computer, phone, tablets, or any other devices?

12. How often do you browse your photos?

13. Do you have any video clips that you or your friends captured for events that you were involved in?

Q5	Q6	Q7	Q8	Q9
No (9/13)	Digital/Paper (6/13)	Not tracking (11/13)	Rarely/Never (5/13)	No (10/13)
Yes (4/13)	Digital Devices (4/13)	Organize Properly (7/13)	Sometimes (4/13)	Yes (3/13)
	Notebook (2/13)	Leave Notes (2/13)	Often (4/13)	
	Not Keeping (1/13)			

Table 4. Pre-Study questionnaire answers group 2

As we can see in Table 4 for question 5, 9 participants reported (69%) they have never done video chat with their friends before. Further, 6 people (46%) use both digital methods, such as cell phone or computer as well as a paper-based notebook to keep track of their contacts information. Four people use only digital devices, and two people use only traditional notebook to keep their friends' contact information. When it comes to keeping track of their personal belongings, 11 people (85%) answered that they did not lose their stuff at all, and it is because some of them (7 participants, 53%) think they have organized their items orderly. Only two people would write down somewhere to keep track of their items. Based on this fact, 9 (69%) participants believe that they never need to find a personal item. As the results, only three participants use computer to keep track of their personal belongings, and two of them were doing it for insurance inventory purpose only.

Q10	Q11	Q12	Q13
Both (6/13)	Yes (12/13)	Rare (5/13)	No (7/13)
Digitally (4/13)	No (1/13)	Often (4/13)	Yes (6/13)
Paper		Sometimes	

(3/13)		(4/13)	

Table 5. Pre-Study questionnaire answers group 3

In table 5, the results from questions 10 to 13, regarding how they keep and consume their digital media are presented. 6 of them use digital and traditional methods to keep their photos, whereas 4 participants use only digital media, and 3 people only use paper media to preserve their photography. Interestingly, when asking them if they have any of their photos on a digital device, 12 people said they do, which may be due to very limited and exceptional cases of using digital photos. Regarding how often they browse their photos, 5 people said they do not browse them often, but 8 people claims they view their photos "sometimes", or "few times a week". Lastly, for having any videos of themselves, the answers were distributed very balanced: 7 people did not have any, and 6 people did.

For the last question:

14. What are the improvements you would want to have in terms of the way you communicate with your friends, watch your photos and videos, find your items and keep track of your appointments?

4 people answered they were happy with the things like now, and did not need any improvements. The rest of participants commented on different aspects of the technologies, but these "wishes" are already existed, and they just do not know yet. For example, one participant mentioned how she would like to have a better way to rename her photos. Once the researcher introduced her a free software with such functionality, she agreed it was what she was looking for. Another participant wanted to print his calendar appointment from his smart phone wirelessly, but he does not know that he could purchase a wireless printer that will fulfill his requirement.

6.1.2 Criteria Scale Rating

During each experiment, the time that participant spent to finish each task was recorded by a stopwatch application from a smartphone. The table 6 below shows the mean, max, min and standard deviation of each task that user performed. For Item Finder, Reminder, and Video Call tasks, the participants normally spend much less time to complete with the multimodal interaction than mouse/keyboard. The only exception was the Media task, where participants needed to spend extra time to get use to the gesture-based interaction, though they were given the training at the beginning of the study.

	M	Max	Min	SD
Item Finder Traditional	50s	82s	23s	16s
Item Finder Multimodal	30s	47s	15s	10s
Reminder Traditional	218s	421s	22s	101s
Reminder Multimodal	104s	170s	43s	41s
Video Call Traditional	34s	77s	14s	18s
Video Call Multimodal	18s	35s	7s	8s
Media Traditional	61s	116s	28s	25s
Media Multimodal	129s	230s	62s	50s

