Real World Strategies for User Centered Approach to Functional Assessment and Design of Age-In-Place Support for Older Adults

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved April 2015 by the
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ARIZONA STATE UNIVERSITY

May 2015

ABSTRACT

As people age, the desire to grow old independently and in place becomes larger and takes greater importance in their lives. Successful aging involves the physical, mental and social well-being of an individual. To enable successful aging of older adults, it is necessary for them to perform both activities of daily living (ADL) and instrumental activities of daily living (IADL). Embedded assessment has made it possible to assess an individual's functional ability in-place, however the success of any technology depends largely on the user than the technology itself. Previous researches in in-situ functional assessment systems have heavily focused on the technology rather than on the user. This dissertation takes a user-centric approach to this problem by trying to identify the design and technical challenges of deploying and using a functional assessment system in the real world.

To investigate this line of research, a case study was conducted with 4 older adults in their homes, interviews were conducted with 8 caregivers and a controlled lab experiment was conducted with 8 young healthy adults at ASU, to test the sensors. This methodology provides a significant opportunity to advance the scientific field by expanding the present focus on IADL task performance to an integrated assessment of ADL and IADL task performance. Doing so would not only be more effective in identifying functional decline but could also provide a more comprehensive assessment of individuals' functional abilities with independence and also providing the caregivers with much needed respite.

The controlled lab study tested the sensors embedded into daily objects and found them to be reliable, and efficient. Short term exploratory case studies with healthy older adults revealed the challenges associated with design and technical aspects of the current system, while inductive analysis performed on interviews with caregivers helped to generate central themes on which future functional assessment

systems need to be designed and built. The key central themes were a) focus on design / user experience, b) consider user’s characteristics, personality, behavior and functional ability, c) provide support for independence, and d) adapt to individual user’s needs.

DEDICATION

To my parents, who has been a source of great inspiration and for being a pillar of strength in this journey. To my wife, who stood by my side, encouraged me every step of the way and placed great trust in me, I was lucky to have so much support from her. To my family, for their unconditional love and support. To all my friends, who encouraged and motivated me through this journey.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my advisor, Winslow Burleson, who provided great support and guidance for me to work on a topic that was of great interest. Without his help, this dissertation would not have been possible.

I would also like to thank my committee members, Baoxin Li, Diane Mahoney, Erin Walker and David Coon for their expertise, guidance and invaluable comments on my dissertation work. Special thanks to Diane for providing valuable comments and feedback at every stage of my dissertation journey. I would like to extend my thanks to Jisoo Lee and Cecil Lozano for assistance in the research presented in Chapter 4 and 6. It was a great pleasure to work with them.

It has been a great privilege to spend six years of my doctoral journey in the Department of Computer Science at Arizona State University (ASU). I greatly appreciate the time shared with many of its members, who are inspiring, friendly and always willing to help. I am grateful to all my friends who made this journey less stressful and more enjoyable. Special thanks to my friends Balaji and Prashanth, for the innumerous conversations / discussions / brain storming sessions which helped me tremendously in completing this dissertation and for providing me support when I needed the most.

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INTRODUCTION

As demographics change, the number of people who are older than 60 is increasing rapidly, both in developed and developing countries. It is projected that by the year 2050, the number of people who are older than 60 will reach 2 billion [2]. Older adults generally prefer to live independently (aging in place) in their own homes. However to do so, it is important to ensure they are functionally stable and able to perform all their daily activities by themselves. Successful aging requires them to be well aware of their cognitive and physical abilities and adapt themselves by making necessary adjustments to live independently. Even caregivers of older adults, who live with them and watch them perform their daily activities every day, cannot accurately identify many subtle changes. It is hard for individuals, without specific training, to track these changes reliably, day in and day out.

For example, an older adult who is making coffee might make a few mistakes or forget to do a task in between, however, overall, he/she may still be able to recollect and complete the activity successfully. Identifying these mistakes and the tasks that were forgotten could provide valuable information on individuals' functional ability. To monitor these subtle changes in individuals' cognitive and physical abilities and to, thereby, have an understanding of their functional abilities, this thesis argues that it is more useful and necessary to track how well they performed both their Activities of Daily Living (ADL) and their Instrumental Activities of Daily Living (IADL). ADLs are basic self-care tasks, akin to the kinds of skills that people usually learn in early childhood, e.g., bathing, feeding, dressing, toileting, etc. IADLs are the complex skills needed to successfully live independently. These skills are usually learned during teenage years, e.g. managing finances, shopping, preparing meals, etc. Tracking users on how they perform these task-based activities can provide critical information that can be used to reliably determine functional ability.

1.1 Motivation

To enable older adults to age in place independently, it is critical to assess their functional ability. It is difficult in this regard for older adults [65] as well as their caregiver(s) [38] to accurately keep track of all their activities and look out for subtle changes in their movements and actions. Sensor based technologies have developed substantially in recent years and with the increasing popularity and availability of smart homes and embedded sensor technologies, they present greater opportunities for the advancement of embedded assessment of functional ability, than ever before. Sensors embedded into objects of daily use paves the way for unobtrusive, objective tracking of a person's activity and analysis of the collected information can be used to assess functional ability. The collected information might provide enough knowledge to make informed decisions at critical moments--a capability which is crucial in supporting and increasing individuals' capacity for living independently.

In the current literature, to the best of my knowledge, there is no technology research that assesses functional ability based on ADL activities; every research paper or project (technology) to date has focused on IADL activities. It is important that a person be able to perform both their ADL and IADL activities to be able to live independently. What kind of data or information might we get if we tracked ADL activities, and to what extent this is possible and how useful are important research problems to tackle. Another important piece of information that is missing in almost all functional assessment systems is that they do not provide any meta-data or in other words they provide only superficial information of what happened and when it happened; there is little or no information on why it happened (reasons for those actions). It is important for all stakeholders involved to know "why" something happened, to further analyze or to provide any preventive measures.

For example: let us assume, we have a system to track an older adult of their medication taking activity. One day, the system recognizes that they did not take their pills; the possible reasons for that action could be cognitive (they forgot) or physical (not able to reach the pillbox) or emotional (stressed and not feeling like taking them) or financial (not able to afford them) or they could be sleeping or away from home, etc. If the stakeholders are not sufficiently aware of the underlying reasons for an action, the individual in concern with their caregiving team will not be equipped with the information necessary to provide neither meaningful nor improved assessments; they will not be in a position to develop appropriate and beneficial solutions that maintain the independence and dignity of aging individuals, in their own homes. To solve this problem, I propose a feedback mechanism to mitigate those gaps and explain its usefulness through data analysis.

Another important aspect of this thesis, which makes it unique, is the way it approaches the problem. By and large prior research has focused on technological advancements. While technological development is important, to make it more useful and efficient, there needs to be a greater emphasis on the users. This thesis takes a user centered approach to designing a functional assessment system. By conducting interviews to capture user's needs and reactions to the design of the technology, it provides information that can inform technological system development that is more discreet, convenient, easy to use and understand on a daily basis.

The goals of this thesis are to track, collect, and analyze information from embedded sensors, to understand: (1) how tracking ADL activity can improve functional assessment; (2) how tracking ADL in conjunction with IADL activity, can help refine information available to stakeholders; (3) how to increase awareness of individuals' abilities through analysis of collected data; (4) how to provide critical information (the missing "why" part) to stakeholders (family, caregivers, and health teams) so help them make more informed decisions; and (5) how to design systems and user interfaces to present performance data to stakeholders, such that is easy to use, understand, interpret, and act upon.

1.2 Thesis Approach

To better understand how to design a functional assessment system and to identify how data from embedded sensors could be useful in assessment of functional abilities, We developed a system for tracking an ADL activity (dressing), and tested it with users, to assess its efficacy in detecting different tasks associated with the dressing activity (section 4). The development of a system to track dressing activity represents the most technically challenging component of this thesis. Subsequently, a more comprehensive system to track multiple activities, including both ADL and IADL activities (dressing, brushing, coffee making and medication taking) was developed.

The rationale for choosing these four activities are (1) dressing is one of the most structured ADL activities which could be plausibly tracked, (2) brushing is one of the most simple ADL activities which can be reliably tracked, (3) coffee making is one of the most common IADL activities and it is relatively structured with a sequence of steps to follow, and (4) medication taking is one of the simplest IADL activities to track. The process of using performance data from these activities to help provide better interventions can be divided into three steps: a) sensing activities; b) processing and evaluating sensor data; and c) presenting aggregate information to stakeholders in an appropriate manner. The development of systems that track daily activities through objects embedded with sensors, comprised the sensing activities step. The next step is processing the raw data captured from these sensors. Processing involves extracting meaningful information from raw data, for example, consider on a particular day, the user is taking his pills and while doing so, refills medications in the pillbox for the coming week. Now, here is where context comes into play. If the software does not take context into account, it could identify the actions as mistakes because the user opened the wrong pillboxes. However if you consider the context, we could eliminate those, which are irrelevant and process the relevant ones. The next step is presenting the data in a human readable format. To do so, I developed user interfaces to display information relevant to users in an easy, understandable format. Basically it gives the user control on how much information they want to see. The first page that they see when they access the web interface, gives them an overview of all the activities for that particular day. If they want to get more details about a particular activity, they can get an overview (status, start time and end time). If they want to explore more, they can track how they performed each individual steps involved with that activity. I deployed the system in user's homes to collect real world performance data to evaluate the effectiveness of the system for assessing functional abilities.

The process of developing systems and deploying them in user's homes was conducted in different phases. The first phase involved development of the software, building hardware including attaching sensors to different objects that are being tracked and testing them to make sure it worked as intended. Once the development phase was complete, a controlled lab study was conducted to test the sensors. This is important as you cannot predict how the objects with sensors will be used in the real world. This is a simulation per se to test multiple ways to operate the objects, make simulated errors and test its robustness. This controlled lab study was performed with young adults who have familiarity with the three activities under test (brushing, coffee making and pills taking). Each participant involved with the lab study were asked to perform the three activities correctly as it is supposed to be used. Then each participant simulated one error condition with each of those three activities. The researcher instructed the participants to make specific errors on each activity. For ex: One user might open the wrong pill box, forget to turn on the coffee maker and so on. This simulated testing was also used to test proper functioning of the sensors, and the logging of data (functionality which gathers information from the sensors and writes the data to a text file, this data was then uploaded to a MySQL database through timed apple scripts located in the server). The deployment of the system in older adult's homes was scheduled after the lab study was complete. In the next phase, interviews with caregivers of older adults (aged 65 and older) were conducted. In this phase, caregivers were recruited based on their past experience with caregiving and also their current experience with a minimum of 12 months of caregiving experience. These interviews helped us to identify their needs, their challenges in caregiving, feedback on the current system and also ways to improve the current system.

In the last phase, the complete system was deployed in participant's homes for a period of 2 weeks and data from the sensors were captured to analyze task performance. This phase co-existed with the previous phase and they were conducted in parallel. There were also two interviews with the participants of the case study, one before the case study starts and one at the end of the case study. These interviews helped to get better understanding of their perception of using objects with sensors embedded onto them and also to identify any technical or design challenges of using them on a daily basis. Also, the interviews captured their feedback about the system and ways to improve them for future long term deployments in user's homes. The aim of this approach was to be ecologically valid, unobtrusive and unbiased.

1.3 Expected Contributions and Research Aims

The aim of this thesis was to design and develop a user-centered intelligent home monitoring system and generate evidence to robustly assess the extent to which embedded sensors together with a context aware approach can provide ecologically valid and timely assessment of functional abilities for older adults through tracking ADL and IADL task performance.

This thesis makes the following contributions:

HCI / Design: Identify user centered approach to designing functional assessment systems in the future, and identify design guidelines for supporting age-in-place for older adults

Computer Science: Build and evaluate technology to track ADL activities in the context of functional assessment, propose and build a feedback mechanism to solve or reduce false positives by capturing ground truth from caregivers of older adults.

Health Theory and Practice: Identify if near real time feedback on task performance helps users in increasing their awareness and to provide timely interventions and also if their perception of sensors affects their behavior or performance.

CHAPTER 2

BACKGROUND AND RELATED WORK

2.1 Embedded Assessment

Around 10% of the world population has some form of disability, 20% of those are over 70 years of age and 50% of those are over 85 years of age [86]. Unfortunately these disabilities often remain undiscovered by health care providers until an event, such as a fall, precipitates the onset of disability [3]. Older adults are aware of physical deterioration before the development of overt functional limitations and reduce or modify task completion, which prevents a sense of difficulty. Fried et al., 1991 [22] called this transitional functional state “preclinical disability”. As a result, researchers have measured preclinical disability within a domain of tasks to identify early warning signs that disablement is in progress [22, 90, 91]. Theoretically, identification of preclinical disability would afford the chance to intervene early when there is a greater chance to promote recovery and prevent the onset of disability.

Clinical diagnostic practices frequently fail to notice health problems in the early stages as it is often conducted after the onset of the health problem, when there is no data about the individual’s baseline functioning. It is important to note that self-report data that has repeatedly been shown to be unreliable [24, 87] and is thus not suitable for clinical assessment once individuals’ abilities have decreased. Clinical diagnostic practices are also limited in their ecological validity as they are not performed in the individual’s homes and do not account for other environmental factors in their daily lives. Even if clinical assessments were performed in patient’s homes for direct observations, they are infrequent and often occur after a problem arises. They can also be biased by performance efforts where patients may act differently, during the one-time assessment, from how they would normally function in their everyday lives.

Objectively, timely, and ecologically valid information about the functional abilities of an individual is important for proper diagnosis and treatment of the causes of functional decline [59]. Thus, clinicians need more frequent, less expensive, and more objective measures of an individual's functional ability, which may be obtainable through embedded assessment technologies.

Morris et al [58] introduced the concept of embedded assessment to assess long-term functional decline in older adults. According to the researchers, embedded assessment should focus on monitoring, compensation and prevention. In this thesis proposal, the focus is on monitoring, prevention, and to some extent compensation to help older adults and the other stakeholders involved to obtain a better understanding and awareness of individual’s health. Having this integrated approach will greatly increase the likelihood of adoption of this technology among end users especially among baby boomers.

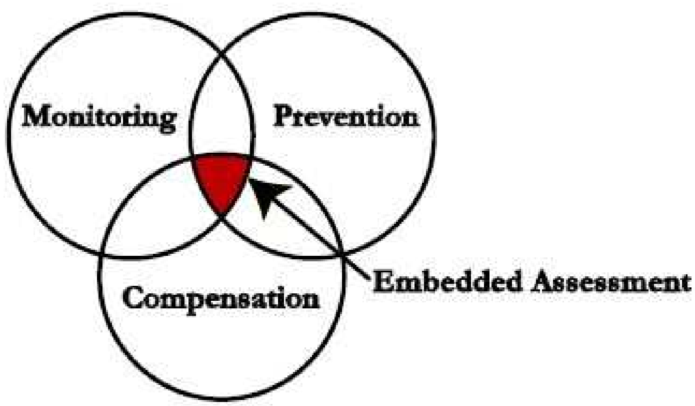

Figure 1. Embedded assessment [58]

Embedded assessment technologies strive to bridge the gap (Figure 1) between actual functioning and perceived functioning [59]. This gap is due to the psychological and behavioral changes that take place when older adults start to contemplate the possibility of illness. This gap may have a major impact on their independence and quality of life. It therefore is important to identify this gap at the earliest opportunity and to provide supportive interventions as needed. Another important goal of embedded assessment is to help identify preclinical disability. There is a substantial gap between actual functioning of an individual and their perceived functioning (Figure 2) where the individual is in denial about their functional status. The goal therefore is to forecast the actual functional status as early as possible, and provide interventions to prevent / prolong further decline.

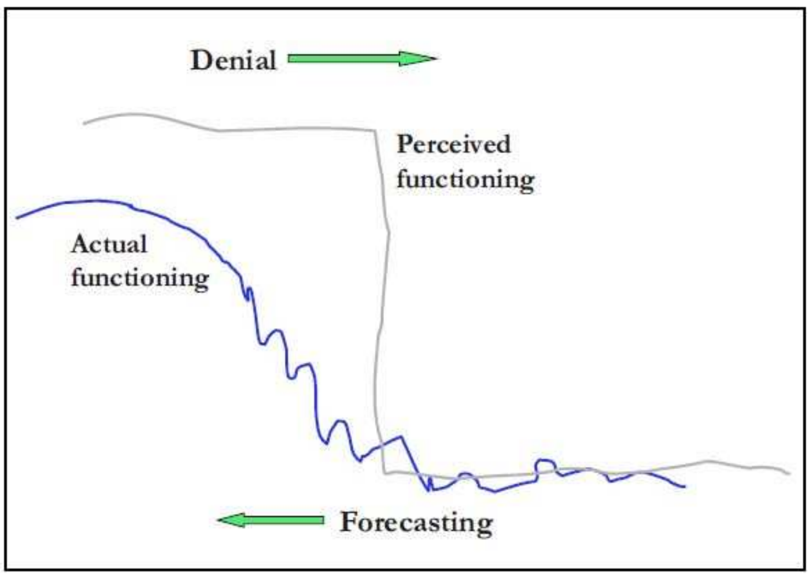

Figure 2. Heuristic model [60]

Embedded Assessment falls under a larger category of technology research called Ubiquitous Computing [85]. Most prior work in the field of ubiquitous computing for healthcare has been in the area of activity monitoring. Ubiquitous computing researchers have, for a long time, advocated for in-home and on-body monitoring to help users to assess their own health as well as their loved ones [62]. Sensors embedded in the home are used to collect longitudinal and contextually relevant data that can be processed to automatically detect changes in behavior patterns caused by the onset of illness. There has been some research, which uses sensors on mobile devices for detecting patterns of activities [67]. These types of systems, either continuously monitors the user or when the user is engaged in an activity of interest such as gaming [34]. There are a few other studies, which evaluate in-home monitoring systems with a small sample size and shorter observation period [8]. Larger, longitudinal studies correlating home and clinical assessments are not yet feasible for most ubiquitous computing trials. There are some exceptions though [73]; Lee et al., 2012 [43] has installed his in-home monitoring systems for 18 months at a stretch however the number of participants was small. Also his system is designed to track only IADL activities, and does not provide compensatory strategies, it does provide real time information to help with prevention. Another important feature that is not present in his system is the ability to identify why something (a failure or departure from the standard behavior) occurred in the context of functional assessment.

In the areas of compensation, many researchers have explored context dependent delivery information. There are several systems that are designed to compensate for cognitive or physical impairment, some are designed to promote independence in and out of the home [67]. There are systems that are designed to compensate for specific functional daily activities, for example cooking [63], taking medications [18, 72], social engagement [58], and making connections in social settings [64]. Most systems that are designed for compensation have typically been demonstrated with prototypes. Few have been developed and tested outside the laboratory setting or with a plan to gain wide acceptance.

In the areas of prevention, providing real time information about their daily activities to users has been mainly conceptualized to either lower the possibility of serious illness of those at risk (primary prevention) or help prevent worsening of an illness (secondary prevention) [31]. Behavior change has been motivated by providing the information at the right time to help in the decision making process [19]. The goal of prevention systems or ubiquitous systems in general is to provide "just in time" information to users such that the system acts as an effective personal trainer, delivering tailored messages at the right place and right time and when the person is most receptive to information in order to motivate behavior, belief or attitude change [30]. Many preventive technologies developed by medical researchers have been designed to focus on a particular illness. Systems for people at risk for diabetes or eating disorders [89], taking care of their diet [4], support for dementia through active and socially integrated lifestyle [20] are some of the examples of preventive technologies. For embedded assessment systems to be successful they have to focus on all three strategies, monitoring, prevention and compensation. Also, it has to be extremely flexible in terms of personalization of information that is captured and presented. An individuals'' needs, their functional ability, their skill and comfort level in terms of using the technology are all important parameters, necessary for the customization of the level of information captured and subsequently presented to them and their care giver; that's where smart homes with embedded assessment can play an important role.

The concept of smart homes was one of the first types of ubiquitous computing systems which explored the possibility of using sensors embedded within objects of daily use [13, 37, 39, 40, 41, 56, 77]. These were advanced with the goal of creating a smart living environment. Some other examples of smart homes for specific needs include systems designed to: help people compensate for cognitive and physical decline [63]; to promote independence in and outside the home [67]; to create context-aware reminder systems to help people compensate for attentional deficits by reorienting them after they are interrupted from a sequential task such as cooking [63]. Other systems use ubiquitous computing to help people compensate for memory loss by prompting them to take medications [18, 72] or by providing assistance [54]. The majority of the research in smart homes in the early years was focused on identifying the technical challenges of achieving the vision. One key example that provided an overview of the challenges is the seminal work by Edwards and Grinter in 2001 [16]. Living lab initiatives such as the Aware home [40] or MIT's house_n [29] facilitated the study of smart home technologies in more depth and in contexts that closely resemble real world domestic spaces. Mozer's (2004) approach of installing sensors in his own home [61] was another way of attempting to study actual user experiences with automation technology.

More recently, researchers have been studying actual context of use in family homes by deploying sensors in their homes [10, 52]. It should be noted that the focus of most research in smart homes has been to advance the technology, pushing the boundaries of what's possible in the context of sensor based technology. However, if the focus is solely on technology, there is a high chance the usefulness of the technology may not be fulfilled as the needs and preferences of the user may not adequately be taken into account. Taylor et al., 2007 [83] argues, "Technology is less to be understood as something intelligent, but more of a resource for intelligence, in which intelligence emerges through our interactions with technology". Similarly Rogers (2006) [75] argues for more engaging technology that "enables people to do what they want, need or never even considered before by acting in and upon the environment". In simple terms, he wants technology that enables people to do tasks which they have not even thought about before, when acting in an environment. It is therefore important to consider the goals and values of users and to use this to inform the advancement of smart home research. In the context of functional assessment, it is important to incorporate tracking an individual’s daily activities as part of the smart home capabilities. There are several past and ongoing research projects that focus on tracking daily activities, however very few (if any) have conducted studies in the real world with older adults. They are discussed in the next section.