Table 6. The *M*/Max/Min/SD of the time spent completing tasks

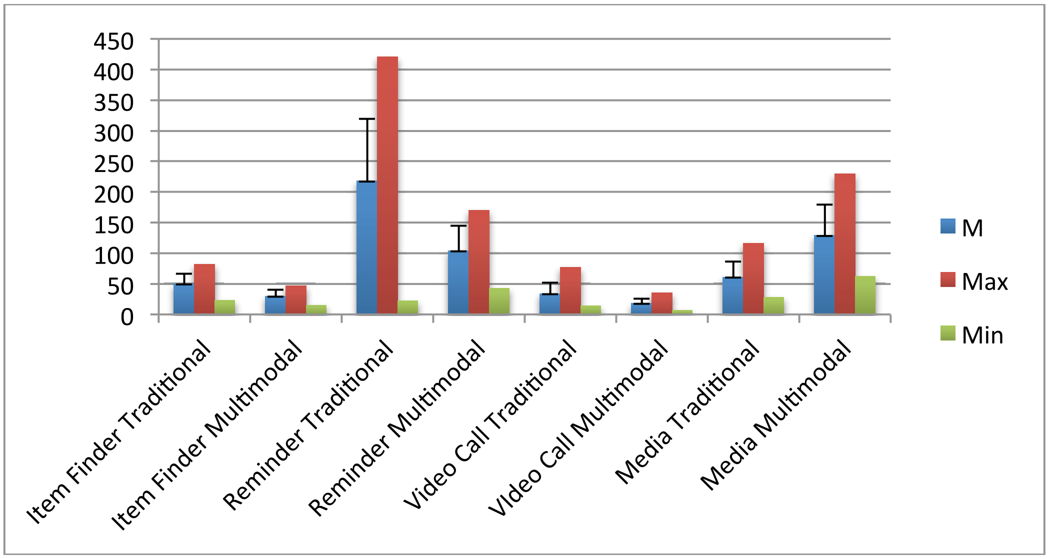

Figure 19. The *M*/Max/Min/SD of the time spent completing tasks

Criteria	Traditional				Multimodal			
	M	Max	Min	SD	*M*	Max	Min	SD
Pleasantness	4.03	5	2	0.87	4.44	5	2	0.70
Fatigue	4.26	5	1	1.10	4.34	5	1	1.04
Ease Of Learning	4.32	5	2	0.86	4.00	5	2	1.02
Naturalness	4.06	5	2	1.05	4.51	5	2	0.70
Perceived Efficiency	3.69	5	2	1.13	4.02	5	1	1.12

Table 7. The *M*/Max/Min/SD scale rating points by Criteria

Pleasant	Mean	Std. Deviation	Maximum	Minimum
ItemFinder	4.333	0.711	3.000	5.000
Reminder	4.071	0.940	2.000	5.000
VideoCall	4.267	0.785	2.000	5.000
Media	4.267	0.828	3.000	5.000

Table 8. The *M*/Max/Min/SD scale rating points for Pleasant by Tasks

Naturalness	Mean	Std. Deviation	Maximum	Minimum
ItemFinder	4.333	0.935	2.000	5.000
Reminder	4.214	0.957	2.000	5.000
VideoCall	4.300	0.877	2.000	5.000
Media	4.200	0.925	2.000	5.000

Table 9. The *M*/Max/Min/SD scale rating points for Naturalness by Tasks

Ease of Learning	Mean	Std. Deviation	Maximum	Minimum
ItemFinder	4.300	0.915	2.000	5.000
Reminder	4.000	1.018	2.000	5.000
VideoCall	4.100	0.858	2.000	5.000

Media	4.233	0.858	2.000	5.000

Table 10. The *M*/Max/Min/SD scale rating points for Ease of Learning by Tasks

Fatigue	Mean	Std. Deviation	Maximum	Minimum
ItemFinder	4.600	0.675	3.000	5.000
Reminder	4.036	1.261	1.000	5.000
VideoCall	4.300	1.119	1.000	5.000
Media	4.267	1.112	1.000	5.000

Table 11. The *M*/Max/Min/SD scale rating points for Fatigue by Tasks

Perceived Efficiency	Mean	Std. Deviation	Maximum	Minimum
ItemFinder	3.967	1.217	1.000	5.000
Reminder	3.714	1.213	2.000	5.000
VideoCall	3.800	1.186	2.000	5.000
Media	3.933	0.944	2.000	5.000

Table 12. The *M*/Max/Min/SD scale rating points for Perceived Efficiency by Tasks

Criteria	Sig (Mann-Whitney)	Mean Rank	
		Traditional	Multimodal
Pleasant	0.009	51.840	67.160
Ease of Learning	0.077	64.680	54.320
Naturalness	0.027	54.200	65.800
Fatigue	0.771	58.700	60.300
Perceived Efficiency	0.106	54.640	64.360

Table 13. Mann-Whitney Tests by Criteria

Pleasant	Sig (Mann-Whitney)	Mean Rank	
		Traditional	Multimodal
ItemFinder	0.340	14.100	16.900
Reminder	0.005	10.430	18.570
VideoCall	0.443	14.370	16.630
Media	0.541	14.600	16.400

Table 14. Mann-Whitney Tests by Task [Pleasant]

Naturalness	Sig (Mann-Whitney)	Mean Rank	
		Traditional	Multimodal
ItemFinder	0.766	15.100	15.900
Reminder	0.065	11.860	17.140
VideoCall	0.195	13.570	17.430
Media	0.361	14.170	16.830

Table 15. Mann-Whitney Tests by Task [Naturalness]

Ease of Learning	Sig (Mann-Whitney)	Mean Rank	
		Traditional	Multimodal
ItemFinder	0.392	16.730	14.270
Reminder	0.498	15.500	13.500
VideoCall	0.768	15.930	15.070
Media	0.099	17.970	13.030

Table 16. Mann-Whitney Tests by Task [Ease of Learning]

Fatigue	Sig (Mann-Whitney)	Mean Rank	
		Traditional	Multimodal
ItemFinder	1.000	15.500	15.500
Reminder	0.366	13.210	15.790
VideoCall	0.613	15.330	15.670
Media	0.906	16.200	14.800

Table 17. Mann-Whitney Tests by Task [Fatigue]

Perceived Efficiency	Sig (Mann-Whitney)	Mean Rank	
		Traditional	Multimodal
ItemFinder	0.299	13.930	17.070
Reminder	0.211	12.640	16.360
VideoCall	0.107	13.030	17.970
Media	0.602	16.300	14.700

Table 18. Mann-Whitney Tests by Task [Perceived Efficiency]

Table 7 shows the mean, max, min, and standard deviation of the scale rating questions based on the criteria and input method, where the multimodal has showed higher marks than the traditional method. The rating scales are from 1 to 5 as 1 is strongly disagreeing, and 5 are strongly agree. The criteria were pleasantness, fatigue, naturalness, ease of learning, and perceived efficiency. Then, the following tables 13, 14, 15, 16, 17, and 18, are the results from the Mann-Whitney Test results, because the results of these questions were not continuous, and the statistical significance needed to be evaluated. Two different calculations were performed; the first method is presented in Table 13, and the results from the Tables 14 to 18 used the second method. Firstly, the scale rating points from all tasks are combined by the criteria, and as table shown, the pleasantness and naturalness have showed statistic significance, and almost all the multimodal input method (except ease of learning), have showed higher results. However, this method can only be used for reference purpose and to see the general trend of the data points. Thus, the second method is used, which calculate each input method categorized by criteria and different tasks. For example, under the criteria pleasant, each task's pleasant questions were evaluated independently. Even though the results only showed only a significance, which was the criteria pleasant for the task reminder, some valuable information can still be revealed based on the mean rank results. For instance, across all criteria and tasks, multimodal has earned higher points among all these criteria and tasks.

6.1.3 Post-Study Questions

After the participants finished all the tasks, the post-study questions were filled in. The main purpose of these questions is to understand their first hand experiences, whether they liked the multimodal interface, and whether they would like to use these as their main input methods for the future. Next, all the questions will be reorganized and each group of questions will be discussed accordingly.

Q1a	Q1b	Q2	Q3	Q4a	04b
Media (2)	Voice (8/15)	Yes (15/15)	Gesture (10/15)	No (9/15)	Gesture (5/6)
Reminder (3)	Gesture (2/15)		Voice (1/15)	Yes (6/15)	

ItemFinder (2)	SmartObject (2/15)		Nothing (4/15)	Learning (2/15)	
VideoCall (1)	Mouse (1/15)				

Table 19. Post-Study questionnaire answers group 1

In table 19, the first four questions and results are presented as following:

1. What was the most interesting and satisfactory task you performed during the study, the one that you have enjoyed the most?
2. Did you find it was more fun to use these new technologies?
3. What was the most frustrating task you performed?
4. Did you find it confusing to use these new technologies? If yes, please describe the event?