2.2 Functional Assessment through Activities of Daily Living

Functional assessment is a multidimensional and often interdisciplinary diagnostic process, which assesses and quantifies an older adult’s medical, psychosocial, and functional status [51]. Information gathered in this process is used by practitioners, patients, and families to develop a comprehensive plan for therapy and future care decisions and can also help in the process of long-term care decision-making. Using limitations in activities of daily living (ADLs) and instrumental activities of daily living (IADLs) to measure disability, in 2010, 28% of community-resident Medicare beneficiaries age 65+ reported difficulty in performing one or more ADLs and an additional 12% reported difficulty with one or more IADLs. By contrast, 92% of institutionalized Medicare beneficiaries had difficulties with one or more ADLs and 76% of them had difficulty with three or more ADLs [2, 51]. For a person to be functionally independent, it is important to perform both their ADL and IADL activities by themselves without seeking the help of another person. By observing how a person performs their ADL and IADL activities, we would be able to identify if he/she is functionally stable. Numerous research efforts exist that monitor activities of daily living [8, 26, 41, 50, 55, 62, 69, 82, 88], these systems usually collect data continuously or when someone is engaged in an activity of interest like exercise [78] or gaming [33]. They often provide binary information about whether an activity was initiated or completed. However, to accurately predict or measure any decline in functional ability, it is important to not only know if they completed an activity but also how well they performed an activity. The concept of preclinical disability explains that individuals first enter a stage where their abilities start to decline but can still maintain their functioning at a level high enough to complete the task. In this stage, all too often, neither the individuals nor the caregivers notice decline in the abilities. For example, an individual who struggles with an activity may slow down, taking more time to complete tasks. If these ubiquitous systems provide only binary information, then the task is recorded as being completed, however, the system has failed to detect and record the underlying errors made during the task or how much effort was put into completing the task. Research shows that functional declines are strongly co-related with how much time individuals spend on tasks [66]. Thus information on how well an individual performs a task is crucial in detecting any functional decline in its early stages before it becomes a disability. Embedded assessments potentially can provide information for early prediction [7] and treatment of decline and possibly further delay the onset of disability.

2.2.1 Functional Assessment through IADL activities

The Lawton Instrumental Activities of Daily Living (IADL) Scale is the most common professional instrument used to assess independent living skills [42]. The instrument is most useful in identifying how a person is functioning at the present time and for identifying improvement or deterioration over time. There are eight domains of function measured with the Lawton IADL scale. As with any functional assessment tool, it does not identify how a person performs a task, rather it focuses on whether he/she is able to complete a task. Many sensing systems have been developed that focused on monitoring how often IADLs such as cooking are performed, e.g., [70, 79, 82], with some of these systems correlating behaviors with clinical outcomes [37]. Some systems focus on recording the outcomes of a particular IADL such as medication taking [28]. Mihailidis et al., 2007 [54] developed a computer vision based system to monitor the steps in a hand-washing task, what errors were performed, and to provide appropriate prompts to assist the user in completing the task. Cook & Schmitter-Edgecombe (2009) [12] developed an intelligent system that can detect step errors, time lags, and missteps in the IADL task process, which can give a measure of how well the task was performed. Lee (2010) [44] designed and developed a system which monitors how well individuals perform their daily activities specifically IADL activities. In addition to monitoring the frequency of task completion, Lee monitored how well the task was completed. Haigh et al., 2003 [26] developed a machine learning system to passively monitor how well individuals perform their daily activities. Their test concentrated on medication taking and mobility. All of these systems mentioned above use IADL activities to monitor and assess functional abilities as they are the first to get affected as a person starts to lose their cognitive abilities. It is however important to assess their ADL activities as well to get a real sense of their functional ability.

2.2.2 Functional Assessment through ADL activities

The Katz Index of Independence in Activities of Daily Living, commonly referred to as Katz ADL [36], is the most appropriate instrument to assess functional status as a measurement of a person’s ability to perform activities of daily living and their ability to live independently. The index ranks adequacy of performance in the six functions of bathing, dressing, toileting, transferring, continence, and feeding. A score of 6 indicates full function, a score of 4 indicates moderate impairment, and a score of 2 or less indicates severe impairment. Many researchers have worked on developing systems to observe and monitor ADL activities. Gendron et al., 1993 [23] developed a tool to observe four activities of daily living to evaluate the functional autonomy of demented persons. Matthai et al., 2004 [70] developed a system using a probabilistic inference engine to monitor ADL activities. Their Proactive Activity (PROACT) toolkit represents activities as probabilistic sequence of objects used and develops a model to identify patterns of usage. Fluery et al., 2009 [17] designed an apartment embedded with sensors to classify activities of daily living performed by individuals residing in the apartment, through the use of support vector machines. The data from these sensors were collected and analyzed to detect, as early as possible, a loss of autonomy for the residents. Some research projects are working towards ADL task assistance such as the one developed by Peters et al., 2014 for brushing [68].

Even though many researchers developed systems to monitor ADL activities, they have largely focused on identifying what activity was performed and if the activity was completed or not. They have not yet captured enough information from the activities to assess individuals' functional abilities to be able to better predict preclinical disability. There is currently no system, that I am aware of, that is capable of tracking and monitoring the different steps involved in ADL and IADL activities, information which could be critical to reliably assessing individuals' functional decline and help in providing timely interventions to prolong their independence and their autonomy. Some systems which track IADL activities for functional assessment do so without incorporating user centered design (considering the user's needs and usability) which is paramount in the success of using the technology. They also miss out on the opportunity to provide the users with information on why something happened in the context of functional assessment. For example, most healthy adults tend not to monitor their performance on a daily basis. If they are monitoring their activity performance once or twice a week, and find out that they missed their pills few times during the last two weeks, they have no idea or understanding why they missed. The current systems have no way to inform them about the possible reasons behind the data captured and thereby miss out on an opportunity to identify potential decline or the users could just ignore the data as a false positive. These problems provide us with an opportunity to re-think the way we design, build systems and present information in ways that could benefit the users and other stakeholders involved.

CHAPTER 3

CONCEPTUAL FRAMEWORK

Current literature clearly informs us about the gaps in the present state of in-home embedded functional assessment systems. Embedded sensors are great for identifying what activities are performed and tracking how that affects behavior. Many researchers have worked on building systems which can help in daily activities such as taking pills, social engagement, hand washing, and to promote independence to name a few. Very few people have worked on tracking ADL activities and use them in the context of functional assessment. There are also those who have worked on behavior change and "just in time" interventions. The focus has clearly been on building technology for assistance or to promote independence or behavioral change. What is more important than the technical aspects of their products is the user experience. There is a need to focus on design, incorporate user's needs, and their perceptions about technology and how that affects their performance or behavior change. To fill those gaps, this thesis tries to answer the following research questions.

	Research Questions
	How to design functional assessment systems for in-home monitoring of older adults and what are the challenges of deploying/using it in the real world?
1	What kind of data can be captured from tracking activities of daily living (ADL and IADL) and how useful it is in the context of functional assessment?
2	What is the perception of users working with objects embedded with sensors that track their activities and behavior?
3	How does capturing skin conductance measure help to assess the performance of their daily activities?

4	What is the information needs of the stakeholders?
5	Does providing real time feedback on user's performance help stakeholders by increasing awareness and in providing timely interventions?

Table 1. Research Questions

By answering these research questions, this dissertation contributes the following to the fields of HCI, Computer Science and Health theory.

HCI / Design:

- Identifies the design challenges of using in-home sensing systems that tracks user's daily activities for health monitoring
- Identifies the reactions of older adults to using wearable devices for tracking their health (skin conductance sensor)
- Identifies the information needs of older adults and their caregivers for understanding functional changes associated with aging
- Identifies if information about the performance of an older adult on daily activities leads to self-awareness and provides opportunity to make necessary changes to live independently
- Identifies how much information is too much for the caregivers and how to avoid information overload
- Identify how controlled study and objective study can inform the design of future embedded systems

Computer Science:

- Design, build and evaluate a system which can track ADL activities (dressing, brushing) and capture user performance on the activity

- Design, build and evaluate a system which can track IADL activities (coffee making and meditation taking) and capture user performance on the activities
- Develop an algorithm to capture raw data from different sensors and process them to be presented to the stakeholders in an easy, understandable format

Health Theory and Practice

- Identify how near real time feedback can support individuals in carrying out their activities of daily living (ADL and IADL) with greater adequacy and independence
- Identify how perception of older adults working with objects embedded with sensors can affect their behavior or performance
- Identify how the usage of video cameras (in dressing) affect their perception of the monitoring system and how it relates to their privacy

To advance these contributions, this thesis started with a pilot study with young healthy adults on dressing activity to test if we can track them reliably. After the pilot test, a system to track four daily activities (brushing, dressing, coffee making and medication adherence) was developed. After the development, controlled lab studies were conducted to test the sensors before deployment in user homes. Interviews with caregivers were conducted in parallel to the in-home deployment. After the studies were complete, data was collected, processed, analyzed and presented.

To achieve the desired results, it is necessary to have a solid foundation for building embedded systems which can track ADL and IADL activities, identify context in which an activity or action is performed, enable users to provide feedback on task performance and use it to improve accuracy, have ability to store emotional state of the user and find correlations between emotional level and task performance, and finally provide guidance in performing daily activities if need arises. This section presents the methodology that is used for the development of a system (see section 4) and how current literature in functional assessment, embedded assessment, and affective and context aware computing paved the way for a new developmental methodology that uses the best in each field.

This thesis presents a methodology conceptualized from background literature in embedded systems and user centered design. The goal of embedded systems is to integrate traditional areas of monitoring, compensation and prevention as proposed by Morris [58]. To build a system that can perform all of the three tasks, it's important to build a suite of sensors that can track daily activities efficiently. Lee's [43] work guided the development of a system to track IADL activities while Mahoney and Burleson's [47] work guided the design and development of a system to track ADL activities, specifically dressing. The inclusion of a skin conductance sensor to capture emotional states of the user was guided by Poh et al.'s [71] work on wearable sensors. The HCI aspect of this thesis, specifically to focus on user centered approach to design was guided by the seminal work done by Morris [60] and Abras [1] and their colleagues on ubiquitous computing and user centered design respectively Birnholtz et al.'s work [32] on senior's privacy and awareness needs contributed to the focus on privacy concerns for the interviews with caregivers performed as part of this thesis. The focus on providing real time feedback to increase user awareness was inspired from Intille's [30] work on "Just in time motivation for behavior change". The proposed method builds on the GALLAG platform (described below) and allows for tracking ADL and IADL activities efficiently at the same time providing support for "real time feedback" and audio interventions when necessary. There is also support to track user's task performance remotely in real time. It also provides a platform to capture data from diverse sources (activities) and integrate the information captured for efficient and timely interventions to assess functional ability and to prolong independence.

3.1 GALLAG

The system is based on a platform called Game as Life – Life as Game (GALLAG) [8], developed at ASU as part of an NSF sponsored project. GALAG is a collection of hardware and software technologies that allow for the interfacing of various physical devices as shown in Figure 3 and for dynamic real-time feedback based on Activities of daily living (ADLs). The system server is a Mac with Lion operating system running Indigo 4.0. It integrates X10 and Tagsense sensors, including skin conductance sensors, and camera's that can image customize visual markers on clothing while maintaining privacy.

The platform has the capability of delivering supportive interactive experiences through mobile devices, such as Apple's iPod touch, to provide visual cues, wireless speakers to enhance audio feedback, and changes in room lighting to attract attention. The sensors will send small amounts of information identifying a sensor's state and ID, and a radio frequency receiver in the base station that relays information to a central Indigo server. On the software end, an Indigo home automation application receives these data and, depending on user input, executes trigger actions (in our scenarios, these are embedded AppleScripts) that are manifested in either or both the physical and digital world.

The Indigo 4.0 server is a robust home control server that communicates with INSTEON and X10 compatible hardware, such as televisions, light switches, etc., using their existing wiring arrangement. Indigo 4.0 uses a small fraction of the computer's CPU cycles so it does not significantly disrupt the availability or performance of an existing home computer, rather it augments it by extending its functionality beyond the traditional screen interface, to realize a low-cost off-the-shelf smart home environment. The server facilitates the programming of interactive feedback, and communication (e.g., activity and time based logic and audio/visual interactions), which when grounded in the context of user needs facilitates interventions. Likewise, feedback and communication are facilitated through the Indigo 4.0 server.

Tracking human activity can be a tedious and complex process and often requires the use of several different hardware and software technologies. To track the activities such as dressing, coffee making and medication taking, we have used several different hardware products (Figures 4) ranging from simple heat sensors to a complex full scale motion controller like a Kinect. Kinect for Windows is a motion sensing device from Microsoft, which supports movement, voice and gesture recognition technology [53]. Kinect consists of two infra-red cameras to capture depth information, one RGB camera, multi array microphones for voice recognition, and a tilt motor. It has the ability to track one or two people moving within the Kinect field of view. We use Kinect to track the user's skeletal data and try to predict what actions they make with respect to the activity they perform. It is only used in the dressing activity. Next hardware is the ps3eye camera, this is from Sony, which is used mainly as a webcam which is used by a software named reacTIVision for tracking fiducial markers. It is described in detail in the software section. We also use an RFID reader, skin conductance sensor and heat sensor, which acts to transmit data back to the server.

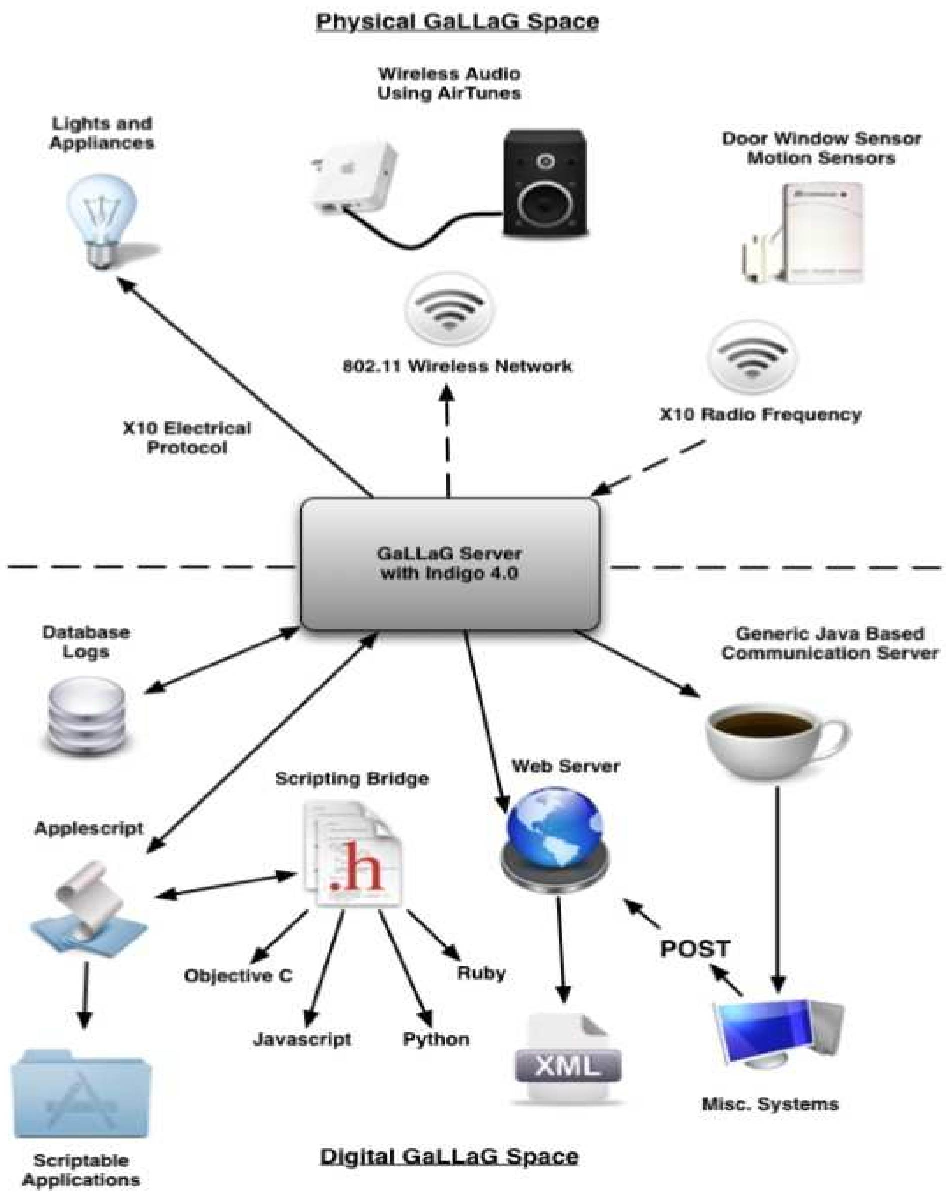

Figure 3. GALLAG Platform

Figure 4. Hardware components for X10 devices

1	Door sensors	6	Coaxial cable
2	Motion sensors	7	Antenna
3	USB to serial adapter with USB cable	8	Airport Express
4	Serial cable	9	Speaker sets
5	Serial to coaxial adapter with power supply	10	Apple Computer with Lion OS and Indigo 4.0 (Not shown in the picture)

Table 2. Hardware components for X10 devices

The different parts which are essential in enabling communication between X10 devices, speakers and the control server are displayed in Figure 4 and Table 1 above.

A wireless heat sensor is attached to the coffee machine and used to track if the user turned on or off their coffee machine. An iPad and 5 iPod touch devices are used to display visual cues to the user when there is a need for it. Guidance is provided only when requested by the caregiver. The control of these different devices would be present to the caregiver through an iPod touch device. This is only for dressing and this setup is not used for the case study.

CHAPTER 4

DEVELOPMENT OF RESPONSIVE, EMOTIVE, SENSING SYSTEM (DRESS)

The gaps in the current literature on functional assessment systems elucidate the need for a human centered approach to designing and developing a more robust, efficient, easy to use and intelligent functional assessment system. Previous research in human computer interaction and product development has taught us that when it comes to building a product to be successful and efficient, the design of it plays as much importance as its functionality [5]. Previous research in functional assessment tells us that the symptoms of cognitive decline (dementia in particular) are so many and varied that it is not possible to capture all of the important cues from just tracking instrumental activities of daily living (IADL) activities. With the advent of embedded assessment and wearable devices, it is possible to track basic activities of daily living (ADL) and also the user's emotion. The motivation to develop or redefine development of functional assessment system came from working on a project named "Developing a Responsive Emotion Sensing System (DRESS) for cognitively impaired patients" [46]. Diane Mahoney, gerontology professor and a member of this thesis committee, conceptualized DRESS (patent pending). It was then tested for feasibility in her collaboration with Winslow Burleson [47] and she later did extensive focus groups with caregivers to identify their needs [48, 49].

The goal of DRESS as the name implies is to develop an intelligent dressing system for cognitively impaired patients. Cognitively impaired patients such as those in the later stages of Alzheimer's are unable to perform their own basic daily activities such as bathing, dressing, eating toileting and transferring. Currently the only way someone with severe onset of cognitive decline can dress themselves is with the help of a caregiver who is in the same room as the person and provides instructions or guidance to help them get dressed. This not only violates their privacy but it also takes away their independence. As one gets older, the desire to be independent and age in place, tends to become increasingly important. To tackle this problem, in collaboration with the investigative team, I developed an intelligent dressing system that, by the use of intelligent sensors, software, and hardware, guides persons with cognitive decline to dress independently, with the help of audio prompts and visual cues.

One of the key features of this project is its ability to predict user's emotion with the help of a skin conductance sensor (wearable device) worn by the user and also in its ability to provide appropriate interventions when needed. It provides audio prompts to complete an activity only when the user is stuck or when the user makes some mistake during the dressing activity. This is to ensure that support is provided only when needed and not otherwise. By being context aware it aims to provide greater independence to users and also relieve the caregiver of the stress in caring for them. Working on this project and conducting feasibility studies with healthier adults in a closed lab environment lead to the conceptualization of a similar system to address embedded functional assessment. DRESS assessment, also indicated that it would be possible to efficiently track and monitor basic activities of daily living (ADL) and use this information for the assessment of individuals' functional ability.

4.1 Feasibility Study

The dressing system built for the study is a first of its kind system that provides personally tailored feedback to support the dressing process for people living with dementia (PLWD) in an automated unobtrusive way [46]. The feasibility study for DRESS was conducted in a closed lab environment at Arizona State University (ASU). The study was conducted twice with slight variations in the system setup to find the optimal system design for efficiently tracking the dressing activity and its performance.

The system unobtrusively and continuously monitors user's correct and incorrect dressing states to provide corresponding cues necessary to complete the dressing process adequately. This is performed by combining the detection of clothing location and orientations through fiducial markers on the clothes and identifying limb movements relative to the clothing using skeletal detection through Kinect. Based on the results from the first study, kinect was replaced with a webcam for the second study.

4.1.1 Study 1: DRESS with Kinect

In the first study, the system was evaluated with 6 healthy participants who engaged in simulating common dressing scenarios. These scenarios included dressing errors and correct dressing actions with shirt and pants. Based on the data collected from the experiment, it was found that the system was 78% accurate in identifying acted dressing and 86% accurate in identifying common errors in dressing and assisting in dressing.

The entire setup consisting of a dresser, Microsoft Kinect, Apple iPods and iPad, ps3 eye webcam, RFID reader and x10 sensors is shown in Figure 5. One of the primary elements of the system is its ability to detect and identify correct and incorrect actions performed during dressing. This is made possible by a computer vision based approach employing Kinect for Windows and Fiduciary Markers (shown in Figure 7). Kinect is a motion sensing input device from Microsoft, which supports movement, voice and gesture recognition technology [40]. Kinect consists of two infrared cameras to capture depth information, one RGB camera, multi array microphones for voice recognition, and a tilt motor. Kinect has the ability to track the skeletal image of one or two people moving within the Kinect field of view. Skeletal tracking is optimized to recognize users standing/sitting, and facing the Kinect. Kinect can track 20 body joints when it is in skeletal mode as shown in Figure 6. In the default-tracking mode, the user has to stand in front of the sensor to recognize and start tracking. In the seated mode (PLWD may sit on a chair to wear pants), it is necessary that the user moves to be detected. If the user is not moving in a seated position, it would be difficult for the sensor to recognize and track the user's joints.