It seems every participant would have their own favorite task, where 3 people liked the creating reminder task, 2 people liked media, and 2 people liked the item finder task. Only 1 person liked the video call, and 7 people did not specifically mention their favorite task, but the attitude was optimistic. For example, 8 people believed the voice speech was a good interaction method, comparing to 2 people voted for the gesture input and 2 people voted for the tangible objects. Similarly, everyone thinks that they had fun using the multimodal interface. In contrast, 10 participants specified that the gesture-based tasks were the most frustrating task. Even though, 9 people think these technologies were not confusing, 5 out of 6 who think they were confusing, who all blamed the gesture-based input, because “did not feel natural”, “cannot remember which gestures to use” and “not working consistently”.

Furthermore, next group of questions investigate if they would like to use these method and tasks as part of their daily life. The questions were:

5. Would you like to use what you learned in this task for your day to day life

6. Do you think you would spend more time on doing those tasks on a daily basis, because of the ease of use and ubiquity of the computing power? If yes, please describe which task you would want to do more?

7. For this task, you mentioned above, why do you think it was more enjoyable and want to spend more time?

Q5	06a	06b	Q7
Yes (10/15)	Yes (10/15)	Speech (9/10)	Easy to speak (5/9)
No (1/15)	No (5/15)	SmartObj (2/10)	Better Response (2/9)
Maybe (4/15)			

Table 20. Post-Study questionnaire answers group 2

As shown in table 20, the question no.5 and no.6 have suggested that the participants (both 67%, 10 out of 15 agreed) would like to use the new interaction system for their daily life. More specifically, 9 participants have enjoyed the speech interaction the most, and 2 people enjoyed the tangible interface. The main reason found from the answers was that the naturalness, easiness, and the efficiency were satisfying for the voice commands.

The last group of questions asked for the overall experiences and satisfaction with the prototype system. The answers from the tables 21 and 22 show the answers to these questions:

8. Describe your overall experience after all the tasks? was it enjoyable?

9. If it can be improved what would you suggest to improve this task?

10. Overall, did you find the gestures, tangible devices, and speech input methods were more efficient than mouse and keyboard?

11. Overall, would you like to comment on using gestures, speech and tangible device to interact with

the computers or screens?

Q8	Q9
Fun/Interesting/Enjoyable (15/15)	N/A (7/15)
Too “techy”(2/15)	Improve Voice (3/15)
	Improve Gesture (5/15)

Table 21. Post-Study questionnaire answers group 3

Q10	Q11
Yes (12/15)	Enjoyed overall (13/13)
No (3/15)	Multimodal are better and fun (5/13)
Gesture and accent	Gesture not good (4/15)
	smart object (3/13)

Table 22. Post-Study questionnaire answers group 4

The participants were all agreed that the system was “fun”, “interesting”, and “enjoyable”. However, 2 people commented it was too “techy” for them. 7 people did not think anything needed to be improved, but 5 people want the system to improve the gesture interaction and 3 people want better voice command input system. 12 (80%) people think gesture, voice, and tangible devices are more efficient than mouse and keyboard, but people think gesture recognition need to be more accurate, and the voice command should be able to pick up the accent. Last but not least, 13 out of 13 people reassured that they enjoyed the entire experiments, and they think the new interaction technologies are better and fun (5/13), but 4 people mentioned again the gestures interaction need more work.

6.2 Discussion

6.2.1 Overview

According to the results above, the targeted senior citizens have enjoyed using our multimodal interface. For example, from the rating scale questions, and the post study questions, their answers have clearly stated that they found the multimodal system is a lot of fun to use. They also felt the system is more effective than their current system, which can be proofed by the time for them finishing each data (3/4 scenarios). They also provided comments on how they would like the system to be improved, such as the gesture recognition. The data has indicated, similar to the reviewed literatures on studies with general population [29, 34, 35, 39], within the multimodal interface, voice and tangible interfaces have been favored the most, and the gesture based interface were less desirable due to many factors. One factor would be the nature of how the Kinect sensor works. It emits infrared light and analyzes the reflected infrared light. This mechanics work fine in an ideal environment, where is dark, and with no direct sun light. However, during the experiment with some of the participants, it was impossible to find a place at their home that would avoid the bright sun light. This environmental factor was one of the major reasons why the gesture recognition was less favored. A possible solution for this issue would be a combined 3D and 2D motion recognition and tracking system. In our experiments, the Kinect App only utilized the 3D tracking system, and did not have any mechanism for 2D tracking. It would be beneficial if the Kinect App could automatically switch to the optimal tracking mode based on the lighting condition.