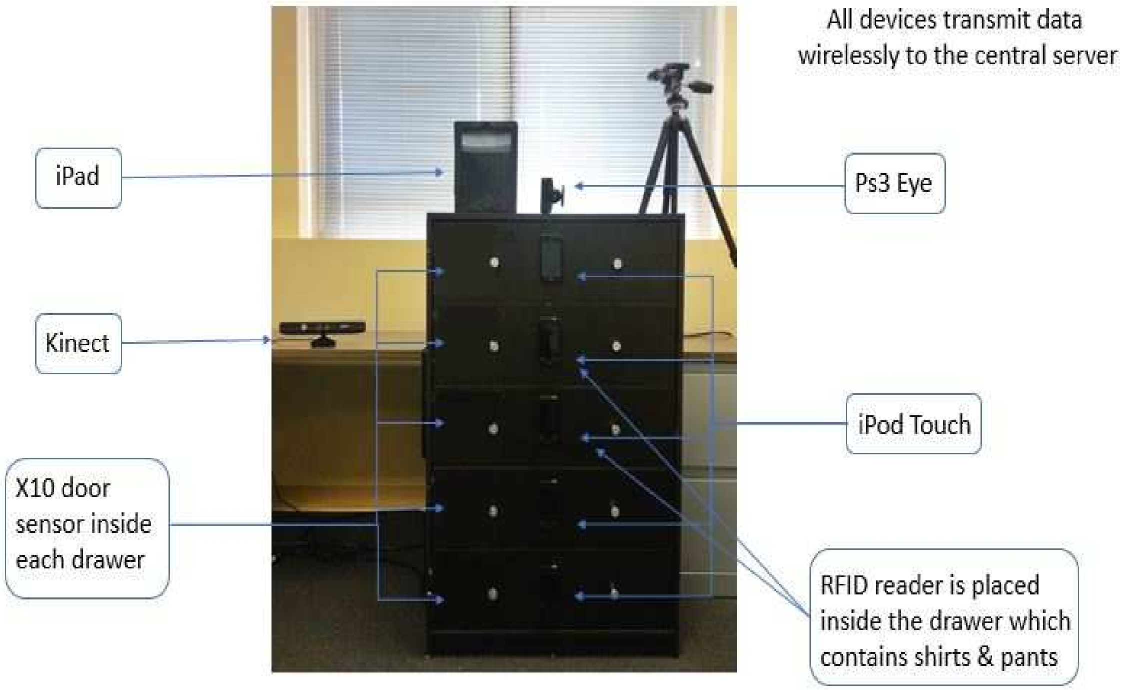

Figure 5. Dresser with Sony's Ps3 eye camera, Microsoft's Kinect and Apple's iPad and iPods

Kinect runs in the background continuously, even before the caregiver initiates the dressing process. There is a threshold with respect to Kinect that was fixed, which must be satisfied in order for the system to detect which leg has been lifted. This threshold is common for both legs and was fixed after capturing values from skeletal data during dressing. However, skeletal data is used only after the PLWD picks up the clothing from the drawer. Skeletal data alone does not provide enough information to predict whether the PLWD is wearing the clothing properly. It can track body movements and track what action the PLWD is doing; however, identifying how they dress is impossible with skeletal data alone.

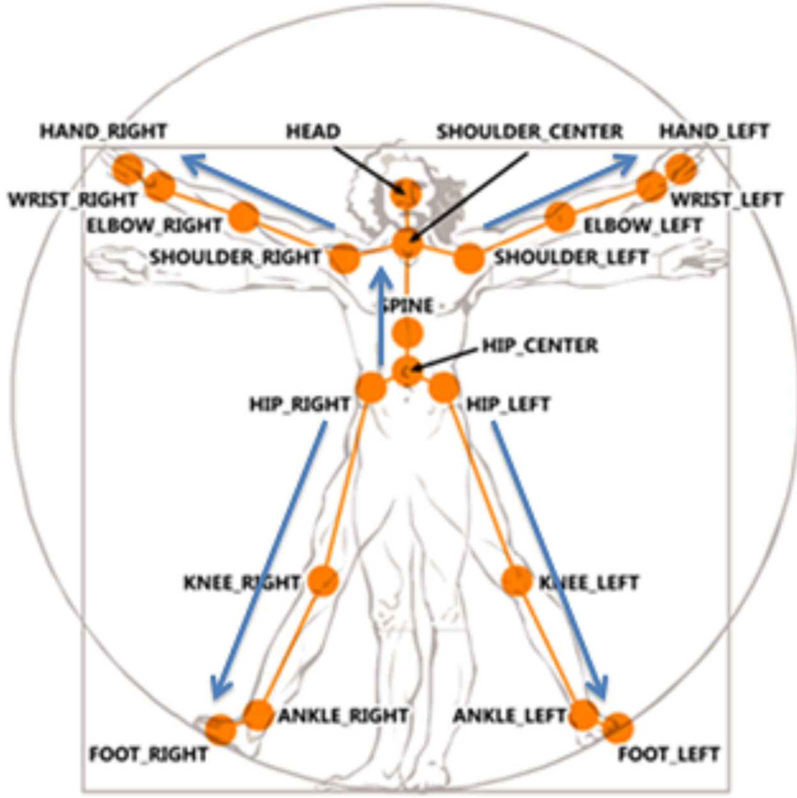

Figure 6. Skeletal joints tracked by Kinect

To solve this challenge, skeletal data is used in combination with fiduciary markers to predict the action PLWD perform during dressing and to detect the orientation of the clothing item. A fiduciary marker or fiducial is an object placed in the field of view of an imaging system which appears in the image produced, for use as a point of reference or a measure [54]. Note that the video images taken from the camera detecting the fiducials is only used programmatically and not presented to the users to keep their privacy. Figure 7 shows an example of the fiducial markers used in our system. Fiduciary markers are tracked by software called reacTIVision, which is an open source, cross-platform computer vision framework for the fast and robust tracking of fiducial markers, attached onto physical objects. It is a standalone application that sends TUIO (tangible user interface object) messages via UDP 3333 to any TUIO enabled client application. It tracks specially designed fiducial markers in real time video [17] captured in our system by a Sony's ps3 eye. Data is then captured and processed for tracking the markers by "processing", an open source language environment.

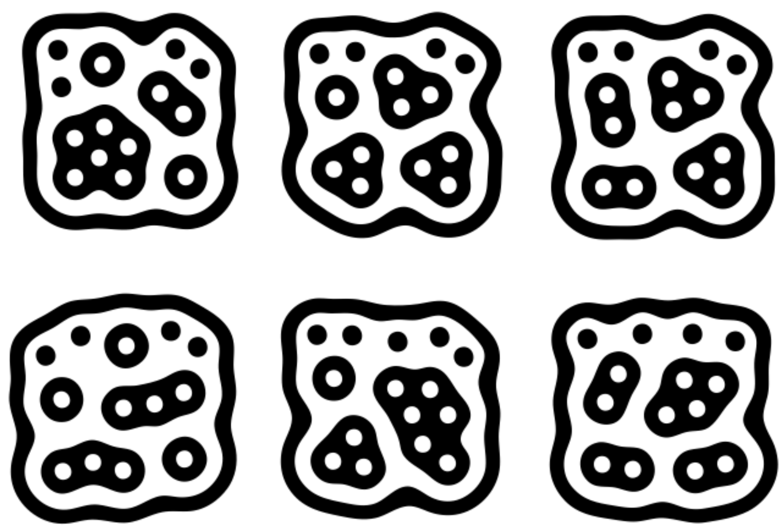

Figure 7. ReacTIVsion's fiduciary 2-D bar code marker

In our experiment, the markers were attached to each clothing item at different positions such that the software that tracks these markers would be able to identify the position in space and the clothing orientation, when the markers are in the camera's field of view. Each clothing item that needs to be tracked has a separate processing program. In our experiment there are two processing programs to track the location and orientation of the marker in clothes.

4.1.1.1 Study Methods

To evaluate the system, the experiment was conducted with 6 healthy adult participants, all of whom were reasonably familiar with the challenges PLWD encounter while dressing after a short briefing from the experimenter. After giving their consent, participants completed one ~30 minute session in which each completed 9 different "acted dressing" sequences presented in random order. The term "acted dressing" is used since the participants were asked to dress in a specific manner as instructed by the experimenters. Specifically, they were asked to perform seven common dressing errors (Figure 8) and two correct dressing sequences for shirt and pants in ways that simulate real-world in-home PLWD experiences (Table 2).

Shirts and pants were chosen for this experiment as they required different levels of dexterity and number of steps in dressing them. At the same time, I did not want to complicate having too many and too different clothing items to evaluate and so decided to experiment with these two clothing items. This enabled us to evaluate the system's efficiency in identifying each of these contexts paving the way for in-home deployment in homes of PLWD and their caregivers, in the near future. Images of the 9 acted dressing scenarios were shown to the participants before each sequence. Images were used instead of description or video so participants were less biased on the process they used on creating the respective error.

Figure 8. Acted Errors

First row (l to r) - Partial dressing, Reverse (front in back), Inside out,

Second row (l to r) - Misaligned, Partial dressing, Reverse (front in back),

Third row - Inside Out

Before starting each dressing scenario, the clothing item in turn would be placed inside the drawer so each time the participant had to open to access it before wearing it. For the scenarios in which shirt or pants were supposed to be worn inside out, the clothing items were set to be taken from the drawer in the incorrect manner to avoid having the participant turning the clothing twice. Once participants complete the specific dressing scenario, the experimenter would collect the clothing item and put it back in the drawer for the next sequence.

S-C	Shirt - Correctly worn
S-P	Shirt - Partial dressing
S-R	Shirt - Reverse (back side in front)
S-I	Shirt - Inside out
S-M	Shirt - Misalignment of Velcro
P-C	Pants - Correctly worn
P-P	Pants – Partial dressing
P-R	Pants - Reverse (back side in front)
P-I	Pants - Inside out

Table 3. Nine acted dressing scenarios (for visuals, check figure 8)

Accuracy of the system is defined by the percentage of sequences the system can correctly identify from the nine acted dressing scenarios. When a correct dressing is detected by the system (S-C or P-C in table 2), it would acknowledge the user by prompting “Good Job”. When the system was able to detect any of acted error scenarios (Other than S-C and P-C in table 2), it would verbally prompt the user, informing them of the error and asking them to rectify it. They were instructed to rectify their mistake on their own, upon hearing a prompt. If when the acted error was completed (i.e., participant stopped moving waiting for a prompt) and the system was not able to detect the dressing error, the user was asked by the experimenter to rectify the mistake on their own. Acted dressing was performed to evaluate the system’s detection capabilities and to test whether such a system could perform at a level that might assist users in rectifying the errors. During the experiment, there were four types of data recorded for data analysis: (1) Data from Kinect, which tracks skeletal joints and records 6 data points from the skeletal data, (2) Data from processing software, which tracks fiducial markers and records the ID and orientation of each marker which are in the line of sight of the camera (3) Data from Indigo server which records each trigger action and any device change information and (4) Data from a video camera, which records everything the user does during the experiment from the front of the user. In addition to this, the system would also record a time-stamped detection event to a text file whenever it detected any of the nine acted dressing events.

To detect participant's acted dressing, the system uses fiducial markers for shirts and combines fiducial markers with Kinect's skeletal tracking data for pants. Fiducial markers are imprinted onto clothes at multiple locations such that they maximize the likelihood of the camera system identifying them and detecting the position of the clothing based on its ID and orientation.

4.1.1.2 Study Results

Overall it was found that the system was 78% accurate in detecting the nine acted dressing scenarios. Specifically, it was 86% accurate in detecting common dressing errors, where it had the most difficulty on detecting pants dressing errors (66.7% accuracy). Figure 9 shows the number of instances of correct, incorrect, non-detection, and no-visible markers, in each of the acted dressing scenarios. For example, for S-P, the value is six and all events are yellow, indicating the system was successful in detecting S-P, (partial dressing for shirt; Table 2) six out of six times, i.e., S-P had 100% accuracy in our study. In Figure 9 it can be observed that most of the challenges of the system to detect incorrect or correct dressing patterns (P-P, P-C) was with wearing pants mostly due to Kinect not being able to detect user lifting their legs to push it into the pants. Errors occurring from not detecting the markers were only found in the condition where pants were worn inside out (P-I). It's likely that this problem occurred from the lack of markers on the inside part of the pants, and recognition might thus be improved by adding these to the clothing. It must be noted that all six trials of P-C were not detected.

Closer analysis of the errors made by the system, indicate that the main reasons for this poor result was twofold. First, when participants hold pants in front of them, Kinect recognizes the pants as part of the user’s body and fails to detect them as an article of clothing. Second, each participant engages in putting on pants in a more individualized manner than they do shirts. Also, Kinect uses a threshold to detect, which leg was lifted and it is common for both legs. It was found that all the participants lifted their right leg much higher and lifted their left leg much lower when they were dressing (pants). If the threshold value of left leg was reduced, there is a possibility of some trials to be successful. To test the hypothesis for both (P-I and P-C), another experiment was carried out with 4 participants who performed these 2 acted dressing twice each. The results of this experiment are promising and supported our hypothesis. Out of 8 trials of P-I, the system was able to accurately detect the error 8 times, giving an accuracy of 100%. For P-C, the system was able to detect 5 out of 8 trials. Kinect assuming the pants as part of human body is still a problem and solving that is a challenge.

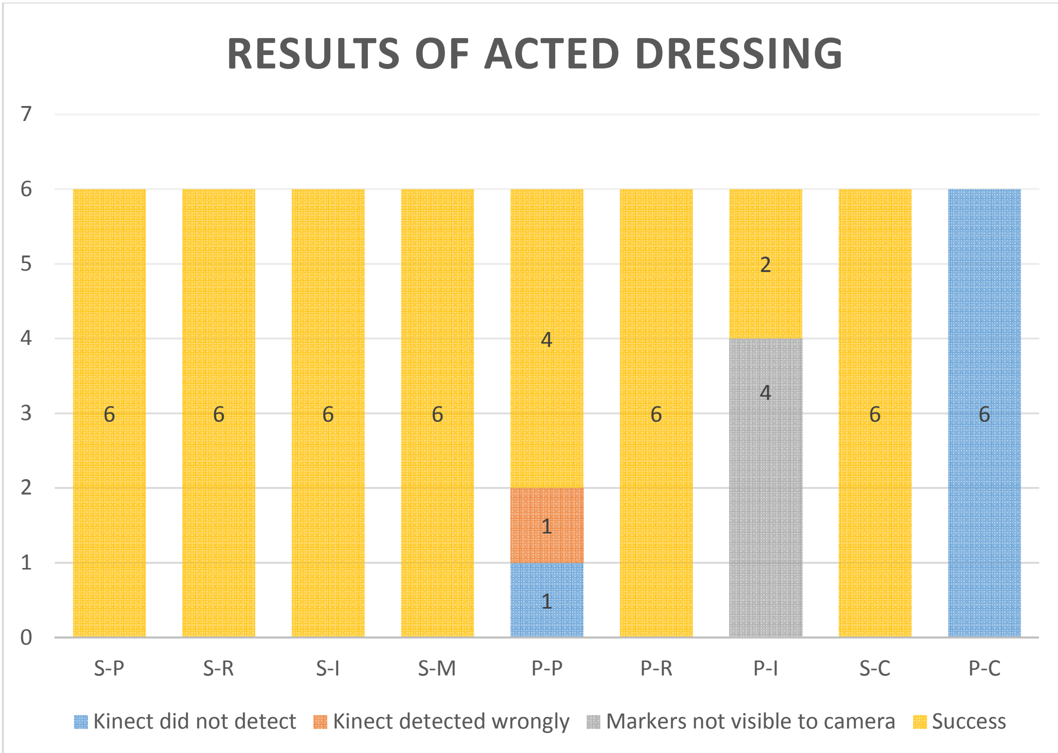

Figure 9. Results of acted dressing

There were also a couple of instances of incorrect prompting. One of these events occurred when the system verbally prompted the user saying that the shirt was inside out when it was not. This was due to the system inadvertently detecting the markers which were on the inside part of the shirt during the process of dressing and reporting that the shirt was on inside out. Another false negative occurred when the system verbally prompted a user saying that the pants were worn partially; this prompt occurred at a time in which the user was in the process of putting the pants on.

4.1.2 Study 2: DRESS without Kinect

In the first iteration of the system a combination of ps3 eye camera and Microsoft's Kinect were used to identify and detect the different conditions for both shirts and pants. However after our initial study results and after careful analysis to identify the reasons for failure in some of those cases, it was decided to replace Kinect with one more ps3 eye camera. One ps3 eye camera would be positioned at the top of the dresser as shown in Figure 10 (circled in yellow). While another one would be placed in the middle drawer (near the third drawer in dresser, circled in yellow).

Having two ps3 eye cameras helps us in identifying the markers from two different angles and thereby eliminates some of the errors that were encountered in the first lab study. Having the cameras at two different locations helps because of the inherent distance of the marker locations in shirt and pants and also because, Mahoney et al (2013) prior research with caregivers revealed that older adults with dementia tend to put on their pants sitting down and wear their shirts standing up. Because of this change in how a user wears each clothing item, it is not possible for one camera to detect all the markers at any instance and hence we positioned cameras at two different strategic locations to detect the most possible markers to suit our cause. The bottom camera will be used to detect pants markers while the top camera will be used to detect shirt markers.

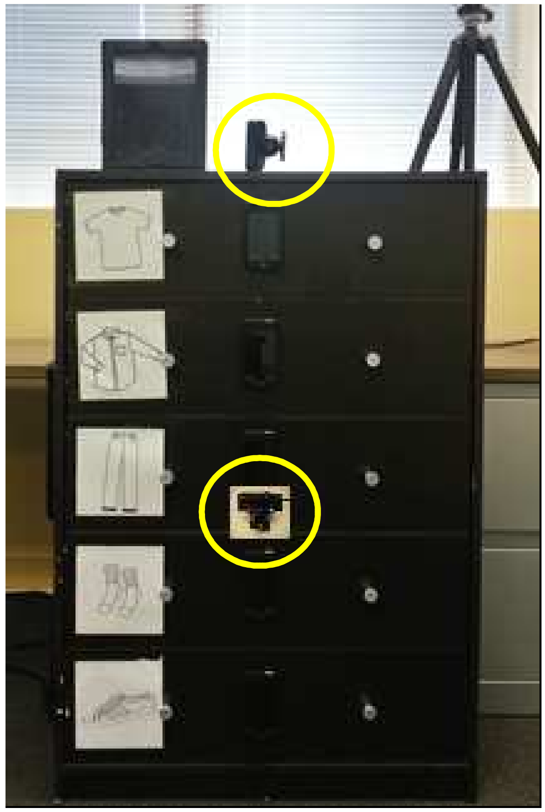

Figure 10. Dresser setup without Kinect

Each ps3eye camera is connected to a computer and it sends the information it captures to a software named reacTIVision, which scans those markers, and this data is then processed using software called Processing. It is in Processing where all the conditions for identifying different scenarios are programmed and the system decides the current state of dressing based on what it observes. Each marker on both clothing items is placed at optimal location to ensure we identify at least one of them during the dressing process and each marker captured through the ps3eye camera tells us the orientation of the clothing item and the scripts in the server uses this information to identify the current state of the user in the dressing process.

Shirt Detection: For capturing the current state of dressing with shirt, the system uses the ps3eye camera located at the top of the dresser. It does not use the one located in the middle of the dresser. To identify correct dressing, the system first looks for any marker located on the left/right side of the shirt and followed by the other side of the shirt (Figure 11). Once the sides are captured, it looks for 4 markers, which are placed near the Velcro, and capturing the location and orientation of those markers helps us in identifying if the Velcro of the shirt is fastened correctly. Any misalignment is captured using the location of those markers. If they are at close proximity within each other, the system identifies the current condition as correct dressing. The threshold for identifying the location of markers is fixed by wearing the shirt properly and capturing the x and y co-ordinates of the markers. The exact values of those thresholds are shown in the table below. By identifying the position of those markers with respect to each other, we were able to fix a threshold to identify correct dressing.

For errors, we look for markers specifically with those IDs. Dressing errors like wearing the shirt back in front or inside out are identified using the specific markers attached to those parts of the clothing. For example markers 7 and 9 which are attached to the back side of the shirts (B) and inside parts of the shirts (I) respectively are used to identify the correspondent errors cases. More than one marker of the same orientation ID is placed on each part of the clothing to increase the robustness of the dressing detection process. There is a possibility that while wearing the shirt, the backside of the shirt might have been visible and the system should not recognize that as an error. To mitigate this problem, when the system sees the marker 7, it checks whether the marker is visible for more than 3 seconds to decide it's an error. We fixed the time duration as 3 seconds based on observing multiple people who dressed in front of the dresser for our initial study.

Figure 11. Shirt Fiducial Markers (left) on front, (right) on the back

Misalignment is identified by identifying the location of two pairs of markers namely 208/209 and 211/212 and based on their location and how far they are with each other. The close proximity between the right matching markers of both sides of the shirt and their orientation determines whether there is any misalignment. The proximity threshold between matching markers is fixed and previously determined by testing and capturing this distance with a correctly worn shirt. If the alignment conditions are not met, the system indicates a misalignment error (M). For partial dressing, once the system captures one side of dressing using markers located on the side, it waits to capture the markers attached on the other side of the shirt and if it is not captured, then it identifies the current condition as partial dressing.

Pants detection: For capturing the current state of dressing with pants, the system uses the ps3eye camera located in the middle of the dresser. It does not use the one located at the top of the dresser. To identify correct dressing, the system first looks for pairs of markers located in the bottom half of the pants, specifically for markers

25/26 and 28/29 (Figure 12). Each set is located on either side of the pants. It uses the similar concept as used for shirt, if it identifies one marker on either side of the pants; it waits to identify the marker on the other side of the pants. Once it captures both, the system assumes that the user has worn both the legs of the pants and is about to stand up.

Figure 12. Pants Fiducial Markers

(left) markers on the front side, (right) markers on the back side

To identify if the user has indeed stood up and pulled the pants up and worn correctly, it looks for markers in the upper half of the pants, specifically for pairs of markers 15/16 and 24/27. When it sees all four, it detects the current state as correct dressing. The idea of using the bottom half markers of pants for the intermediate step and the upper half markers of the pants for complete dressing is derived from studying user's pattern of dressing and analyzing the video from several users. It makes more sense to develop our algorithm this way as the user would be sitting on a chair while wearing pants and not all markers would be visible at all times.

For incorrect dressing scenarios, we look for markers specifically with those IDs. For example, 17 identifies the pants is worn inside out, 19 identifies as inside out and in reverse direction and 22 as wearing the pants in the reverse direction (back side in front). For partial dressing, we would use the similar concept used for shirts, wait for the system to identify any one of the marker pairs 25/26 and 28/29. If one of them is captured, the system waits for markers located on the other side of the pants. If it is not captured, then the system identifies the current state as partial dressing.

ID	DETECTION DESCRIPTION	IDENTIFICATION RULES
SHIRT		
F	Front side of the shirt	Any marker from front of shirt (5,6,10-14,30-34,208,209, 211,212) is visible for 2+ sec.
B	Back side of the shirt	Any marker from back of shirt (7) is visible.
I	Inside part of the shirt	Any marker from inside of shirt (8,9) is visible for 2+ sec. marker 8 is for center part of inside, while marker 9 is for the sides (left and right) of the inside part
R	Right arm of the shirt worn	Any markers from front right of shirt (5,10,11,12,13,14, 208,211) are visible for 2+ sec.
L	Left arm of the shirt worn	Any markers from front left of shirt (6,30,31,32,33,34, 209,212) are visible for 2+ sec.
A	Both arms of the shirt worn	Any one marker from detecting R and one for detecting L is visible for 2+ sec.
M	Velcro unevenly fastened	Any one of the following absolute differences of markers' distances are true: $\lvert Y208-Y209\rvert > .05$, $\lvert Y211-Y212\rvert > .05$, $\lvert X208-X209\rvert > .18$, or $\lvert X211-X212\rvert > .18$.
p	Partial dressing (incomplete)	Any one of the markers from either L or R is visible, the other is not visible for more than 5 seconds
C	Shirt worn correctly	All the following absolute differences of markers' distances are true: $\lvert Y208-Y209\rvert < .05$, $\lvert Y211-Y212\rvert < .05$, $\lvert X208-X209\rvert < .18$, and $\lvert X211-X212\rvert < .18$
PANTS		
B	Back side of the pants	Any marker from back of pants (22) is visible for 2+ sec.

I	Inside part of the pants	Any marker from inside of pants (17,19) is visible for 2+ sec. Marker 17 is for inside out, front side and marker 19 is for inside out, back side
L	Left leg of the pants worn	Any markers from low part of the left side of the pants (28,29) are visible for 2+ sec.
R	Right leg of the pants worn	Any markers from low part of the right side of the pants (25,26) are visible for 2+ sec.
p	Partial dressing (incomplete)	Any one of the markers from either L or R is visible, the other is not visible for more than 5 seconds
C	Pants worn correctly	All markers from upper part of the front of pants (15,16,24,27) are visible for 2+ sec.

Table 4. Detection event descriptions and the system rules to identify them

4.1.2.1 Study Methods

We conducted a lab controlled subject study to evaluate the detection capabilities of the DRESS system during the process of putting on two clothing items: shirt and pants. We chose these items as they required different levels of dexterity for both the top and bottom of the body and they are common and applicable for both genders.

We were specifically interested in observing the dressing pattern through Fiducials markers' detection at the different stages of the dressing process for 9 dressing scenarios common to those found for PLWD. These included the clothing worn: correctly, partially or one limb (leg/arm), backwards with the back in front, inside out, and misaligned (for shirt only). Although it would be important to examine the natural way to make common mistakes, this is not feasible in a short-term controlled experiment, so these errors were staged as "acted errors". All dressing actions performed in the study were done on top of participants' clothing recommended to be comfortable and light for the task at hand.

Eleven healthy young participants (7 female / 4 male, aged 20 to 35) partook on a single one-hour session. At the beginning of the session participants learned about the research goal and outline of the session, and filled out a pre-survey after giving their informed consent. We included a pre- and post-survey containing few questions related to common dressing practices (e.g., How often they use the specific clothing item?), How often they put the clothing the wrong way? If any, what have been the most common dressing mistakes they had made?), and reporting any discomfort about both the setting and the tasks.

After the pre-survey, participants were introduced to the system setup, highlighting the location of the cameras that they needed to face, and the space between the dresser and the chair where they were asked to stay while getting dressed. They were also informed to use chair in putting on/taking off the pants when doing the dressing scenario study conditions, as this was likely to be the way the target population would put them on. And they were shown the special characteristics of the clothing items to be worn, especially the fact that to close the shirt they would need to attach the Velcro (no buttons) that had marks to assist alignment.

Before any specific instructions on how to perform the dressing conditions of the study, participants were asked to pick each of the two clothing items from the dresser (each clothing item was inside of one drawer) and wear them in the most natural way possible, as they would normally do at home. We included this step to identify if there were dramatic differences due to the constraints of the dressing scenario instructions, which was not found to be the case, and for future analysis of the natural dressing process. For this task, chair use was optional and no participant opted to use it.

Following this task, participants were first informed about the dressing conditions to be performed. The experimenter explained each of them with respective pictures (examples in Figure 8). We used pictures of the target dressing conditions instead of video or specific description of interim procedure to minimize bias.

They were then instructed that each trial would consist of the following: 1) wait for the experimenter cue of when to start and what dressing condition to perform, 2) pick the respective clothing item from the drawer, 3) put it on in the way prescribed for the condition, once completed wait standing in front of the dresser saying slowly "DONE 1 2 3", if the condition was an acted error rectify the acted error, 4) once the correct dressing is completed say again slowly "DONE 1 2 3", and 5) take the clothing item off and give back to the experimenter. The experimenter at that point would put the clothing back in the respective drawer setting it up for the next trial. If the next trial were an inside out condition the experimenter would turn the clothing inside out to prevent the participant from having to do it twice. Participants were reminded to complete each trial by wearing the clothing correctly in a way that they would if they were to go out with it and to use the chair when putting on or re-adjusting the pants. All participants performed the 9 dressing conditions 2 times following complete randomized block design. Finally, the session ended with a post-session survey.

Type of data collected for analysis included data from: (1) the processing software tracking fiducial markers on the clothing items recording the ID and orientation of each marker with the respective time stamps; (2) the Indigo server recording each trigger action as a "detection event" with the respective time stamps (detection event descriptions in Table 2); and (3) the screen activity including the video from the cameras used for fiducial markers recognition which recorded all the participants' actions as they faced the dresser.

4.1.2.2 Study Results

Analysis of system's ability to identify dressing status was based on quantifying how well the recorded detection events, automatically produced by the system, fit the different phases of the dressing process. We identified 6 phases of the dressing process, they are (1) adjusting the clothing after being worn incorrectly spontaneously or by design (conditions with acted errors); (2) putting the first limb on; (3) transitioning between limbs; (4) putting second limb on; (5) transitioning to completion and adjustment; and (6) completing the correct dressing process by standing in front of the camera. As an example, In the case where participants were asked to wear the shirt correctly we expected that the system detected and recorded the front of the shirt (F) then one arm worn (R/L) then the other arm worn (L/R) then completing wearing both arms (A) and finally correctly completing the dressing process by aligning and attaching the Velcro (C).

Our results show that for both shirt and pants, the first limb worn (in phase 2) was always correctly identified by the system, as well as the front of the shirt at the preliminary adjustment phase 1. For the second limb this reliability held for all conditions for the shirt, but only in the correct scenario for the pants (phase 4). We found that the system did not reliably record the dressing completion (phase 6) in all the trials across conditions (18/86 for pants and 46/108 for shirt). Video inspection of trials indicated that in some cases the completion was identified by the system, but apparently not recorded. Inspection of videos for the shirt correct dressing condition showed that missing detection included in order of frequency: incompletion of task from the participants where they did not fixed the misaligned Velcro (a mirror might have prevented this); markers not visible in the camera as participants' position with respect to the camera was not optimal (tilted, too close, too short) or the clothing item was large and became folded; failure of the system to recognize the visible markers or record the detection event on time; and small alignment threshold.

Missing detection of completeness in the pants correct condition included similar conditions as the shirt with the exception that in one case the participant wore the clothing too fast. Her strategy was putting the two arms in first and flipping the shirt around quickly. This prevented the system to identify the markers on time. We also expected that in some occasions some other detection events would be recorded at transition phases (1, 3, and 5). At the beginning (phase 1) the back (B) part of either clothing could be shown briefly as participants got it out from the drawer and adjusted it, as we found happened. It was also expected that the inside of the shirt (I) would be shown as participants adjusted the clothing in each transition phase like when the shirt had a fold or it was brought up on the air showing the inside back.

There were cases where unexpected detections were recorded at transition phases. Also unexpected were few times (5) in which the back of the pants was detected in middle transition phases. Different events related to adjustment of the clothing accounted for these detections including: turning the pants around while wearing one leg; holding the pants in front of the camera in a way and for long enough that the system detected wearing one leg, affecting the interpretation of the following detections; taking the pants off after completing the partial scenario and when readjusting the pants in such way that the back markers were visible momentarily; and on while adjusting the pants after turning them inside out in the inside-out dressing condition.

Partial dressing (P) was expected to be detected some times between the first and second limb (phase 3), when participants took longer than expected to adjust the clothing item. However, we did not expect to see partial dressing detection (8 times) after the second arm was worn for the shirt conditions. These unexpected detections were also mostly due to adjustments right before closing the shirt for instance opening and closing the shirt to bring the two parts of the shirt together, holding the neck or Velcro occluding the markers, and for females adjusting the hair. In one case, the shirt was too large for the participant and frequently had folds that made it hard to show the markers.

Finally, in the last transition before completion we expected that in some cases participants would attach the Velcro from the shirt incorrectly or misaligned (M) before correcting it. Detection of the acted errors in dressing scenario conditions was analyzed only on the corresponding phases. High frequency or longer inside-out and back in front detections were expected for each of these dressing conditions in the first phase. Only inside-out pants were detected 100% of the time. Still high recognition was also found for the back in front for pants (18/22; Figure 13). Lack of back in front detection was observed to be due to strategy like holding pants in front of the camera misleading detection. And several times video recordings showed that markers were detected too briefly and in a flicker fashion, making it hard for the system to record the detection event.

For the shirt 14 out of 21 were detected for back in front condition (Figure 14). Video inspection (2 videos missing) showed that in most cases the system did not record as detection event of back in front even though the marker seemed to be identified, possibly by slow processing of data. In some cases, no detection of all the markers was seen because the areas of the shirt with the markers rounded to the sides making it hard to be identified. Possibly having markers in the middle would be useful. A couple of times the markers were visible in the video, but not recognized by the system.

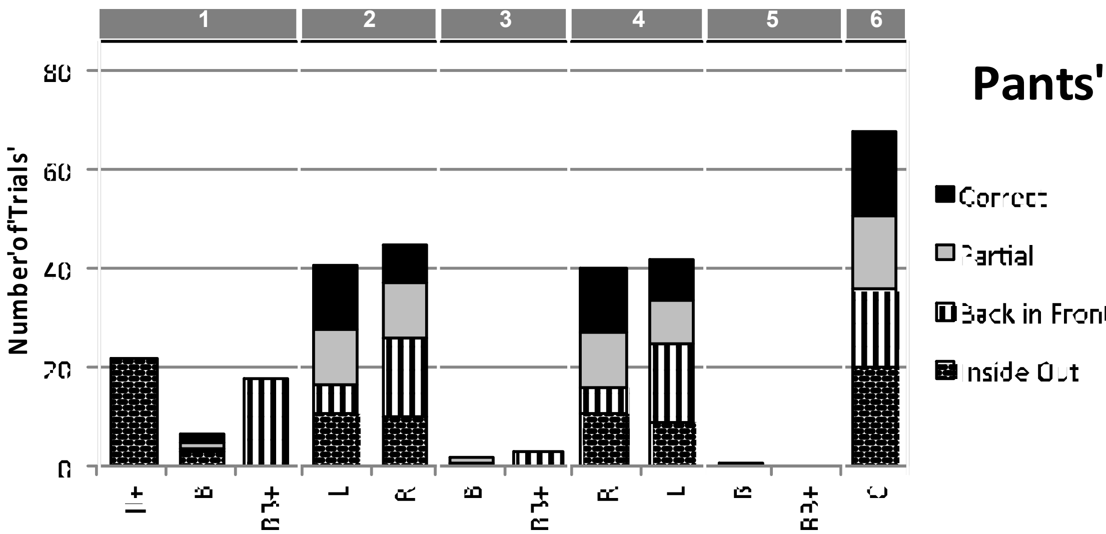

Figure 13. Pants detection counts
(Number of trials for each recorded detection in each of the 6 phases of the pants' dressing process for each condition). A "+" symbol means that streams of same recorded detection label was counted as one. Maximum amount of trials (86)

For the shirt only 13 out of 21 had long of inside-out detections (n) and all (21/21) had a combination of short detection of inside out with other front parts of the shirt before fixing it (Figure 14). This is similar to what happened in the correct dressing condition in which parts of the "other" side of the shirt (i.e., the front, or back) were visible while in the process of putting the shirt. Only in one occasion the participant appeared confused about the orientation of the shirt and turned it inside out multiple times before completing the task, resulting in a recognition pattern that was not expected but yet accurate.

In the case of the misaligned Velcro for the shirt, only 14/21 was identified by the system. Missing detections at the end of the trial could be due to not enough time to record. Video inspection informed that it was due to clothing occlusion. For the partial (only one limb worn) condition the shirt and pants are expected to have different detection patterns. When worn partially, the shirt only shows half of the shirt as the body occludes the rest of it.

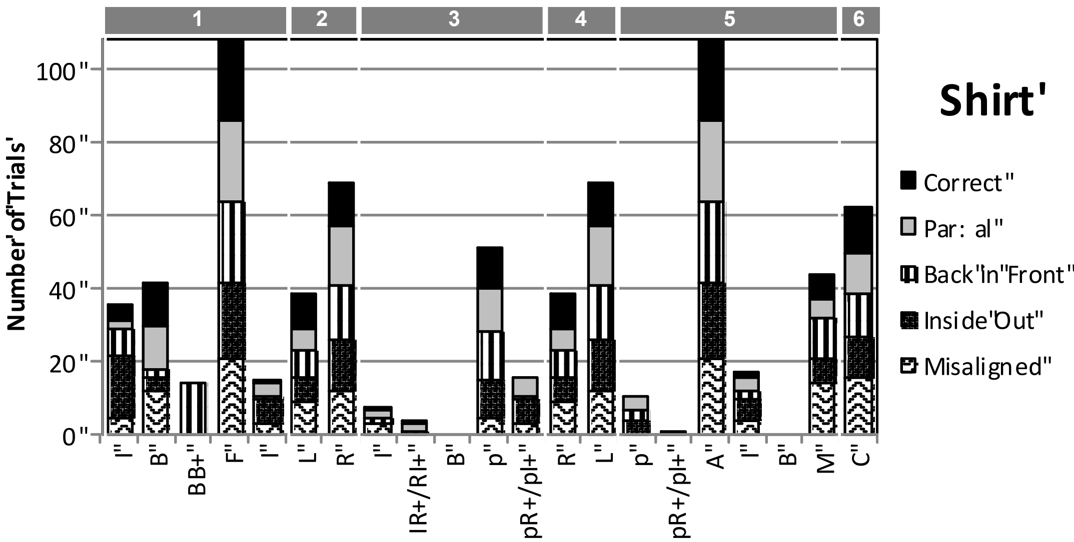

Figure 14. Shirt detection counts.
Maximum amount of trials (108). '+' sign means that the pattern repeated more than once

However, the pants can either have some of the markers showing from the leg not worn if the pants are held by the person tight on the upper part of the legs or be slightly folded falling down. In the case of the shirt, the system was able to identify partial dressing most of the time (17/22). The 5 missed times were mostly due to participants completing the task quickly. For the pants, the system did not recorded partial dressing. However, we verified that the system did not identify as completed when participants finished the partial condition with only leg was worn (22/22). Further inspection of the videos should indicate patterns of recognition that may allow identification of partial dressing. It'd be important to also pinpoint the reason that completion of dressing was not registered in all cases in order to minimize the possibility of the system to incorrectly identify partial dressing.

4.2 Discussion and Analysis

Being able to detect the current state of the dressing process accurately is highly dependent on the system's ability to detect the markers on the clothing and predict the context in which it is visible (explained with an example, below). Inferring context is the most challenging task in improving the accuracy of the system. The other challenge is to ensure the system identifies markers even if they are occluded by clothing orientation or/and user actions.

For example, if the sequences of steps to wear a shirt correctly is followed, the inside part of the shirt is not likely to be seen until the very end of the process when the two sides of the shirt are closed. They can be seen either while adjusting it before putting it on or within the transitions right before closing it up. Our analysis showed that fiducial markers that were used to detect incorrect dressing (e.g., back and inside of the clothing) were visible for more than a second both during normal transition phase as well as during other instances (e.g., they were seen when the user was not instructed to wear the clothing in that specific incorrect manner and in all dressing scenarios, within the transition phases after putting the first limb on). With the current set of rules to detect actions, the system would infer incorrect dressing status based on detection of markers assuming that the shirt was worn inside out when it was not. For this condition (inside of the shirt,) the system should infer that the detection of the inside part of the shirt following the action of putting the first arm on, corresponds to a transition and not an error. To improve performance, the rules of detecting current dressing state would need to incorporate the information about all prior states. This would require a significant change in the current set of rules to identify dressing progress.

Implementing such modifications would require a system with a highly complicated set of rules and pinpoint accuracy. Inconsistency in the detection of dressing events such as errors or dressing completion could not only affect detection of the next step in the sequence, but also the inference of how far the user has advanced with respect to dressing. For example, consider the case where the system failed to detect an error state (wearing shirt with the back in front), if the system did not detect the marker that is responsible for detection of shirt being worn back in front, there is no way the system would notify the user of the error and ways to rectify it. In the same way, if the system did not detect the markers which signal completion of dressing for the current clothing item. It would continue to wait for those markers and not continue with the next clothing item and would signal error (incomplete dressing). We found that the system had trouble in detecting markers, especially at the point of completion. This is mainly due to the fact that the users did not try to make sure the clothing item is aligned properly and all the markers are clearly visible.

In our initial study we found that poor marker visibility / detection was caused by multiple factors such as poor lighting, reflection or contrast, position of the user (tilted or standing too far or too close); and markers occlusion due to bad clothing fit. To minimize some of these problems, we used the optimal size of fiducial markers, placed them on multiple locations on the clothing items for easy detection, improved lighting by attaching two lamps to the side of the dresser, and asked the user to face the dresser and stand in the area where the cameras' field of view was optimal. We also improved our chances of fiducial marker detection by using different clothing sizes for different users to get the best possible fit. Based on these changes for the second study, we found that the fiducial sizes seemed adequate however their placements could be improved. Some markers, which were placed to detect one dressing event, interfered with another dressing event and this affected the accuracy of the system. More trials would be needed to accurately identify the optimum positions for placement of markers, such that the system is able to detect dressing events without causing interference with other user actions.

In the second study (the one with 11 adults and two webcams (ps3 eye) without the Kinect), we improved the field of view of the camera to detect markers by adding another webcam and this helped in accurately identifying dressing events which was not possible before (ex: for pants - inside out, back in front, and correct dressing). The error rate reduced substantially from 38% with one camera to 10% with the use of 2 cameras. It would be interesting to test if dynamically changing the cameras' view to follow user's actions could result in better results and accuracy. We could add more cameras to the system setup to augment detection of markers, however with the addition of cameras, the system increases in complexity as currently reacTIVision can only process data from only one camera. The current system setup uses two machines to run reacTIVision software on each to process data from the two ps3 eye webcams (one webcam for tracking shirt and one for tracking pants). In adding more cameras, we would need more machines and then there is always a problem of synchronizing data across machines.

Improving the accuracy of marker detection is only one part of the solution. To provide efficient feedback and guidance to the user, the system assumes that the user will follow a fixed pattern in their dressing sequence. The sequence of actions the user takes to put on different clothing items plays an important part in how the system functions. For example: it does not matter what order the user puts on the shirt (starting with left arm or right arm). So the rules embedded are universal and work well for both right handed and left handed persons. However we found that one participant tried to don the shirt with both arms simultaneously and quickly swung the shirt around to put both arms through the sleeves at the same time. This prevented the system from identifying the dressing pattern accurately as this sequence was not part of the rules set. Similarly for pants, it is possible that users may use both their legs to put on the pants at the same time. From our observations we also discovered the following to be important factors for marker detection, namely, how a clothing item fits the participant, how they adjusted the neck for shirts or marker occlusion from users fixing their hair. From our analysis it’s clear that a complete set of rules to encompass everything listed above will be extremely complex. Hence its best to tailor our rules set to reflect the end user and, their dressing patterns for efficient performance.

In order to efficiently detect user actions in the context of dressing events, the system relies on more than fiducial markers to make an accurate assessment of the current state of dressing. For example, it has to combine information from x10 sensors (motion and door), RFID data, skin conductance sensor and Kinect (used for the initial study). A chair (embedded with x10 sensor) placed in front of the dresser sends information to the server about the position of the user (sitting or standing). Motion sensors placed on the dresser, detect if the user is closer to the dresser or far away, RFID sensors detect if the clothing item has been picked up or not and Kinect senses skeletal movements of the user which could be used in combination with the fiducial system to identify the current state of dressing. Every sensor used in this system plays an important role in the process of identifying the current state of the user with respect to dressing and to provide appropriate interventions when necessary.

For example: the rules set for detecting pants worn is as follows: If any of the lower pants markers are visible it symbolizes that leg being worn (e.g., the left leg), then the system looks for other markers which symbolizes right leg being worn. Once it can see all the lower markers, it waits for the person to stand up and pull the pants up (they could do the same while sitting as well, however the logical next step is to stand up). When they are standing, the system expects to see all the upper markers of the pants, which symbolizes pants being worn correctly. If the person is not standing up, there is no way the system would be able to see all the upper markers from the pants and it would be classified as incomplete. So for a situation where the person is not standing up, and the top markers are visible, the system would correctly classify the current state as pants not being worn (the person could show the pants in front of the camera, without wearing them). With additional information from a sensor attached to the chair, the system can determine if a person is sitting or standing, helping to make more accurate predictions regarding the current dressing state.

For some dressing events (e.g., shirt worn correctly), determination of dressing processes relies solely on the detection of fiducial markers. We found that the system was mostly accurate in detecting the user's action of putting the arms of the shirt using fiducial tracking. However, for actions at the final adjustment phase, where users tend to adjust their clothing item or hair in the case of women before aligning the two sides of the shirt to join the Velcro, these actions occluded the fiducial markers, making it hard to accurately track completion. At this phase, the system relies on four fiducial markers to be aligned at the right distance and orientation to detect completion. Due to occlusion from various sources, some of the markers might not be clearly visible, forcing the system to classify the current state as incomplete. To mitigate this problem, we tried to complement fiducial data with Kinect's skeletal data to find a reliable way to detect user action. However, Kinect's skeletal data turned out to be of little use in this scenario. When a user holds a clothing item in front of them, it was difficult for

Kinect to differentiate between the clothing item and the person's skeletal information and this resulted in incorrect detections. Relying solely on fiducials has its limitations and we are investigating ways to complement fiducial detection in future studies.

Intelligent dressing systems need to understand differences between clothing items and the respective challenges each item may present. We found that overall our system was more reliable at tracking dressing events for pants than for shirts and made fewer incorrect detections. These differences in reliability come from: having more distinct areas to track, in the shirts in comparison with pants and the fact that there are fewer ways to put pants on than shirts. Considering these factors, it would be logical to expect that a t-shirt would be easier to track than a shirt as the chances of irrelevant markers becoming visible to the system is substantially less than with a shirt. However it would be more difficult to track than pants since there are more ways to wear a t-shirt than pants. Other types of clothing items like socks and shoes pose other challenges. For example the size of the fiducial markers would need to be smaller (and would therefore be less visible) and in the case of the socks they are very likely to be occluded by folds in the material. Additionally, they could be partially occluded by other pieces of clothing, e.g., the bottom of the pants. Dynamic zooming by cameras could improve the probability to view smaller markers. Color codes or alternate makers could also be used to identify socks or shoes before putting them on. We provide further discussion regarding the acceptability of adding color-coding and fiducial markers to clothing below.

In conclusion, our results and recommendations, described above, indicate that the reliability of DRESS is currently promising and can likely be further improved, as well. However, these approaches need to be tested in home settings with PWD as the next stage in the iterative development of DRESS and to more fully understand its potential for this target audience.