6.2.2 Source of Error & Limitations

Even though multiple measuring and researching methods were used during this study, some possible sources of errors exist in our study. First of all, due to the time constrain, it was not realistic to have a qualitative interview with each participants, because it would take too much time, and exhaust the subjects too much. Therefore, the answers from the participants may not reflect their opinions fully, due to the non-interactive nature of the paper-based questionnaires and possible confusions about questions.

Secondly, the environmental factor mentioned above may also have caused improper perception of gesture-based interaction method and its abilities, in the participants, which will be something to be considered by the AAL application designers and developers. Also, since the experiment was set in each participant's home, there are certain variables, such as time of the day, day of the week, or the general state of the participants that may not always be consistent and affect the study.

Furthermore, the participants were very generous to donate their time to perform all the tasks and answer the questions. Sometimes, they may have tried to fill in the answers as a way to please the researcher; especially all the participants had a pleasant experience doing the entire task from the experiments. One other source of the error may be due to difficulties in understanding the language.

Three participants were not native English speaker, and one of them was unable to perform the reminder task. Her answers were also very contradicting throughout the questionnaires. The rest of two non-English speaker participants also did not understand every part of the study.

Even though a tutorial was given at the beginning of the experiment for each participant, the ease of learning involved with memorizing the gestures, voice command and using the system was also a possible source of error. Some participants were saying that they had issue remembering the gestures and voice commands. Our study was limited to only 4 simple tasks and our designed gestures/commands. The type of tasks and gestures used in our study could also affect the results, as these results could be different if the tasks and gestures were defined more appropriately.

The order of performing the scenarios and tasks was always the same which could have caused issues such as later tasks getting lower ratings due to fatigue, or higher ones due to familiarity with the system.

6.2.3 Research Questions

Based on our data and results, the answer to the research questions will be discussed here:

1) How senior citizens react to the use of a multimodal digital interface?

   From the results section in this chapter, the seniors have showed a lot of interests with the multimodal digital interfaces. Majority of them were thrilled and impressed by the ability to talk, wave hand and use smart object with their day-to-day life. The attitude was very positive.

2) How do different modalities compare to performing common tasks?

   The time participants spend for each task, and the rating scale they filled after each performed scenario have proofed that they are more efficient, feel natural, less tiring and more pleasant comparing to the mouse and keyboard input method. However, since it is something they have never used before, the learning was more difficult than the traditional input methods as every participant has used computer before.

3) What modalities are more suitable for these tasks in the context of a smart home?

According to the answers from the participants, voice was the most preferred way for performing these tasks, following by the smart objects. The gesture-based interaction was not perceived very well due to the environmental factor and the ease of learning for familiarizing the different gestures.

7 Conclusion

As the aging population grows rapidly, the lack of proper and sufficient caregivers and facilities to accommodate this increase becomes a significant issue. It is valuable to explore other possibilities as early as possible. Increasing the number of the years that elders live independently can reduce the expenses for the healthy and long care facilities significantly. Ambient Assisted Living environments implement advanced technologies into seniors' home, providing them emergency, autonomy and comfort services, so the aging population can maintain the same quality of life, and staying their home much longer than before. A number of studies have been conducted on this topic, but a significant lack of studies in comfort services with multimodal interfaces has been identified.

This thesis has developed a prototype system with a multimodal interface allowing participant to use their gesture, voice and smart objects to perform their day to day tasks, such as item finding, reminder, video call and consume digital content. By conducting a empirical study with 15 senior citizens, we have answered our research questions regarding the use of multimodal interfaces for comfort services. The main contributions of this study are:

Comfort services in smart homes

By reviewing the previous works, we have identified the lack of focuses for the comfort services. Based on the interview we conducted with field professionals, we learned the importance of this category and the impact it has for our target population.

This resulted in the study of AAL systems from a novel point of view that focuses on comfort services.

Multimodal interface for common everyday tasks

Through existing studies, we have selected four tasks that are important and essential for senior citizen's daily life. We developed a multimodal system that provides different options for performing these tasks.

User study on gesture and voice based interfaces

We conducted a novel user study that provides data from the senior citizens, who performed all the tasks at their home. This is an important factor, because the participants are completely relaxed and most of them have also enjoyed the study. Based on the first hand data we gathered from the participants, the experiences the user had are evaluated from ratings and comments.