CHAPTER 5

SYSTEM ARCHITECTURE

The system architecture that is necessary to enable tracking of both ADL and IADL activities builds on top of the GALLAG platform described in section 3. GALLAG provides the basic infrastructure necessary to build complex embedded systems on top of it. The various system components that are used to build this architecture is described in the chapter. Since this architecture involves interfacing with a wide variety of hardware technologies (Figure 15), we need to have a software infrastructure that communicates between all these hardware products and processes information captured efficiently and reliably. The different software products that we use to interface between these devices are Indigo 4.0, Kinect SDK, reacTIVision, Xcode and Processing. Programming languages used to build the interfaces are Apple scripts, Java, C#.Net, Objective C, HTML and JSP among others. The different hardware components used for this thesis are explained below.

5.1 ADL and IADL Tracking

The system was designed to monitor how well individuals perform their daily activities in their own homes. Since it is imperative for an individual to perform both their ADL and IADL activities well to be able to live independently; the activities were chosen in such a way that it covers both these types of activities. Two ADL activities (dressing and brushing teeth) and two IADL activities (coffee making and medication taking) were chosen to track for cues to functional assessment. Special care was taken to ensure that the sensors embedded into devices for tracking do not alter their daily routine or change their behavior in anyway during performance of these activities.

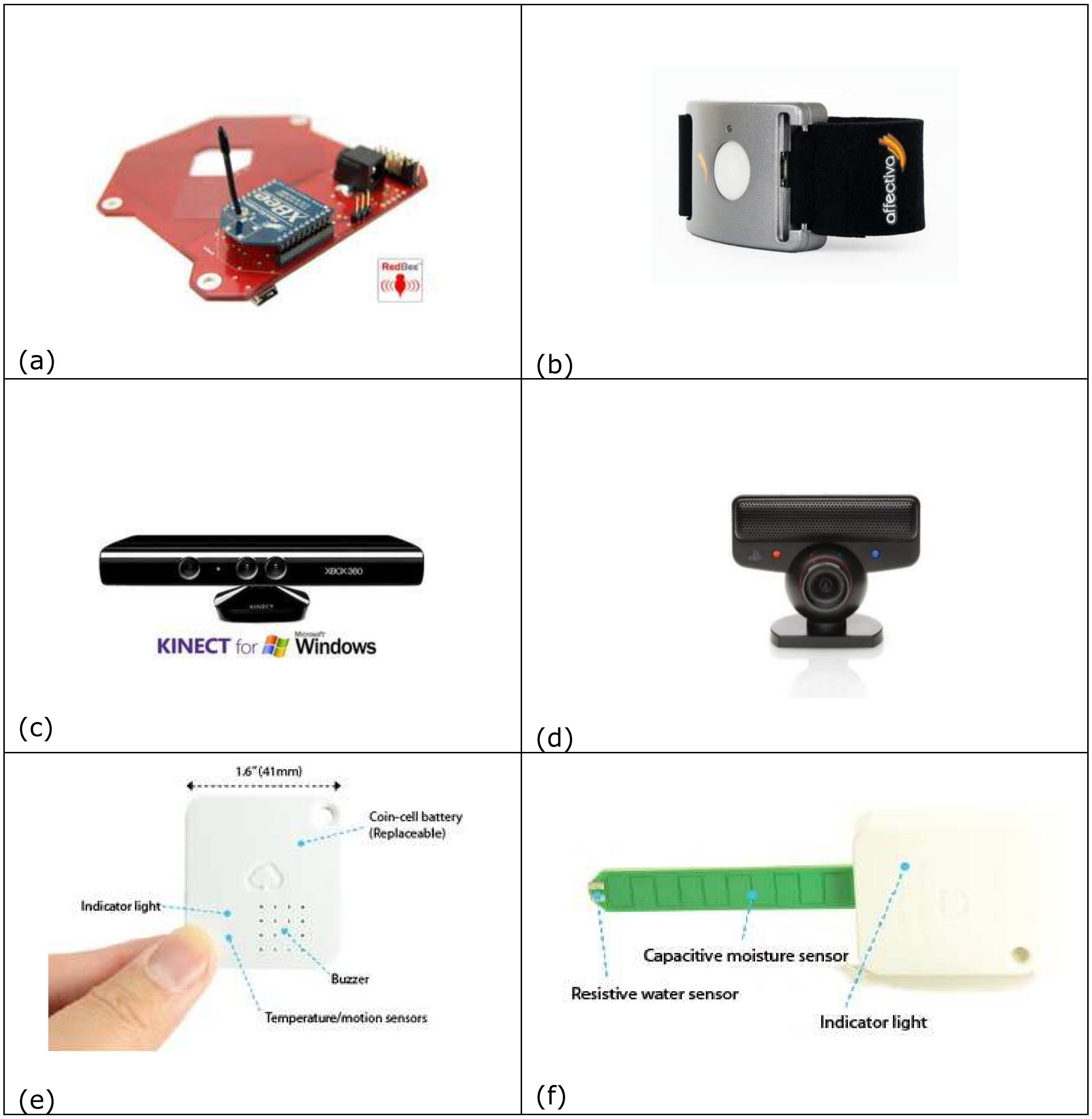

Figure 15. Hardware Components

(a) RFID reader (b) Skin conductance sensor (c) Microsoft Kinect (d) ps3Eye camera

(e) Motion Sensor (f) Moisture sensor

5.1.1 Intelligent Dresser

To monitor dressing, DRESS system was used (see section 4). A customized dresser, different from the one in Figure 5, was designed and developed to track every move performed during dressing through sensors placed in the dresser as well as outside of it.

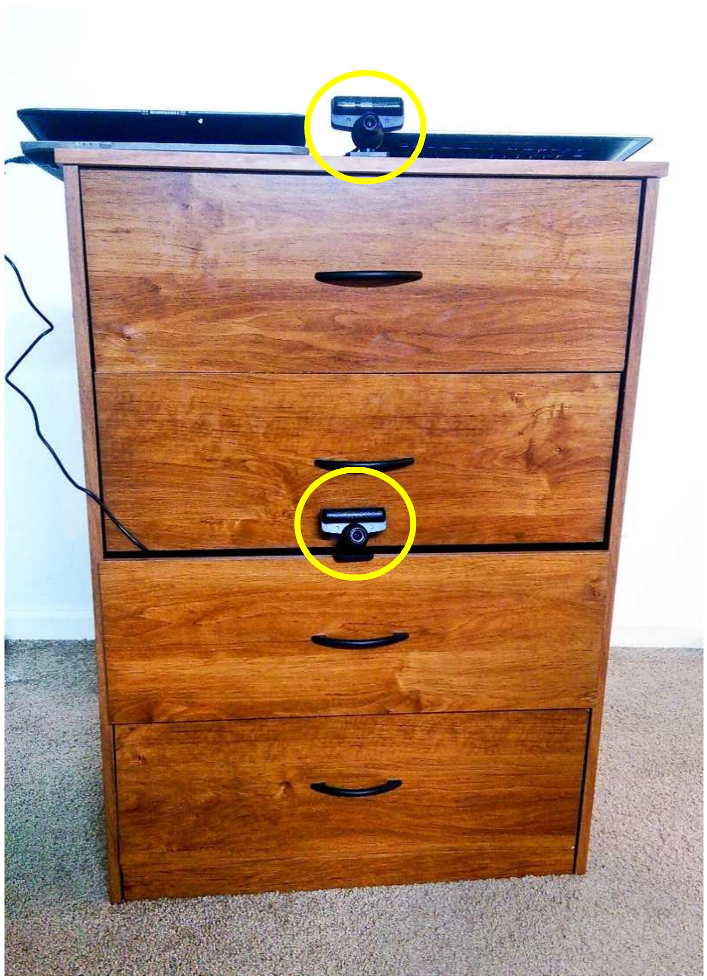

Figure 16. Dresser with 2 ps3 eye cameras

The 4 drawer dresser is a standard consumer dresser available in stores which is fitted with sensors to track dressing activity. Each drawer of the dresser is fitted with an x10 door sensor to detect open / close of the drawer. Each clothing item will be placed in separate drawers in the dresser. To minimize the complexity associated with tracking a dressing activity, only shirts and pants are tracked. Two ps3eye cameras are used to track fiducial markers which are attached to the clothing items to identify its orientation and location (one is placed on top of the dresser, while the other one is placed in the middle drawer). The data from all these devices would be wirelessly sent to the central server which is placed in the user's home.

5.1.2 Coffee Tracker

To monitor various steps of making coffee, we have embedded sensors in the coffee machine and to the cabinets that contains the coffee filter and ground coffee (Figure 17). The sensors in the cabinets track if the user opened the cabinets for adding coffee filter and ground coffee. The sensors in the coffee machine, track if the filter basket is opened, if the water is added into the machine, if the switch was turned on and also to detect the temperature of the carafe. All the sensors transmit data wirelessly to the server. Based on the data received, system would be able to identify which steps were performed, how long it took to perform and any errors performed during the activity. Voice guidance through speakers placed in their home can be provided to rectify errors (if any) detected as an option.

Figure 17. Smart Coffee maker setup

5.1.3 Smart Pill Box

To track medication taking, a smart pill box (Figure 18) was devised. It is a standard pill box available in consumer stores augmented with sensors to detect whether the user opened or closed a box. The system has the capability to detect if the user opened the wrong box based on their daily routine. Since users perform medication-taking task differently from one another (for example, some may get the water first to swallow the pills and then go get the pills, others may do the opposite), we can customize the environment with sensors to detect if they went to the kitchen faucet to get water based on how they perform the task. Based on the data received, the system would be able to identify errors and time taken to perform each task. Voice guidance through speakers can be provided to rectify detected errors, if any, as an option.

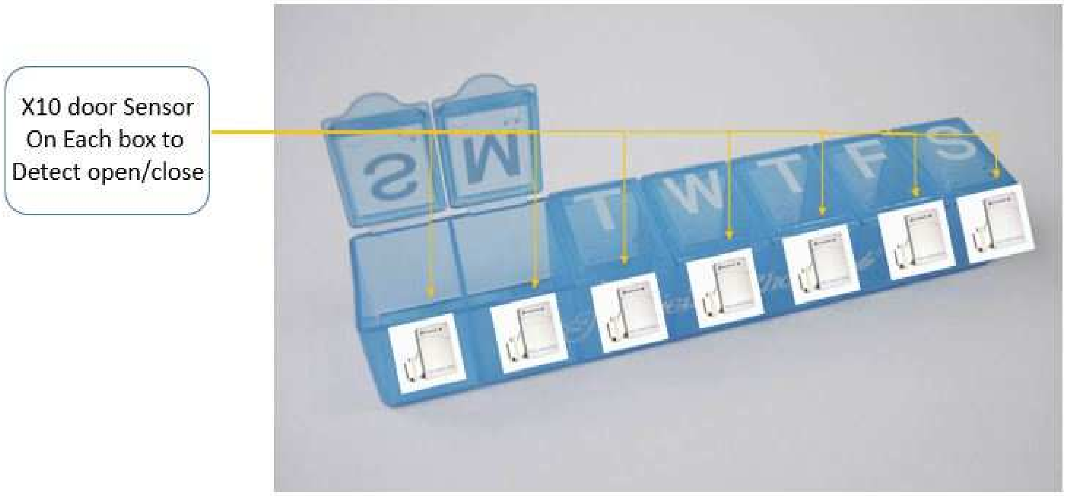

Figure 18. Smart Pillbox Setup

5.1.4 Smart Toothbrush

To track brushing activity, I attached a motion sensor with the tooth brush (Figure 19). The tooth brush is a standard one available in consumer stores fitted with a motion detecting sensor to detect whether the user moved it or not. The system has the capability to detect if the user is brushing or not based on its movement.

Figure 19. Smart Toothbrush Setup

Since users perform brushing differently from one another (for example, some may brush longer, some may brush for a shorter period of time), knowing their routine and customizing the software to detect accurately is important. Based on the data received, the system would be able to identify when they brushed and time taken to perform the task. Voice guidance through speakers can be provided to notify the user if they skipped brushing, if needed, as an option.

5.2 System Components

There are three key components of this system, a) sensing activities; b) processing and evaluating sensor data; and c) presenting aggregate information to stakeholders in an appropriate manner. As shown in Figure 20, the hardware devices and the sensors form the sensing component, the processing of raw data to a more useful and usable data forms the processing component and the final stage of making the processed data user readable and understandable forms the presenting capability. In the Present part, the processed data is sent to a web UI (user interface) for the user to track their task performance as well as view any errors (if any) they made during any of those tasks. Whenever an error or an anomaly occurs, the system sends a feedback form to the user automatically to capture the ground truth or in other words, the “Why” part of the puzzle. It’s very important in the context of functional assessment to capture why something happened to provide correct, necessary interventions. The data captured from this feedback form, is sent back to the server, where the software stores this information and tries to eliminate false negatives.

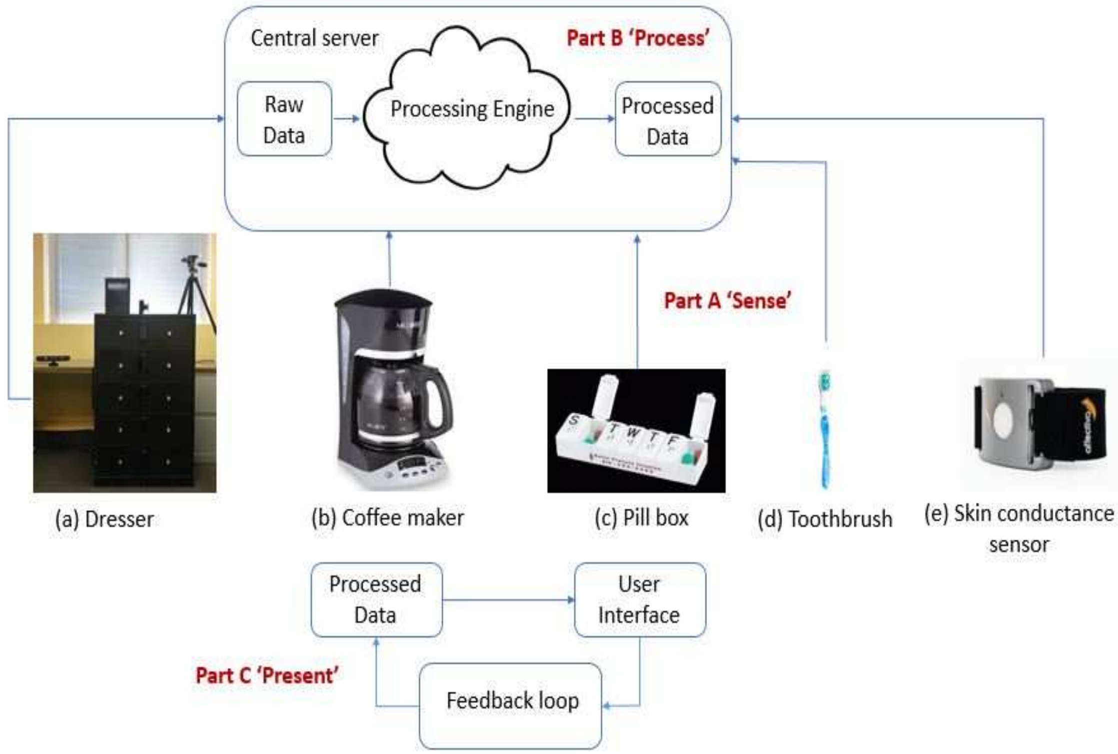

Figure 20. System Components

5.2.1 Sensing

The sensing component is responsible for all the sensor related capabilities of the system. The sensors are responsible for tracking each activity, capture the data necessary and send them to the central server wirelessly (Figure 21). This component is important because if any sensor is not able to capture or sense any signals, we won't have the data to process them and assess the user's functional abilities. Data from the sensors form the backbone for all the processing and analyzing that goes in the background. The sense component very much depends on the hardware that we have embedded into objects in the user's home as well as the skin sensor worn by the user and it is important to check the status of those hardware devices at regular intervals for proper functioning of the system. The different kinds of sensors that are embedded onto objects of daily use are X10 door sensor (used to detect open/closed functionality), X10 motion sensor (used to detect if the user is moving in front of the sensor or not), wireless motion sensor (used to detect if the object to which it is attached is moved or not), wireless temperature sensor (used to detect the temperature of the object to which it is attached), wireless moisture sensor (used to detect moisture level of the object to which it is attached), and skin conductance sensor (used to detect electro dermal activity of the user).

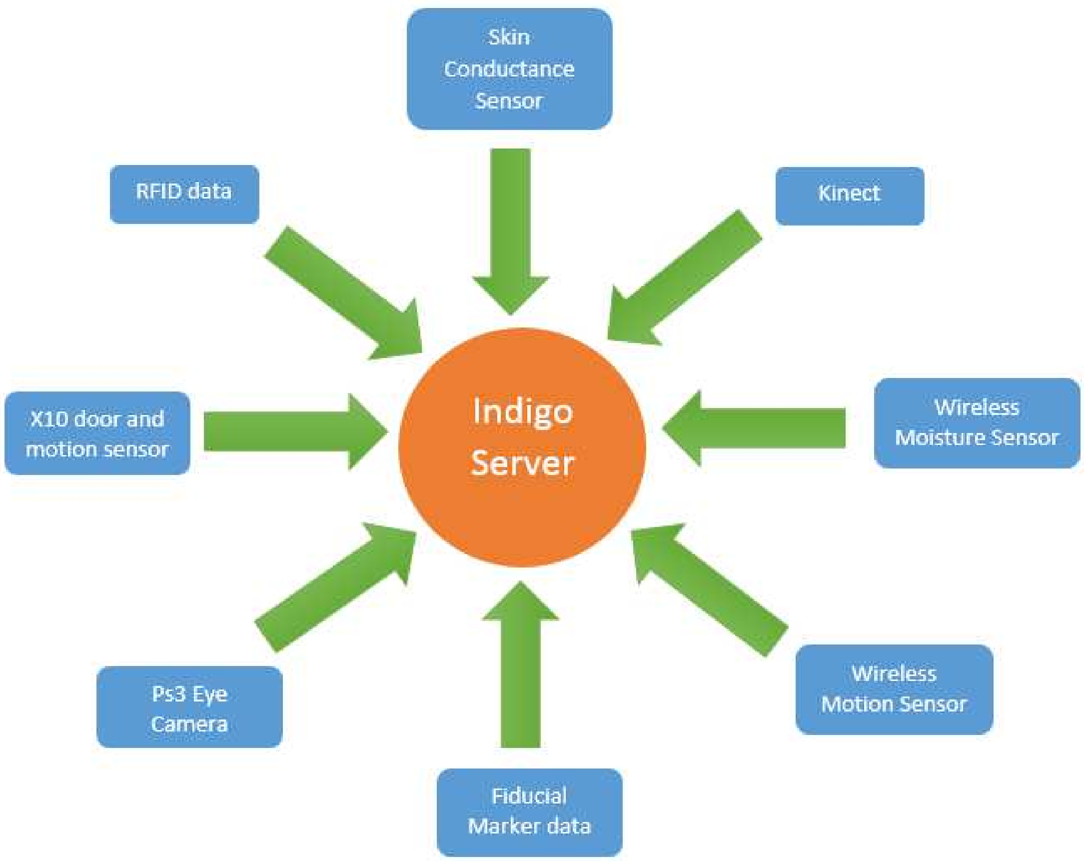

Figure 21. Information flow from different components to the central server

One important aspect of the sense component is the use of a skin conductance sensor to predict the emotional state of the user during the process of performing those four activities (dressing, brushing, coffee making, and medication taking). By tracking skin conductance sensor data when they are performing an activity, we could gain valuable information of how their emotion affects their performance and if it has any relation to their functional ability. Poh et al., 2012 [71] presented a simple way to use a wearable sensor for long term assessment of electrodermal activity. The changes in skin conductance at the surface, referred to as electrodermal activity, reflect activity within the sympathetic nervous system, which is the region of our brain associated with emotion, cognition and attention. Bankole et al., 2011 [6], Poh et al., 2012 [71] and Kapoor et al., 2007 [35] have shown how to use skin conductance sensor to successfully predict emotion specifically stress, frustration and agitation. Cognitive function is one of the important element of a person's functional ability. By tracking their skin conductance values, it gives us insightful information on whether they are stressed or anxious, which can be related to their cognition [71]. There are some obvious limitations of using this sensor as well. The sensor is not 100% accurate and it is hard to differentiate between different emotions and to accurately identify an emotion. For example, sweating resulting from physical activity and sweating from emotional response is hard to distinguish. Similarly, the emotional levels vary for different users, so you cannot fix a baseline for predicting emotion which is common for all users. However, having a tool to measure emotion could be a valuable asset in assessing functional abilities and it is an area worthy to explore.

5.2.2 Processing

The process component is responsible for processing all the raw data that has been sent to the server by different sensors embedded into objects and the one worn by the user. It is at this stage that the system decides which data is important and which are not important and processes them to a more usable format and stores them in a database. This is necessary as the sensors send across all the data it can possible capture from the environment to either the Indigo software or store them in text files in the server. Some are more important for the assessment than the others. If we do not process these raw data, then we are left with lots of junk data that gives us no meaning and provides no help to assess the functional ability of the user. It is also at this stage that the system uses efficient algorithms to sift through vast amounts of data and finds the data that is useful to be presented to the user or the caregiver. The raw data that is captured by different sensors is stored locally in text files, automated scripts in Indigo reads them, processes them and stores them in the database which resides locally as well. The database acts as a central repository for all the data that is captured and processed. The program that is used to display the information to the user through a web user interface gets the information from the database.

5.2.3 Presenting

Once the data is processed to be able to present to the user (caregiver), the system sends information to the user every day on the status of the activities performed during the day through a web interface. The data presented should be clear, simple and understandable to the user to make any sense on what is going on. To that extent, the design of the user interface uses some (if not all) of the universal design principles proposed by Story and Molly (1998) [81]. The design of the interface presented to the user, also follows some (typography, layout and organization) of the web design directives proposed by Morrell and Roger, 2001 [57]. It was designed to be simple, easy to use, intuitive and adaptable. The first three qualities were validated from the interviews with caregivers and case study participants. As an example, for adaptability, the feedback back form that was created to gather near ground truth and to eliminate false positives will be presented to the user only if the system finds an anomaly. If there is no anomaly, the form is hidden from the user. This is an example of adaptable design. Similarly there are other components in the user interface which adapts to the context. Displaying errors, skin conductance values etc. are some of them. The user can access the web interface to get information about which activities were performed the previous day, how much time did each task take for a particular activity, were there any errors during those activities and so on. Care is taken not to burden the users with too much information. When they access the web interface, they are given a snapshot of the status of each activity performed during the day.

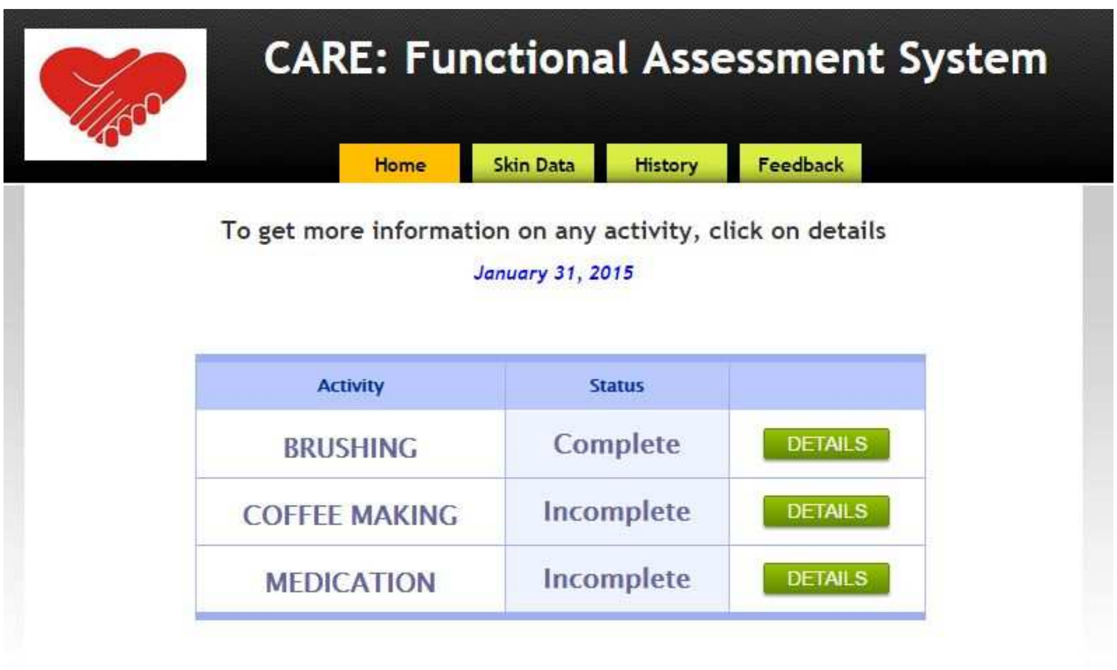

Figure 22. Home screen with snapshot of the status of each activity

If they want to see more details about a particular activity, they can do so by clicking on the details button in the home screen. This will take them to another screen which has some more information about the activity they selected. It has information such as status, time it was initiated, and time of completion.

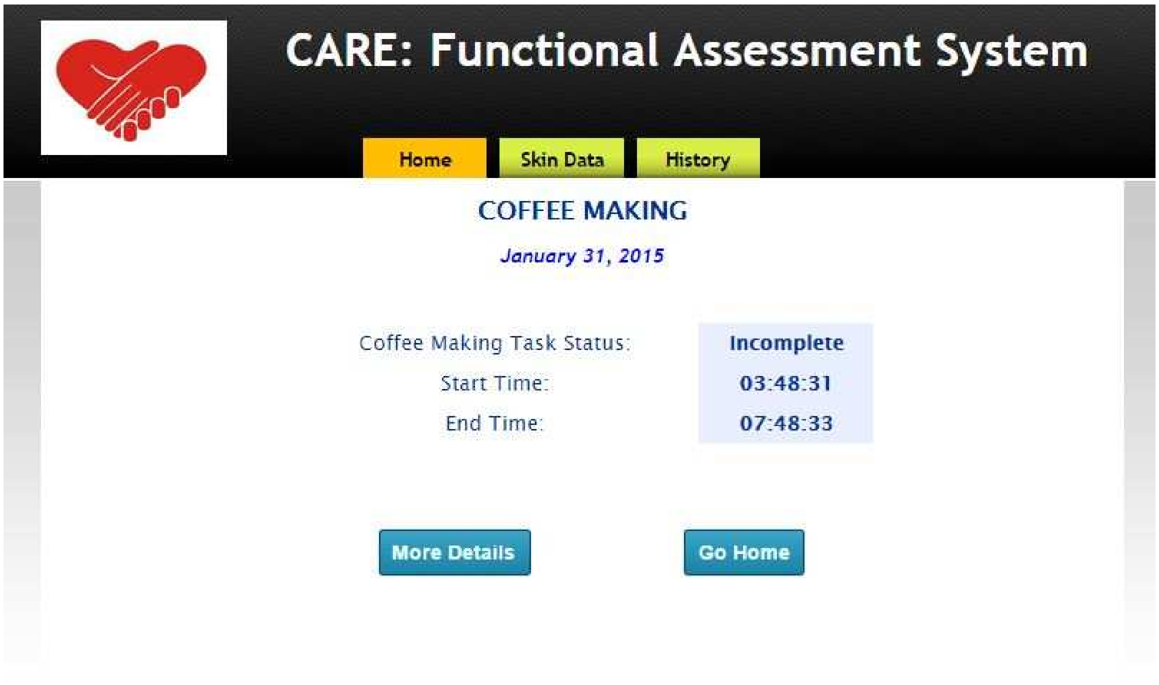

Figure 23. Simple information about an activity

After reviewing the data presented to them, the user might want to explore further. When they click on more details, the interface displays the status of each sub-task associated with that activity including skin conductance values during the activity and any errors they would have made. When the system finds an anomaly in the performance of any activity, it presents the users with a set of feedback questions to identify close to ground truth and to eliminate false positives. They can access the feedback form from the home page. The system uses the responses of these feedback questions and sends it to an algorithm which uses this information to update the data stored in the database. For example, if the user is not present at home on a particular day and the sensor found that the user did not take their medications, based on feedback it could be found that the user was not at home and it could help the algorithm to not classify the data point as 'forget to take their pills', and discard this anomaly. This is important because, it provides a framework for someone to develop intelligent algorithms in the future to make predictions about their functional state.

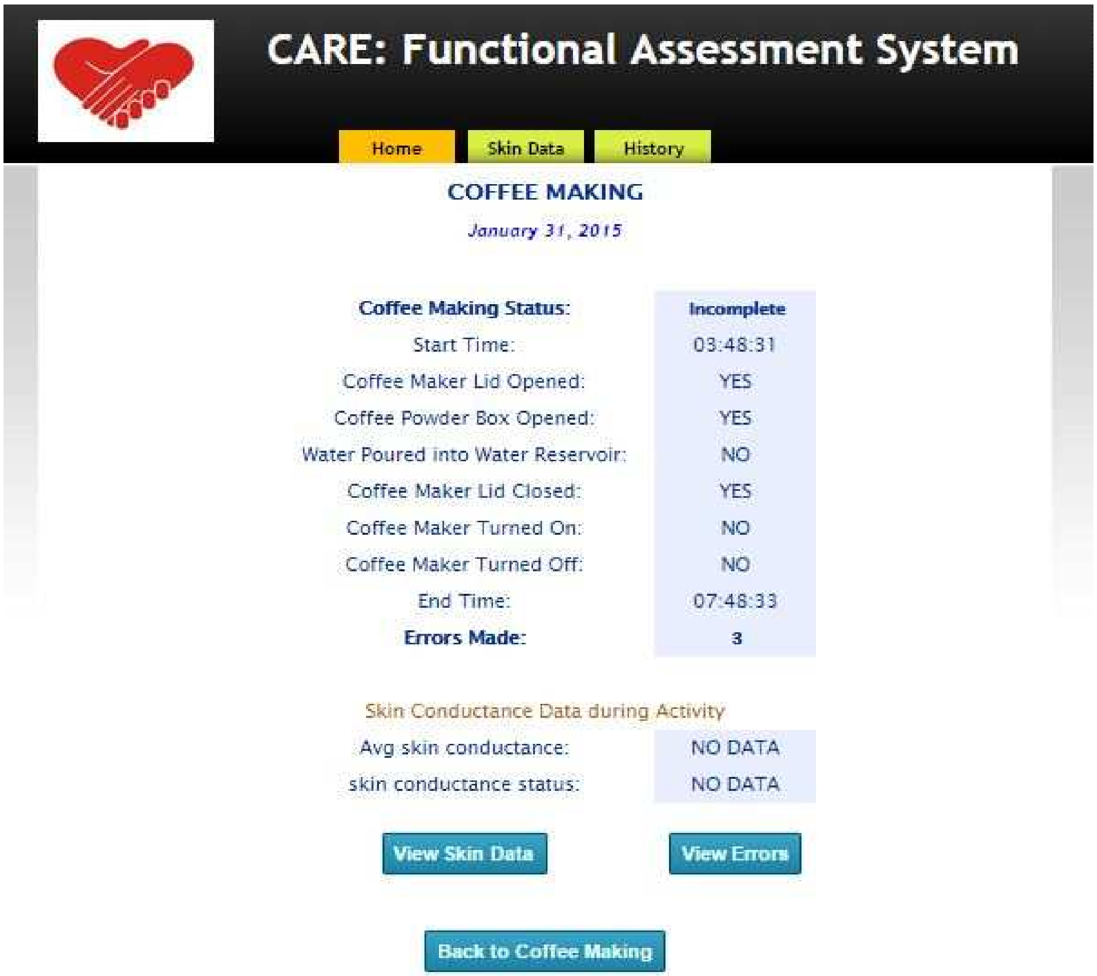

Figure 24. Detailed information about an activity together with skin conductance levels and any errors they made during the activity

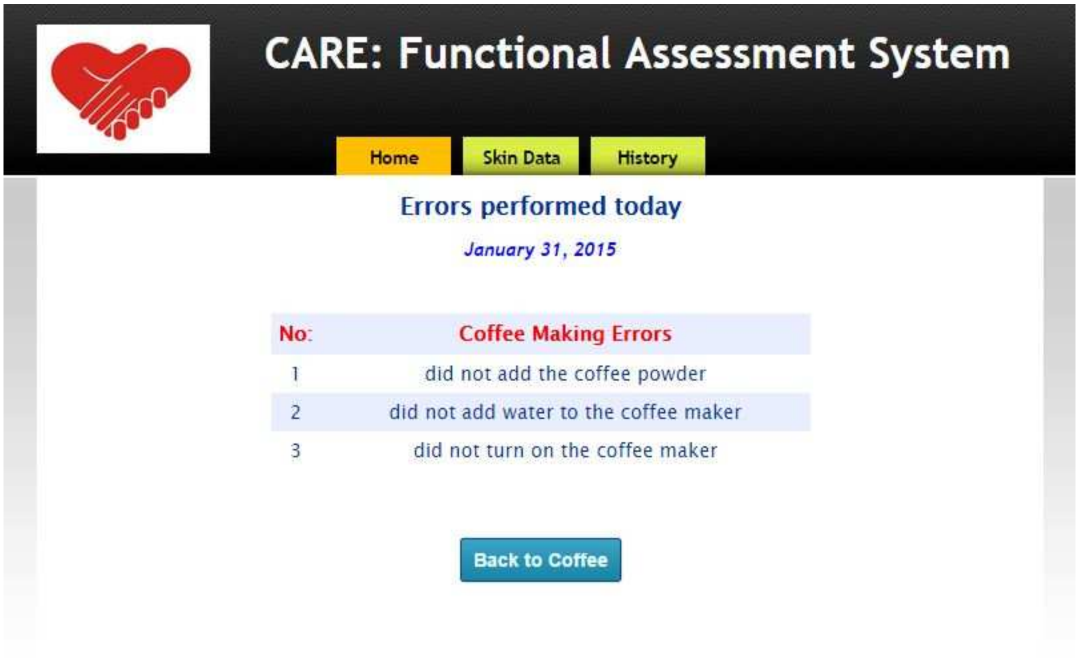

Figure 25. Errors page showing errors made during an activity

The primary purpose of this algorithm is to eliminate anomalies, help users better understand the data and also to peruse the vast amounts of data gathered every day and try to find any patterns if possible. These patterns are an important component in assessing one's functional abilities as they give the necessary information which were previously not found in the day to day results. These patterns allows the user to see "why" something happened and helps them make informed decisions on the functional ability of the person they care about. Without the feedback component, just by looking at the web interface, the user will know that he/she did not take pills on a particular day but have no idea why they did not take pills. Now through the data captured from feedback, we know that they did not forget to take pills rather were not at home to take them. Since the case study was conducted only for a period of two weeks in each user's homes, it is extremely difficult or impossible to identify or predict any patterns. Since the prediction part relies on past performance data, it needs a lot of data to come up with good predictions. It is however one of the features that could be part of a future enhancement for the system, the ability to predict causes of any actions and to find patterns which are invisible to other means of observation. Another feature of the user interface is the history tab, which helps the user to go back in time and look at how they have performed the activities tracked over the last 7 days or 2 weeks. The user will be presented with a graph showing when a particular activity was performed on each day, whether the activity is complete/incomplete/missed etc.

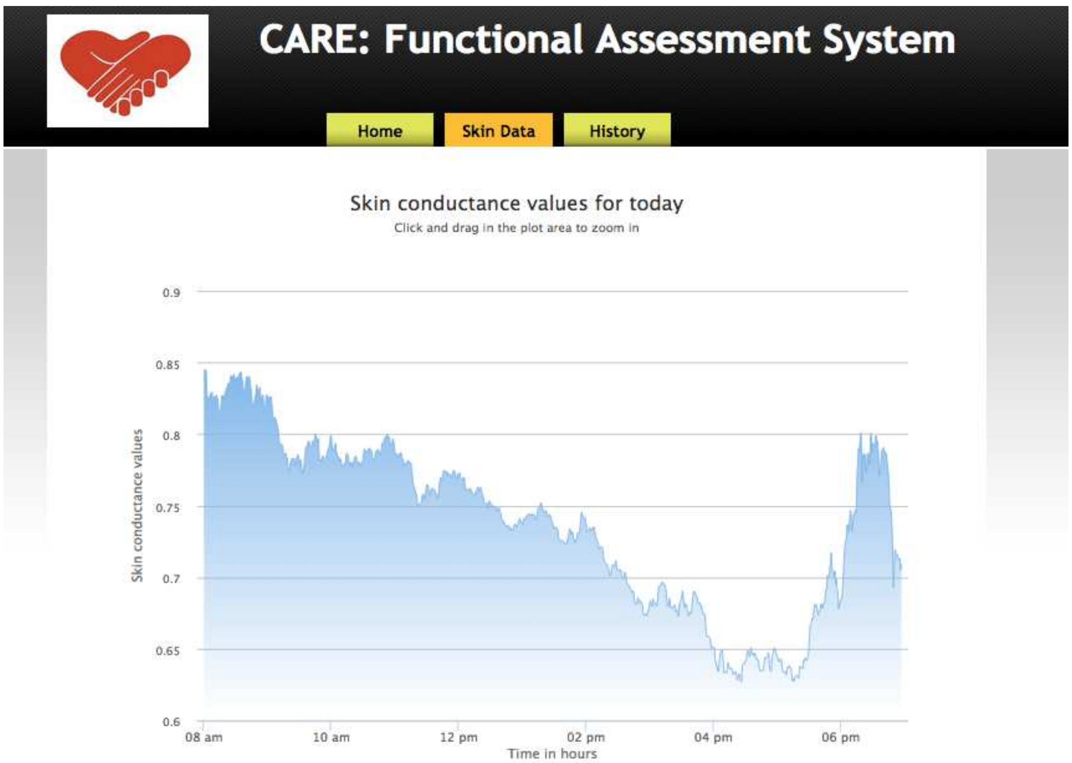

Figure 26. Skin conductance page showing electro dermal activity during the day

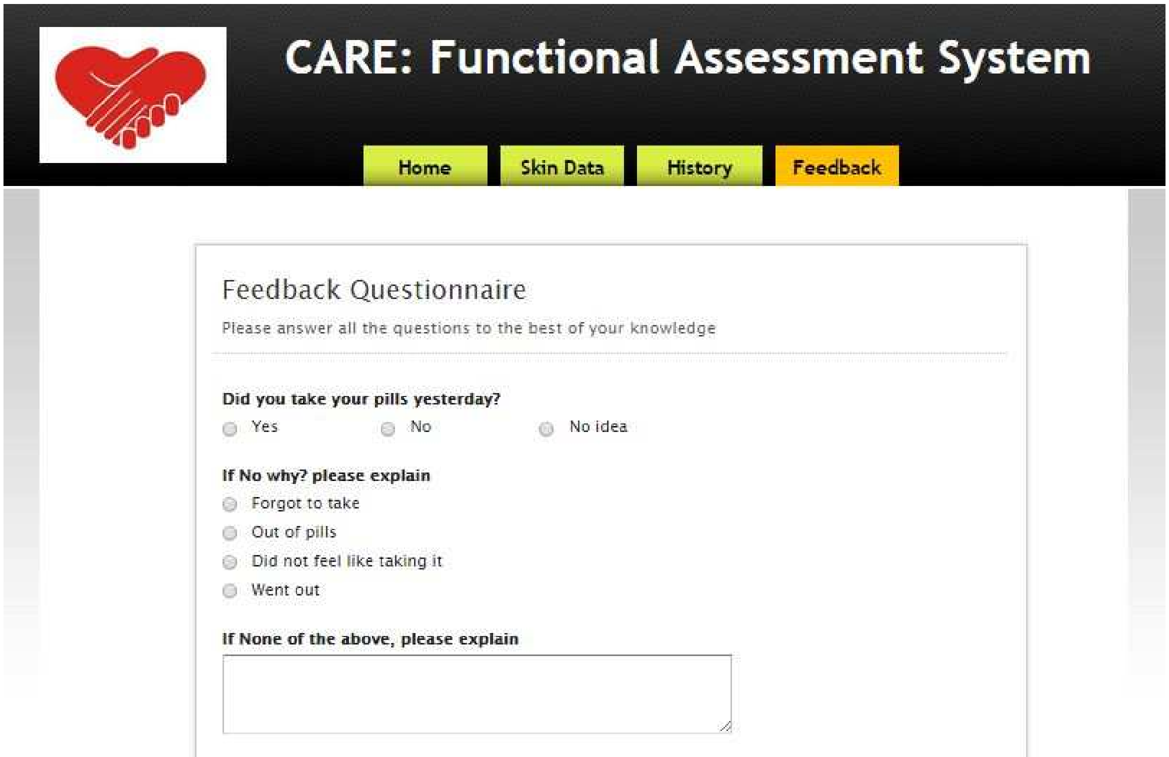

Figure 27. Feedback with a sample question

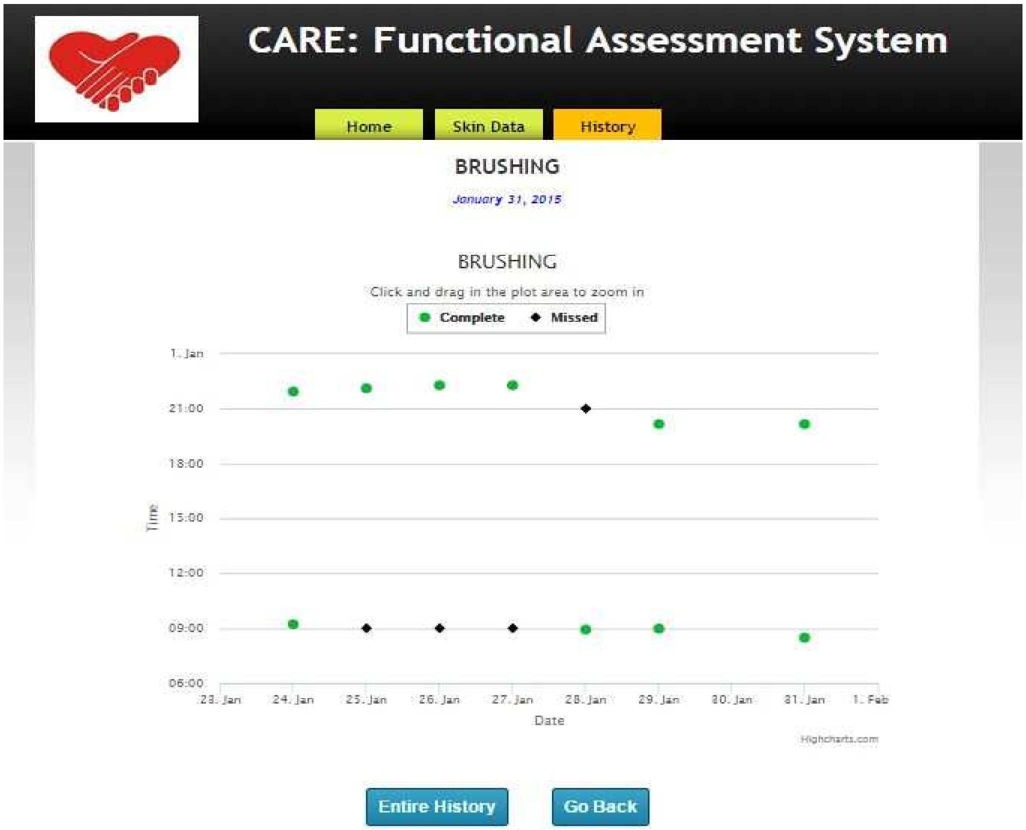

Figure 28. Graph showing history of brushing over the last 7 days

CHAPTER 6

CASE STUDY, INTERVIEWS AND LAB STUDY

To answer the research questions, I employed three different methodologies: (1) Case Study to perform an in-depth analysis and to capture real world challenges (both technical and design); (2) Interviews with caregivers to capture information needs, design challenges and also feedback about the User Interface; and (3) Controlled Lab Study to test the sensors. Using a combination of these three methodologies will provide me sufficient data to answer my research questions. They are described in detail below.

6.1 Case Study

A case study methodology was used to perform an in-depth analysis of how functional assessment systems are used in the real world, and to identify the design and technical challenges of using them. Compared to an experimental user testing approach, which requires a large number of participants and relies on quantitative data to infer, prove a hypothesis and apply to a large audience, a case study relies on qualitative data to support the hypothesis and is more in-depth. It was determined that a study on a larger population was inappropriate, due both to expense and the stage of development of the systems. Likewise, it would be infeasible to answer the hypotheses by conducting studies in a laboratory environment. Thus, to identify design and technical challenges and the effectiveness of using multiple modes of performance based task assessment, the case study methodology was selected to provide the data required to answer the core research questions efficiently.