Different directions can be taken to continue this study and improve the system. At the time this system was developed, a number of new gesture based input devices were announced, but not available for purchase or development. For example, Leap Motion is one of the infrared camera-based input devices that can let users accurately use their both hands and fingers to manipulate their applications. Applications such as Autodesk Maya (http://www.autodesk.com/maya) can use this device to allow users to perform tasks like 3D modeling with their hands and fingers, directly. According to the reviews, this device is found more accurate than the current Kinect sensor. The price of the device is very affordable, so it would be interesting to see if we could transfer some of the interaction from Kinect to this device, by placing it into the smart home. Another example among those newly announced input device would be the MYO (https://www.thalmic.com), an electrical activity monitor wristband, which can be used to perform various basic tasks such as controlling presentation, videos, and images, or browsing web pages. Same as Leap Motion, it also provides API to developer, who can develop any applications to work with these devices. Ultimately, Microsoft also announced the next generation Kinect sensor, which will be available later in 2013, and equipped with a high definition sensor and improved internal hardware and algorithms. These new features would overcome some of the difficulties we had during our study.

Moreover, our study was limited to 15 participants, and 4 simple tasks. It would be beneficial if more participants could be involved, and the participants could perform more extensive tasks. Future studies should also involve more qualitative research methods, such as focus group, and interviews to completely understand and study the participants' feedbacks, comments and experiences.

Appendix A

Pre-study Questions

The purpose of these questions are to give the researcher a general idea of the participants' comfort level with the technology, and their daily activities, hobbies, etc.

1. What is your gender: Male / Female [optional]
2. What is your age group [optional]

   50- 55 56-60 61-65 66-70 above 70

3. What do you normally do in a normal week or in a day?
4. Do you have a computer at home, and how often do you use it?
5. How do you keep your address book? on a small notebook? or on your mobile phone or on computer?
6. What do you normally do with your computer, e.g. surfing the Internet, checking emails, watching videos?
7. Have you ever had a video chat via your computer with your friends?
8. How many hours do you spend on your TV? Do you have any gaming console, such as XBox, Playstation, or Wii?
9. How do you keep track of your personal belongings inside your home, what would you do to prevent from forgetting where they were placed?
10. How often do you found yourself seeking something but unsuccessfully?
11. Do you use computer software to keep track of your personal belongings?
12. How do you save your pictures from the past?
13. Do you have any video clips that you or your friends captured for events that you were involved in?

14. How often do you browse your photos?

15. Do you have any photos on your digital devices, e.g. computer, phone, tablets, or any other devices?

16. What are the improvement you would want to have in terms of the way you communicate with your friends, watch your photos and videos, find your items and keep track of your appointments.

Post-study Questions

Besides the questionnaire, a post study interview will also be conducted so the participants will be able to report their own thoughts and concerns regarding their experiences with the system.

1. Please describe your overall experience after all the tasks? Was it enjoyable?

2. What was the most interesting and satisfactory task you performed during the study, the one that you have enjoyed the most?

3. Would you like to use what you learned in this task for your day to day life?

4. What was the most frustrating task you performed?

5. If it can be improved, what would you suggest to improve this task?

6. Overall, did you find the gestures, tangible devices, and speech input methods were more efficient than mouse and keyboard?

7. Did you find it was more fun to use these new technologies?

8. Did you find it confusing to use these new technologies? If yes, please describe the event.

9. Do you think you would spend more time on doing those tasks on a daily basis,

because of the ease of use and ubiquity of the computing power? If yes, please describe which task you would want to do more?

10. For this task you mentioned above, why do you think it was more enjoyable and want to spend more time?

11. Overall, would you like to comment on using gestures, speech and tangible device to interact with the computers or screens?

Scenario 1: Item Finder

Task Blue:

1. Click on Item Finder Task
2. Scroll through all the items.
3. Find the item Keys

Based on the description from Notes, please find the key.

Task Purple:

1. Use the Handheld Device
2. Locate the Item "Keys" on the screen
3. Tap on "Find Me" button
4. Based on the audible indicator, please find the key

Scenario-1 Questionnaire:

Out from scale from 1 to 5 (1 means strongly disagree, 5means strongly agree), please rate following statements, and add comments when necessary.