The case study was conducted with 4 healthy older adults (No physical or cognitive impairment) for a period of 2 weeks. We decided to conduct the study with 4 older adults as this was determined to be a sufficient number to conduct exploratory studies. Having 4 participants is not too small a number to be discarded as an anomaly while not too large enough considering the challenges in deploying them in user's homes. Due to the complexity of the system and the inherent challenges associated with conducting a study on four daily activities, it was not feasible to increase the number of participants. We also decided to conduct the study for a period of 2 weeks as the focus was not to capture behavior change over long term deployment but to capture their perceptions on working with sensors and identify challenges in using the system on a daily basis. Considering the goal, 2 weeks seemed like a reasonable amount of time to make them not focus on the changes in their environment and continue with their daily routine. All the participants reported that they went on with their lives without noticing the sensors after the first 3-4 days.

This section talks about the case study methodology which involves talking about the assumptions, limitations, constraints and requirements if any. It also presents the procedures used, defines the variables and hypotheses, what instruments were used to collect data, how data was collected and how long, how data would be analyzed and how to present the results.

6.1.1 Assumptions

Since the participants chosen for this case study were healthy older adults aged 65 and older, there are some assumptions made based on the health status of the target population.

1. No loss of independence in functional abilities. They may have mild problems performing complex IADL tasks such as paying bills, shopping etc., and take more time, be less efficient, and make more errors at performing such activities than in the past. Nevertheless, they generally maintain their independence of function in daily life.

2. No evidence of significant impairment in social or occupational functioning.
3. Since the study was conducted for a period of two weeks, and the participants chosen were healthy, it is not expected to find any functional decline through the data captured. It is also not expected, because of the fact that the study focuses on only 4 activities (ADL - dressing, brushing, IADL - coffee making and medication adherence).
4. Users have some knowledge and experience working with technology, minimum criteria - being able to check their emails online.

5.1.2 Limitations and Constraints

Considering this is a case study with 4 older adults and conducted for a 2-week period, there are some obvious limitations and constraints with the study and in interpreting the results as well.

1. The data cannot be extrapolated to the general population. The participants do represent the older adult's community, however, what was found cannot be extrapolated to the entire population. Cognitive and physical impairment symptoms vary from individual to individual and certain forms of cognitive impairment overlap with each other.
2. The case study was limited to only 4 participants, as this was determined to be a sufficient number to answer the primary research questions (see section 6.1).
3. Functional assessment using embedded sensors depends largely on how efficiently the sensors can pick up clues from task performance. Any change in the behavior of the user can be captured as anomaly by the sensor and most human behavior is known to have variability. This limits our interpretations of the data to make accurate and timely interventions.

4. Sensors and other devices used for this study rely entirely on uninterrupted power supply and any changes to that can cause missing data, which in turn could make functional assessment and complicate interpretation of the data.
5. Some sensors used for this study need constant Wi-Fi-capability for communicating with the central server (MacBook) placed in the user's home.
6. The user has the responsibility of ensuring the systems installed in their homes are ON before they start their day. There is a possibility that someone can fiddle with one or more devices and turn it OFF. In scenarios such as this, it is difficult to detect in time and rectify the mistake. This could cause data loss which could affect the assessment.
7. Data collected from embedded assessment systems are merely observed behaviors that require further explanation for anomalous behavior. For example, missing a day's pill can be attributed to multiple reasons which are not related to the person's cognitive ability. The person could have gone out, did not feel the need to take medications and intentionally avoided them, out of medications and so on. To mitigate this situation and to better provide useful information about user behavior, data from feedback forms filled in by the user themselves was included. Whenever an anomaly is found, the system sends out a questionnaire to the user to capture observational data and predict reasons for the anomaly through their answers. If the user did not answer the questionnaire, there is a possibility of erroneous or inaccurate data.

6.1.3 Requirements

Some of the requirements for efficient data collection and interpretation from the case study to be used for functional assessment are listed below:

1. Participants should be 65 and older

2. Participants should be without any physical or cognitive impairment that affects their functional performance on daily activities
3. Participants should not have had a minor or major stroke or major physical injury in the last 10 years
4. Participants should have brushing, coffee making, pills taking and dressing as part of their daily routine
5. Participants should have a Wi-Fi network in their home
6. Participants should have basic knowledge of using computers

6.1.4 Data instruments

This section talks about the different instruments used for collecting data from the case study. The instruments used for this case study are as follows:

1. Questionnaires
2. Standardized tests
3. Interviews
4. Audio recordings
5. Sensor data

A questionnaire was used to filter the participants to find the right match for the case study. Four participants were selected from the participant pool based on their answers to questions about their daily routine and their functional ability. During the case study, the data from questionnaires filled out by caregivers were used as supplemental observational data to validate the data captured through sensors. Once the participants were shortlisted for the study, they were asked to take standardized physical (Timed Up and Go) and cognitive (Mini Mental State Examination) tests. These are used to test their physical and cognitive ability and ensure they are functionally able to perform all the four daily activities. Data from interviews were captured from the participant twice during the study. The first interview was conducted before the start of the case study, and the second interview was conducted at the end of the case study. During interviews, audio was recorded (with their consent, everyone consented) to be used as additional material for later analysis and coding. Sensor data were captured from sensors embedded onto objects of daily use to track daily activities especially from brushing, coffee making and medication adherence. The data from dressing was used to test how efficient it is in tracking the activity, design challenges and to prove its usefulness in functional assessment. The data is not used to assess an individual's functional ability for this case study.

6.1.5 Case Study Procedure

Participants who are healthy, aged 65, and who are independent in performing their daily activities were recruited through a mix of social network, posting ads in multiple senior groups, contacting several agencies and through my professional network. The case study started with a questionnaire (see appendix), to screen participants for the case study in order to find four participants that best match the needs of this study. Filling out the questionnaire did not take more than 10-15 minutes. The study was conducted in three phases. Before the start of the case study, all participants were debriefed about the study goals, what data would be collected, and items of the consent form. They were asked to read, ask any further questions and sign the consent form, if they agreed. 6 participants were screened as eligible, 4 consented and completed the study.

During the first phase, two standardized tests were conducted a) TUG (timed up and go test) to test their physical condition and identify if they are physically stable and will be able to perform their tasks and b) MMSE (mini mental state examination) to test their cognitive ability and identify if they are not at risk for any cognitive decline. Once I confirmed their physical and cognitive ability, second phase of the study started with the installation of the system with all the sensors in participant's home. I trained them on how to use the system, how to check their task performance using a web interface and also provided contact details to clarify if there were any concerns. After the successful installation, an in-depth interview was conducted (lasting close to an hour) to get information about their usage of assistive devices, their functional ability, their information needs and their perception of using a functional assessment system. Interviews were audio recorded (if consented) for analysis purposes. In the last phase, before the two week in-home case study commences; participants were asked to wear the wrist-worn sensor and keep calm to get a baseline of their electro-dermal activity. This data was used to establish baseline for the skin conductance sensor that the participants were wearing during the case study. During this phase, the system provided them with details about their functional performance on three activities namely brushing, coffee making and medication adherence every day through a web interface. If the system found any anomaly on any of those three activities on any particular day, it will send them information to fill out a feedback form through the same web interface (the one used for monitoring task performance). This is important as this will help the system to discard any false positives. It also helps the user to look back and identify why something happened. For ex: if they did not take pills on a particular day and they wanted to know why, through storing information from the feedback form, they will realize that it's not because of their mistake but they were not available at home to take those pills. After the two week study is complete, they were interviewed again for feedback on their usage of objects embedded with sensors and also about the interface which provided them with information on their task performance. This helps to fine tune certain parameters for future long term deployment and also to incorporate their needs and resolve any concerns for the future.

Participants were given the choice to perform the activities on their own schedule. There is no requirement of a specific time on which these activities needed to be performed. Care was taken to ensure the task they were required to perform as part of the study did not interfere with their daily routine. Since these four activities are already part of their daily routine, they did not spend separate time for this case study except for the dressing activity (they were asked to perform dressing activity with shirts and pants every day with the clothes we provided). The system was passive and it monitored, tracked and captured data from sensors when activities were performed without disturbing the participant or their caregiver. One of the activities (dressing) was to be performed for just a week as it is used to identify any design and technical challenges of using it with target population, while the rest of the activities were carried out for the entire two weeks period of the case study and the data were used for assessment. Participants needed to ensure the system is ON and working every day before they can perform the three activities. Clear instructions were given to them on how to check the system status.

The participants were also given the option to withdraw from the case study at any point if they felt the need to do so. Each participant selected for the case study, was paid $50 per week at the end for their participation. If for some reason, they chose to stop the study in between, they would be paid for the number of weeks they participated, but none of the 4 participants dropped out of the study.

6.2 Caregiver Interviews and Lab Study

This section discusses the methodology and procedure used for the caregiver interviews and the controlled lab study with younger adults. It also explains any assumptions, constraints, requirements, kind of data that is collected from both the methods and how data analysis will be conducted to answer the research questions.

6.2.1 Assumptions, Constraints and Requirements

There are a number of assumptions, constraints and requirements for the caregiver interviews and the controlled lab study. The participants for these two studies were decided well in advance to make sure we get proper data for analysis and to complement the data from the two week in-home case study. The requirements are listed below:

- For caregiver interviews
    - Participant should be providing regular care to a person older than 65
    - Participant should be free of any cognitive impairments
    - Participant must be providing care for at least 12 months in total and
    - Participant should be a caregiver in the last 12 months
- For controlled lab study
    - Participants should be 18 years or older
    - Participants should not have any physical or cognitive impairments

The following are the assumptions for both the interviews and the lab study

- For caregiver interviews
    - Participants have an understanding of their information needs
    - Participants have used assistive devices in the past or heard about it

- Participants have knowledge and memory about their care recipient and their care giving needs
- Participants are able to provide feedback on the system when they are shown images of the system I developed

- For controlled lab study
    - Participants are able to perform the three activities on their own
    - Participants are able to understand the needs of the study and perform tasks accordingly

The following are the constraints for both the caregiver interviews and the lab study

- For caregiver interviews
    - Participants should try and recollect their care recipient's functional ability and their caregiving needs
    - Participants should try and recollect the assistive devices used in the past during their caregiving duties
    - Participants should be able to convey what could help them in performing their caregiving duties much more efficiently
- For controlled lab study
    - Participants should be able to perform the three activities under test (simulate brushing, coffee making and simulate pills taking) in a closed controlled environment

6.2.2 Data instruments

This section discusses the different instruments used for collecting data from the interviews and lab study. They are as follows:

1. Screening forms

2. Interviews
3. Audio recordings
4. Sensor data

Screening forms are used to filter the participants for the caregiver interviews. It is important to recruit the right participants so that they provide valuable data about their needs and their care-recipient needs. It is also important to recruit someone with prior caregiving experience as only they would be in a better position to give me feedback on the system developed and also ways to improve it to make their life as well as the lives of their care-recipients better. Interviews are the best way to find the information needs of the stakeholders. By asking questions about their daily routine, their needs, their challenges of caregiving, their usage of technology and assistive devices, I was able to use the data collected to answer my research questions specifically RQ3, and also any design and technical challenges of using the functional assessment system in the real world. Audio recordings from the interviews helped me to find correlations between interview data from different caregivers and also to identify any common opinions, needs or concerns. It also helped to uncover hidden patterns or behaviors which might not be obvious when the interviews take place. Sensor data from the lab study helped to mitigate the risks of unconventional errors or problems with sensors and to identify if the sensors will work at every scenario. These tests help to provide the confidence for long term deployment in the future.

6.2.3 Interview and Lab Study Procedure

Caregiver Interviews: I recruited participants who are caregivers, healthy and are free of any cognitive impairment, for the interviews through a mix of social network, posting ads in multiple caregiver groups, contacting several agencies and through my professional network. All participants have at least a year of caregiving experience with some of those experience coming in the last 12 months. Using a screening form, 8 participants were short listed for the interviews. We decided to select 8 participants as we believed, it was sufficient enough to capture caregiver's needs and reactions of sensors embedded on daily objects. The screening form asks questions about their personal details including age, education and their experience with assistive devices in the past. It also inquires about their caregiving experience and their care recipient's level of functioning. Once the desired number of participants were found, all participants were debriefed about the study goals, what data would be collected, and items of the consent form. They were asked to read, ask any further questions and sign the consent form, if they agreed. The interview questions are divided into four different categories namely a) Identifying and describing assistive devices used, b) Identifying occupational performance, c) Identifying usage of sensors and finally d) Identifying unmet needs. Each section is in-depth and tries to get as much information as possible from the caregivers. The last two sections deals with mostly open ended questions, as they try to understand their perception of using the sensors and also about their needs. This is important because it helps to refine the current system to suit the needs of different stakeholders and ultimately enable it for long term deployment. The participants were also given the option to stop the interview at any point if they feel the need to do so. Each participant selected for the interview, was paid $30 for their participation.

Controlled lab study: I recruited 8 young adults who were healthy, free of any physical or cognitive impairment and who were able to perform the three activities (brushing, coffee making and pills taking) without any help. All participants were debriefed about the study goals, what data would be collected, and items of the consent form. They were asked to read, ask any further questions and sign the consent form, if they agreed. Once consented, they were briefed about the session, each participant was asked to perform the three activities correctly once and also one acted error on each of the activities. They were shown the devices, sensors and how they are connected and how to use them. They were instructed by the researcher at each step and they performed the activity as instructed by the researcher. For each session, the time when it started and when the session ended was noted down, together with what error each participant made for each of those activities. To test the sensors under different simulated conditions, each activity performance data was tracked and analyzed. This study helps in stress testing the sensors under different conditions which are not possible in ideal real world situations. The participants were also given the option to stop the lab study at any point if they feel the need to do so. Each participant selected for the lab study, was paid $10 for their participation.

CHAPTER 7

RESULTS AND DATA ANALYSIS

7.1 Results

The results for this thesis comes from three different sources of data collection namely a) sensor data from controlled lab study, b) responses and audio recordings from interviews with caregivers and c) sensor data, interview responses and audio recordings from case study with healthy older adults.

7.1.1 Controlled Lab Study

The lab study was conducted with 8 healthy younger adults at ASU. The average age of the participants was 27.8 and out of 8 participants, 3 were male and 5 were female. Each participant was first greeted, explained about the research study and their duties as a participant during the study by the researcher. They were asked to perform three different activities which are common daily routine activities of older adults aged 65 and higher. The three activities are coffee making, brushing and pill taking. For brushing, they were asked to simulate rather than actually brush. Each participant was asked to perform the activities correctly once as well as perform *acted errors* pertaining to each of the activities. The whole session lasted less than 30 minutes. Once the process was explained they were asked to read and sign the consent form. After signing the consent form, the researcher demonstrated to them how to perform each of the activities. The researcher instructed them which activity to perform, in what order and what acted error to perform on each of the three activities.

The order of these activities were

- Coffee Making – perform correctly
- Pill taking – perform correctly

- Brushing – perform correctly
- Coffee Making – perform an acted error
- Pill taking – perform an acted error
- Brushing – perform an acted error

The acted errors used for the study are as follows:

- Coffee Making
    - Forgot to add water
    - Forgot to add coffee powder
    - Forgot to close the coffee machine lid
    - Forgot to turn on/off the coffee machine
- Pill Taking
    - Open the wrong pill box
    - Do not close the opened pill box
- Brushing
    - Do not brush but move the toothbrush for a few seconds

The results of the controlled lab study demonstrates that the sensors are reliable, accurate and efficient in detecting activities of daily routine. The sensors were 100% accurate in detecting the different acted errors performed by the participants. Similarly it was 100% accurate in detecting the different activities performed correctly without any errors by the participants.

7.1.2 Case Study with Healthy Older Adults

The case study with healthy older adults aged 65 and over was conducted for a period of two weeks with each participant. The participants were recruited using flyers, professional contacts, and caregiver associations. 4 participants were selected for the case study using a questionnaire (see appendix) to screen them for best fit for this case study. Out of the 4 participants, two are male and two are female. Three participants were in the 60 - 69 age category while one participant was in the 70 - 79 age category. All participants were healthy and standardized tests - MMSE (Mini Mental State Examination) and TUG (Time Up and Go) (see appendix) were conducted with each participant before the start of the case study to ensure they were physically and cognitively healthy to participate in the study. All participants had scores of over 25 in MMSE, which indicates no cognitive impairment and TUG times of <12 seconds, which indicates no physical impairment. Except one, all participants lived alone in their respective homes.

Case Study - Participant 1 Results:

Case Study participant 1 is a male who lived alone in a two-bed apartment. The study was conducted for two weeks, with brushing, coffee making, medication adherence and dressing being tracked as part of the study. This participant had no trouble performing the dressing activity as part of the study with video cameras attached to the dresser. He was also comfortable using the wearable skin conductance sensor as part of the study.

During the pre-interview, the participant mentioned that he does not need any help in taking his medications, making coffee, brushing or dressing; he does not use any assistive device for any of those activities as well. He also felt that it would not be helpful at this point of his life to use an assistive device. He was quite comfortable with having sensors attached to his daily objects. He did not have any difficulty in performing any of his daily activities independently. For the question, if there was a functional assessment system which tracks performance of daily activities through sensors embedded onto daily objects, what do you expect from such a system? He responded that for a long run, he would watch for his deterioration and he would like to see if he is slower, clumsier or more forgetful in the future. He did not like the idea of sharing his activity performance data with his loved ones or clinicians. He liked the idea of the system giving suggestions based on activity performance and he was not interested in tracking the information on a daily basis. He would like to check the data maybe once a week or once every two weeks. Privacy was more important to him than independence and he said he would be comfortable using a wrist worn sensor if it were pretty.

Brushing: the sensor, which was attached to the toothbrush to track the time they brush and how long, worked flawlessly. There was no problem with the sensor however the participant felt slightly uncomfortable using the toothbrush as the sensor was attached to the toothbrush (Figure 19). The sensor was accurate in detecting when the toothbrush was moved and for how long.

Coffee Making: with respect to the coffee making activity, there was no data recorded from the x10 sensors on 2 days during the study period. The cable that was connected to the server for receiving x10 signals was disconnected and the participant did not notice it for 2 days. Once he noticed it, it was fixed and there were no further problems with transmission. There was no problem related to the wireless sensors that track the temperature (to detect on/off), moisture (to detect adding water task) and brushing. Other than the two days of x10 inactivity, the rest of the sensors worked perfectly and the participant performed all his tasks every day without fail during the period of this case study.

Medication Adherence: with respect to taking pills, there was no problem with the sensors and it worked flawlessly. One interesting feature of the participant's medication adherence is that there was no regular time for this activity and it fluctuated drastically, with difference as high as 8 hours between successive days.

Dressing and Skin Conductance Sensor: The participant performed dressing on most days during the case study period (based on his feedback). There was not sufficient data to analyze and study participant's dressing style since the location of the person and lighting of the room determines how efficient the data is captured by the sensors, camera and the software. With respect to the skin conductance sensor, the sensor stopped working after just 2 days as the battery ran out. This was completely unexpected as we expected the battery to last longer. They were asked to use the wearable sensor only during any of the 4 activities but what we did not foresee if that the software was constantly communicating with the sensor and this drained the battery. From the data that was captured, there was no anomaly.

During the post-interview, the participant mentioned that there was nothing he liked or did not like about objects attached with sensors. If he were given an opportunity to change the way it was designed or used, he would probably change the way the toothbrush sensor was used. He felt it looked a little awkward. He also felt the sensors and cameras attached to the dresser did not bother him too much however he felt if it could be less visible or hidden completely, then it would have been better. He reported that he would also be comfortable if the system gave him guidance using audio prompts to perform any of his daily activities. Apart from the four activities that were tracked as part of this study, if given an opportunity, he would like to monitor his cooking. He felt the system was pretty non-obtrusive and he just did what he had to do and went on with his day. He felt the way the information is accessed currently could have been better. He felt that he could not figure it out from the way it was setup and it needs to be simpler. In simple terms, he did not like the idea of going to the computer and trying to figure out how he is performing on his daily activities. He also thought having audio prompts when the system finds an anomaly is very useful rather than going to the computer to look for it.

Case Study - Participant 2 Results:

Case Study participant 2 is a male who lived alone in a one-bed apartment. The study was conducted for two weeks, with brushing, coffee making and medication adherence being tracked as part of the study. This participant who initially volunteered to perform dressing activity as part of the study, chose not to perform dressing as the presence of cameras in the dresser was emotionally overwhelming, making him feel that it would be a violation of his privacy and thus he chose not to continue the use of them. Hence, dressing was removed from the study for this participant and the rest of the three activities were included. He was comfortable to use the wearable skin conductance sensor as part of the study.

During the pre-interview, the participant mentioned that he does not need any help in taking his medications, making coffee, brushing or dressing; not does he use any assistive device for any of those activities. He was quite comfortable with having sensors attached to his daily objects. He did not have any difficulty in performing any of his daily activities independently. However, he does have trouble putting on his shirt because of a shoulder problem and he felt that if there was an assistive device to help with his dressing, it would be good and anything that could help him avoid the pain would be welcome.

For the question, if there was a functional assessment system which tracks performance of daily activities through sensors embedded onto daily objects, what do you expect from such a system? He responded by saying he needs total transparency and in the future he would like to monitor if he left the stove on, if he left the refrigerator doors open, monitor temperature to make sure it’s not too hot or cold inside the house. He also wished to have a device that does not let the water in the shower gets too hot. He preferred to have a mild alarm to indicate that something is out of the ordinary and he needs to take notice Or depending on where he was, maybe a small light to remind him. He did not like the idea of sharing his activity performance with his loved ones or clinicians. He liked the idea of the system giving suggestions based on activity performance as he mentioned that if it was the choice of that or being put in a nursing home, he would gladly accept computer aid before he would accept a personal aid. He was not looking to track the information on a daily basis. He would like to check them maybe once a week or once every two weeks. Independence was more important to him than privacy and he said he would use a wrist worn sensor if it were comfortable to wear.

Brushing: with respect to brushing, the sensor which was supposed to track what time they brush and how long, stopped working after just a day. The sensors were waterproof but somehow the circuit board inside the closed casing got damaged and it could not be recovered in time to make it work during the time of the study for this participant. While the sensor was working, it was accurate in detecting when the toothbrush was moved and for how long.

Coffee Making: with respect to coffee making activity, there was no data recorded on 3 days during the study period. In addition to that, there was no data recorded related to the wireless sensors that track the temperature (to detect on/off) and moisture (to detect adding water task) on 3 other days. Similarly, there was no data recorded related to the x10 sensors that were attached to the coffee lid (to detect open / close) and the drawer containing the coffee powder for 6 days during the study period. The reasons for failure are unknown, considering that the wireless sensors worked few days before and after the problem occurred; a possible reason could be that the receiver was not connected to the Internet or possibly problems with the Internet itself. With respect to the failure of the x10 sensors, the only plausible reason could be that the cable, which contains the antenna to receive those signals, was not connected properly or disconnected. Overall, the system to detect coffee making worked flawlessly only for four out of the 14 days.