1. Task Blue was a pleasant experience.

2. Task Blue was physically tiring.

3. Task Blue was easy to learn.

4. Task Blue felt natural.

5. Task Blue was a better solution for what I need to keep my personal belongings.

6. Task Purple was a pleasant experience.

7. Task Purple was physically tiring.

8. Task Purple felt natural.

9. Task Purple was easy to learn.

10. Task Purple was a better solution for what I need to keep my personal belongings.

Scenario-2: Reminder

Task Orange:

1. Click on the Reminder Task

2. Click on Create Reminder

3. Fill in Following Content:

    a. Event: Have lunch with Allan

    b. Location: Rideau Center

    c. Category: Recreation

    d. Date: August 27, 2013

    e. Time Start: 12:00PM

    f. Time End: 2:00PM

    g. Notes: Bring my umbrella

After filled in all the task, please click on Submit

Task Red:

1. Use voice command “Create Reminder”

2. Use voice to input content as following:

    a. Event: “Have lunch with Allan”

use voice command “next” or swipe left hand to go to next field

    b. Location: “Rideau Center”

use voice command “next” or swipe left hand to go to next field

    c. Category: “Recreation”

use voice command “next” or swipe left hand to go to next field

    d. Date: “August 27”

use voice command “next” or swipe left hand to go to next field

    e. Time Start: “12 PM”

use voice command “next” or swipe left hand to go to next field

    f. Time End: “ 2 PM”

use voice command “next” or swipe left hand to go to next field

    g. Notes: “Bring my umbrella”

use voice command “next” or swipe left hand to go to next field

3. If you missed a filed, you can always say “previous” or swipe left hand to go back.

4. Once you filled in all the content, please use voice command “Submit”.

Scenario-2 Questionnaire:

Out from scale from 1 to 5 (1 means strongly disagree, 5 means strongly agree), please rate following statements, and add comments when necessary.

1. Task Orange was a pleasant experience.
2. Task Orange was physically tiring.
3. Task Orange was easy to learn.
4. Task Orange felt natural.
5. Task Orange was a better solution for what I need to create reminders.
6. Task Red was a pleasant experience.
7. Task Red was physically tiring.
8. Task Red felt natural.
9. Task Red was easy to learn.
10. Task Red was a better solution for what I need to create reminders.

Scenario-3: Calling People

Task Green:

1. Click on the Communication Task
2. Find and Select the person you would like to have video chat with
3. Click on the Call button to initialize the Skype call.

Task Yellow:

1. Swipe through photos of your contacts on the handheld device
2. Tap on the one contact you would like to call

Chat with your contact on main screen

Scenario-3 Questionnaire:

Out from scale from 1 to 5 (1 means strongly disagree, 5 means strongly agree), please rate following statements, and add comments when necessary.

1. Task Green was a pleasant experience.
2. Task Green was physically tiring.
3. Task Green was easy to learn.
4. Task Green felt natural.
5. Task Green was a better solution for what I need to make video calls to my friends.
6. Task Yellow was a pleasant experience.
7. Task Yellow was physically tiring.
8. Task Yellow felt natural.
9. Task Yellow was easy to learn.
10. Task Yellow was a better solution for what I need to make video calls to my friends.

<u>Scenario-4: Media Centre</u>

Task Grey:

1. Click on the Media Task
2. Find the media files you have from May
3. Click on one of images from this month.
4. Browse all your photos by using arrow keys or click on the arrows from this month

Task Black:

1. Use either voice command "gallery", or use right hand swipe left or right to go to

Media task

2. Use either voice command “next” and “previous”, or use left hand to swipe left or right to find the images you have stored from the month of May

3. Use either voice command “go”, or use right hand to draw a circle clock-wise to access to one of the image from May

4. Use either voice command “previous” and “next”, or use left hand to swipe left or right to browse all the images from this month

Scenario-4 Questionnaire:

Out from scale from 1 to 5 (1 means strongly disagree, 5 means strongly agree), please rate following statements, and add comments when necessary.

1. Task Grey was a pleasant experience.
2. Task Grey was physically tiring.
3. Task Grey was easy to learn.
4. Task Grey felt natural.
5. Task Grey was a better solution for what I need to browse my digital images.
6. Task Black was a pleasant experience.
7. Task Black was physically tiring.
8. Task Black felt natural.
9. Task Black was easy to learn.
10. Task Black was a better solution for what I need to browse my digital images

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