Medication Adherence: with respect to taking pills, there was no data for 6 out of 14 days, due to the cable that is responsible for capturing x10 events being disconnected. Before we could identify the problem and rectify it, we lost 6 days' worth of data from the x10 sensors. One interesting feature of the participant's medication adherence is that there was no regular time for this activity.

Dressing and Skin Conductance Sensor: The participant did not perform dressing during the case study period. With respect to the skin conductance sensor, the sensor stopped working after 2 days as the battery ran out. From the data that was captured, there was no anomaly.

In the post-interview, the participant mentioned that he did not know if there was anything he liked or disliked about the system. He said the sensors needed some getting used to visually, other than that; there was no discomfort in using them. If he was given an opportunity to change something about the sensors or the way they are used now, he reported that he would make them more transparent. By transparent he meant knowledge of where the sensors are, what they do, what information they capture and how it is stored and shared (if any). One thing that he was totally uncomfortable with, was having video cameras attached to the dresser to track his dressing activity. He reported, "The cameras freaked me out. It felt like a horrible invasion of privacy and that he would not have expected that before". This was his experience at the beginning of the study and before the dressing activity was initiated as part of the study. His privacy was not invaded or compromised in anyway. Regarding the wearable skin conductance sensor, he mentioned "it was uncomfortable and it was hard to keep it from slipping. I had to make it tight so it would not slip and then when you made it tight, it got uncomfortable. It could be something much lighter and I was constantly afraid of getting it wet". When asked about the resource provided to track his activity performance, he replied, "No, I forgot all about it. No, I mean it was fine. I don't know if there is any information in it that looks like, "oh I did not realize that". However he did want to change few things with the way the resource was accessed or information was delivered if he was to use it in the future. Instead of having to go to the computer to look at it, he would like to have some kind of auditory feedback that said, "Hey Dan, you made a mistake for two days in a row". He felt it had to be a gentle statement with a female voice. He also gave insight into how he wants the future of smart homes to be. He suggested he would use his voice to talk to an intelligent automated assistant, something like a 'Siri' on Apple's iPhone and say something like "Oh Siri, remind me when I go out to lock my doors" and where it can remind him to do certain tasks or remind him about his appointments. Being transparent was his number one requirement from a functional assessment system. He believed that the more transparent it is, the more accurate data you get.

Case Study - Participant 3 Results:

Case Study participant 3 is a female who lived along with her sister in a two-bed independent home. The study was conducted for two weeks, with brushing, coffee making, and medication adherence being tracked as part of the study. This participant was not comfortable performing the dressing activity with video cameras attached to the dresser; thus, dressing was removed from the list of tracked activities. She was comfortable using the wearable skin conductance sensor and hence that was included in the study.

During the pre-interview, the participant mentioned that she does not need any help in taking her medications, making coffee, brushing; she does not use any assistive device for any of those activities as well. She was quite comfortable with having sensors attached to her daily objects. She did not have any difficulty in performing any of her daily activities independently. She was not comfortable with having sensors and cameras attached to the dresser and hence dressing activity was removed from the study. For the question, if there was a functional assessment system which tracks performance of daily activities through sensors embedded onto daily objects, what do you expect from such a system? She responded saying "If I were living alone and I want to stay living alone and my kids are close by or not, I would want them to know if I am in trouble". She said that she sees value in the system, particularly for people who are living alone and want their independence and it is their job to care of their kids and not vice versa. She did like the idea of sharing her activity performance data with her loved ones or clinicians but only if she is in trouble. She also wanted to have a device that can identify if a person is depressed by monitoring how much they sleep. She liked the idea of the system giving suggestions based on activity performance and she was not looking to track the information on a daily basis as that would be irritating and annoying to her. Independence was far more important to her than privacy and she said she would be comfortable to use a wrist worn sensor if it's small and light weight.

Brushing: with respect to brushing, the sensor, which was attached to the toothbrush to track the time of brushing and duration, did not work for one day. On that day, the wireless receiver was disconnected and hence there was no data transmitted to the server. Other than that, there was no problem with the sensor. The participant found the sensor hanging from her toothbrush amusing and took extra care to make sure it was not damaged in anyway. The sensor was accurate in detecting when the toothbrush was moved and for how long.

Coffee Making: with respect to coffee making activity, there was no data recorded for 1 day during the study period. On that day, the wireless receiver was disconnected and hence there was no data transmitted to the server. Once the researcher noticed it and informed the participant, it was fixed and there were no further problems with transmission. Other than this one particular anomaly, the rest of the sensors worked perfectly and the participant performed all her tasks every day without fail during the period of this case study.

Medication Adherence: with respect to taking pills, there was no problem with the sensors and it worked flawlessly. One interesting feature of the participant's medication adherence is that there was no regular time for this activity as is commonly found with other participants of this study. The time when they take their medications fluctuated every day, shifting between morning, evening and night.

Dressing and Skin Conductance Sensor: The participant did not perform dressing during the case study period. With respect to the skin conductance sensor, the sensor stopped working after 3 days as the battery ran out. From our earlier results with participant 1, we expected the battery to not last longer than few days. From the data that was captured, there was no anomaly.

During the post-interview, the participant noted that she liked the pillbox very much as it helped her to know if she has taken those pills. It was the most valuable thing for her. She did not like the sensor attached to the cabinets as it interfered with her opening up cabinets. It was not installed in such a way that it could interfere, but the participant took extra care to ensure she did not damage the sensor and that prevented her from using the cabinets as she would normally do. For the question if given an opportunity to change something with the sensors or the way they are used now, she wanted to make them smaller. She does not want to have the system give her guidance to perform her daily activities. Regarding using a wearable device, she reported, “If I have to wear it all the time, it would have to look better”. She does not want to track her activities every day, rather would like to do it periodically. The two things that she wanted that was not part of the existing system was to check if the doors are locked and to check if the stove is turned off. She also wanted to make sure the sensors are smaller and it is easy to attach and remove them without causing much damage to the environment.

Case Study - Participant 4 Results:

Case Study participant 4 is also a female who lived alone in a two-bed independent home. The study was conducted for two weeks, with brushing, coffee making, and medication adherence being tracked as part of the study. This participant was not comfortable performing the dressing activity with video cameras attached to the dresser so dressing was removed from the list of activities to be tracked.

During the pre-interview, the participant mentioned that she does not need any help in taking his medications, making coffee, brushing; she does not use any assistive device for any of those activities as well. She was quite comfortable with having sensors attached to his daily objects. She did not have any difficulty in performing any of his daily activities independently. She was not comfortable with having sensors and cameras attached to the dresser as well as using a wearable skin conductance sensor and hence dressing activity and usage of skin conductance sensor was removed from the study. For the question, if there was a functional assessment system which tracks performance of daily activities through sensors embedded onto daily objects, what do you expect from such a system? She responded with "If I were having difficulty with something, it would let me know why". She said that she sees value in the system. She did like the idea of sharing her activity performance data with her loved ones or clinicians but only when she is in trouble. She liked the idea of the system giving suggestions based on activity performance. Independence was more important to her than privacy.

Brushing: with respect to brushing, the sensor, which was attached to the toothbrush to track the time and duration of brushing, did not record any data for 5 days during the study period. On inspection, the sensor seemed to have lost signal with the receiver and it had to be manually reset and connected to the receiver again. The time it took to find out the problem and resolve cost us 5 days' worth of data. There is no known way to ping (communicate) with the sensor from outside of their web interface and because of this restriction, there was no alerts setup for notifying the researchers about failure. There was no other problem with the sensor however the participant felt slightly uncomfortable using the toothbrush as the sensor as it was attached to the toothbrush with a thread (Figure 19). The sensor was accurate in detecting when the toothbrush was moved and for how long.

Coffee Making: with respect to coffee making activity, there was no data recorded from the wireless sensors on 5 days during the study period. The same problem that happened for the sensor with the toothbrush happened here as well. For some reason, the sensor lost its signal and it had to be manually reset to connect it to the receiver again. Once she noticed it, it was fixed and there were no further problems with the sensor. Other than the one anomaly, the rest of the sensors worked perfectly and the participant performed all her tasks every day without fail during the period of this case study.

Medication Adherence: with respect to taking pills, there was no problem with the sensors and it worked flawlessly. As commonly found on other participant's medication adherence, this participant too did not have a schedule for taking her pills. The time of her taking pills varied every day.

Dressing and Skin Conductance Sensor: The participant did not perform dressing and also did not use the wearable skin conductance sensor during the case study period.

During the post-interview, the participant mentioned that she was not bothered by any of the sensors that were placed in her home. However, given an opportunity to change something, she would make the attachment that holds the sensor and the toothbrush smaller. She also mentioned that she would like to see a device that can measure her blood pressure and a way to monitor its status.

7.1.3 Interviews with caregivers of older adults

There were 8 caregivers recruited for the interviews and they have been selected to participate using flyers, professional contacts and caregiver associations. Out of 8 participants, 7 are female and 1 male, each caregiver recruited for the study is healthy and free of any cognitive impairment and has had at least 12 months of care giving experience with some experience in the last 12 months. Each caregiver was shortlisted using a screening form (see appendix). The screening form asks questions about their care giving experience, their education background, how much they spend on care giving each day, their comfort level with technology and the care recipient's functional ability as well. The results from the screening form are consolidated and explained below.

Screening Form Results

Out of the 8 participants two were in the 20-29 age category, two in the 40-49 age category, one each in the 50-59, 60-69, 70-79 and 80 or older category respectively. All caregivers have some basic college education with one person having a post graduate degree (PhD). The experience of caregivers ranges from 2-11 years with an average of 5.5 years. Three participants were taking care of their mother; two were taking care of their spouse while the remaining three had no direct physical relation to their care recipient. The caregivers who have a relation to their care recipient spent an average of 8-12 hours per day in caregiving while the remaining three caregivers who do not have a relation with the care recipient spent between 2-24 hours per day in caregiving. One caregiver spent 2 hours and another spent 24 hours per day in caregiving, the last caregiver spent 6 hours per day on average. Out of the 8 caregivers interviewed, 7 caregivers were taking care of a female while 2 were taking care of a male care recipient. One caregiver was taking care of both a male and a female. The age group of 8 of the care recipients was in the 80-89 category while one care recipient was in the 70-79 age category.

The caregivers indicated that 6 of the care recipients had problems with memory, the most common being dementia. While the rest of the care recipients had some kind of physical impairment that prevented them from performing their daily activities independently. All caregivers know how to use a computer and a cell phone, and all caregivers except one were comfortable with using or trying new technology. With respect to the care recipient's functioning, 6 out of 8 have problems with memory and disorientation (to person, space/time, visual etc.). 4 out of 8 had personality changes such as irritability, poor temper control, anxiety etc. and 4 out of 8 had communication difficulties (absent or impaired language abilities, difficulty with word finding and expressing needs etc.).

Caregiver Interview Results

The results of the interviews with caregivers consisted of their responses in digital form as well as audio recordings of the interview. The interview itself was divided into different sections. The first section is about identifying the different assistive devices that is being used for caregiving, the second section is about identifying occupational performance (how they perform their daily activities), the third section is about identifying usage of daily objects which are embedded with sensors and/or those which are wearable. The last section is about identifying their unmet needs as a caregiver and also to get their feedback on the functional assessment system.

a) Assistive devices Used

The first set of questions were related to medication reminders, (Figure 29), half of the participants did not use any device for assisting them in their care recipient's medication adherence. Among the group that did not use a device, the most common reason (75%) for not a device was that they "have not heard of any assistive device" for this purpose. However everyone agreed that it was useful to have an assistive device for this activity and if they knew of one, they would use it.

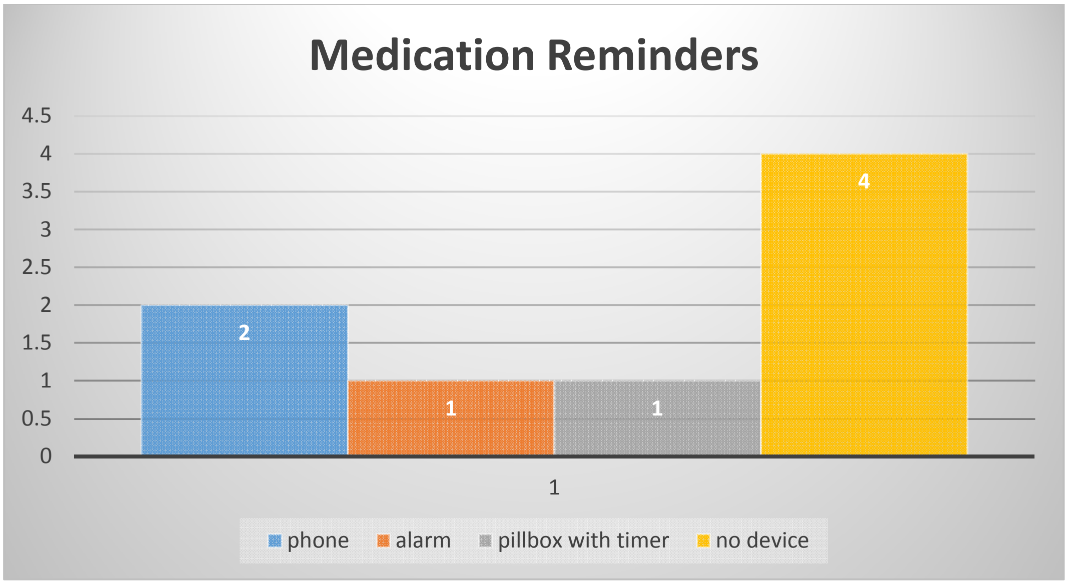

Figure 29. Medication Reminder Usage

The next set of questions in this category was about reminder systems (these are large category of devices. For example, auto shut off kettles or stove minders fall under this category, as do devices that play a short recorded message that can give prompts and reminders. More sophisticated memo minders can play messages when movement is detected (for example, if placed by the front door it can remind a person to lock the door or to not leave the building). One participant used a timer to remind her of her caregiving duties while the rest did not use any reminder systems. The majority, 62.5% of the participants said they have not heard about any assistive device in this category while the rest said it does not apply to their caregiving role. As with medication reminders, everyone agreed that it is useful to a reminder system for their caregiving, and everyone except one said they would use it if they were given a reminder system. The one person who said she would not use it, gave the following reason:

"It is useful for beginners, for those who are experienced caregivers, it might not be useful and for that reason I would not use it".

The next set of questions in this category was about signs, notices and environmental aids (these are simple visual aids that remind people to do things). 62.5% of the participants said they do use notices around the home for reminding them to perform tasks, while 37.5% said they do not use any environmental aids. Everyone agreed that it is useful to use one for their caregiving, and they would use it if they were given an environmental aid which is **simple to use.**

b) Occupational Performance

The first set of questions in this category asked what activity was most difficult for their loved one/care recipient to perform. Bathing was the most difficult activity for the largest number (4 of 11), followed by dressing (3 of 11). Four individuals each felt that incontinence, walking, getting out of bed, and housekeeping/laundry were their most difficult activities, respectively.

Half of the care recipients/caregivers did not use any form of assistive device for their most difficult activity. While the rest use some form of assistive device ranging from simple tools like a cane to more sophisticated tools like lift chairs. All the caregivers who use some sort of assistive devices said they use them every day and they all unanimously agreed that it is useful to have an assistive device for the care recipient's most difficult activity and if they were offered one, they would use it. However one caregiver mentioned that she would not use it. She said,

"A lot of care recipients are quite stubborn, probably if they see it and like it, then they might use it"

The next set of questions in this category was about the most difficult activity for the caregivers to provide support. Bathing, transferring, and medication management seemed to be the most difficult for them. Followed by eating, toileting and leaving them alone.

Three caregivers used some sort of assistive device for their respective most difficult activity, which were transferring and bathing. The two caregivers who used assistive device for transferring used a Gait belt and a Hoyer belt. While the third caregiver used grab bars and shower benches as assistive devices for bathing. All caregivers said if one of these assistive devices were given to them, they would use it. Two caregivers who were using Gait belt and Hoyer belt said they liked using them because it is much safer and the electronic ones are easier to use. One thing, they did not like was the manual ones, which were bulky, and harder to use.

The following positive attributes were mentioned by caregivers who used an assistive device for patient transfer:

1. *"It was a safe way to transfer and not injure anyone. The electronic one was much easier. I do not like the awkward size of the device"*
2. *"Electronic ones are simple to use, you can adjust the position. They are great"*
3. *"Grab bars allows them to be more stable. Chair allows them to sit down while bathing"*

While there were some negatives too about the device they were using. It is listed below.

1. *"The awkwardness of the size of the device (Gait belt and Hoyer belt) makes them difficult to use"*
2. *"The manual ones (Gait belt and Hoyer belt) are harder and trickier to use"*
3. *"They are big and bulky – (shower benches)"*

c) Sensors embedded onto daily objects

The first set of questions in this category was about a care recipient's comfort level in using objects embedded with sensors and their feedback on the design of the existing system. Half of all the participants said having sensors attached to objects might be a discomfort to their loved ones / care recipient. Dresser with camera was the main reason for their answer. They said having a camera might make them feel like they lost their privacy and /or make them paranoid. Except one caregiver, the rest have not seen any daily objects that has sensors attached to it. 37.5% (3/8) of caregivers said there is nothing that they did not like about the idea of having sensors embedded onto objects of daily use if it helps them with caregiving. While the rest had problems with it. Some responses of the caregivers who had problems with sensors are listed below

1. "T*he only thing that I would be concerned about is whether or not they are bulky or difficult to use*"
2. "*It would be better if it was cordless, and it would have a device in the toothbrush. Make it wireless*"
3. "*It has to be accessible but not visible to the participants otherwise there may be questions or they might ignore them. Each individual has their own little thing that bugs them about something. If they don't see it great*"

Fifty percent of the caregivers said they don't want to change anything with the way the sensors are used now. While the rest had suggestions or requirements, examples of which are listed below.

1. "*Make the toothbrush wireless, I think the cameras are intimidating so make them invisible*"

2. "*It would be nice if the system could control the amount of medications that could be taken from the pillbox, it is only two medications per day. So my mother takes like four times*"

The next set of questions in this category was about the sensors attached to the dresser for detecting and tracking dressing activity. Only two participants said that the sensors on the dresser will not bother their loved one / care recipient. The rest had strong opinions or concerns about having sensors, e.g. including cameras in their dresser. They are presented below.

- "*Cameras as intimidating, she will feel she will lose privacy"*
- "*Cameras yes could be a problem. That would confuse more as they would think someone is watching them dress*"
- "*If they know it's a camera, it will bother them. They are not used to cameras and technology*"
- "*It will bother them, it will make them think they are being watched*"
- "*It's a good idea, maybe it does not work with my mom. She takes the clothes in one drawer and puts it another drawer for no reason*"

The majority, 5 out of 8 participants said they were comfortable in having a video camera attached to the dresser for tracking the dressing activity. However, they were concerned about the privacy of their loved one / care recipient with having video cameras attached to their dresser and wanted the cameras to be hidden. One participant who was concerned said that if her mother knows it does not record, then she would not be concerned. When asked about what would they liked to change with the way the dresser is designed now, given an opportunity, 3 out of 8 participants said they would not change anything with the dresser. While the rest had the following comments to say.

1. "*Make the camera hidden, where you don't see them all the time*"

2. “*Try to morph it or change so that it is not obvious*”

3. “*Make it invisible of sort, hide it*”

4. “*Make it hidden*”

5. “*Have big labels on the dresser*”

It was not unexpected that having a video camera would be a sensitive issue considering the concerns of privacy; the responses validated this hypothesis. Most caregivers did not want the cameras to be seen and want it to be hidden or not visible to their care recipients. Having video cameras was their main concern with the way the dresser was designed currently. One important aspect and constraint from the current design of the dressing system is that the user has to be constantly present in front of the dresser for the system to work effectively. Half of the caregivers mentioned that it could be a discomfort to their care recipients if they were restricted to a confined space. One caregiver remarked “*If there was a mirror, then it would be okay*”, as she needs to see the mirror when she is dressing or after she gets dressed. Another caregiver remarked “*it might be uncomfortable for them as lot of seniors are weak*”. Other remarks included “*It would not work as they cannot remember to stand in a place*” and “*put the dresser by the bed*”. For the question “Do you think it would benefit your loved one if the system gave guidance (audio prompts) to perform activities of daily living? Especially the following (dressing, brushing, coffee making and pill taking)”, 75% of the participants said it would help their care recipient if the system gave voice guidance. While those who said it would not help had the following comments:

“*She cannot distinguish between reality and non-existence and she would not be able to distinguish computer voice from human voice*”

“*That would scare them because they would hallucinate*”.

One participant who thought it would help her care recipient said it would not work with the dresser as it might be uncomfortable for them.

Wearable Sensor

Seventy five percent of the participants said that it would be comfortable for their care recipient to use a wearable sensor around their wrist. While the rest were not so sure. One participant remarked "*Some sure, others will not be comfortable, it will hurt their pride*". While another participant remarked "*It might make them uncomfortable if it's too big*". Regarding the question about having the wearable sensor on a different part of the body such as an ankle, 75% of the participants preferred having it on their wrist. One participant explained that having it on their ankle is uncomfortable because "they might think they are under house arrest or something" while another participant who was in favor of having it in their ankle instead of their wrist noted having it on their wrist could make the care recipient curious about the device. There were three suggestions to change the way the wearable sensor is designed currently too. One participant mentioned making it smaller like a bracelet might be a good idea. While another participant remarked "She likes to wash dishes so it could be wet, it is safer if it is on the ankle or make it water proof". Another suggested to make it look like a watch.

Resource to track activity performance

All participants agreed that the user interface provided to track activity performance was useful and they would use it. One participant remarked "*Yes, it aids the caregivers in showing the care recipient factual information. They would not dismiss it because it is an observation not an opinion*". Another participant mentioned "*Yes, it could benefit both the care givers and the care recipients*".

All participants unanimously agreed that the resource provided was useful to them in taking care of their loved ones better. However, they mentioned that it might overwhelm the care recipient. For most care recipients who are at later stages of Alzheimer's or dementia, processing all the information might be overwhelming. However for the caregivers themselves, they said it was not hard to understand and it does not overwhelm them. One caregiver remarked "*Depends on how you use it. If she uses every day, then it can overwhelm her. She is active with technology and she might like it. The level of detail which is presented*". Another caregiver mentioned "*Yes where my mother is in now, it would overwhelm her. For people in earlier stages of dementia, it would not*".

When asked about what they would like to see apart from what is presented, they wanted the following to be tracked and displayed

- Icons, smileys, make it friendly
- Check if the doors are locked at night, stove sensors.
- Identify care recipient's emotions
- What is she doing, where she is, did she change her clothes, did she bath, did she go to the bathroom, any of the ADLs, did she try to get out of the house

Participant were asked about the changes they would like to make to the existing user interface which displays activity performance. One participant wanted the following changes to be made "*Icons, color – green for complete, yellow for incomplete, red for no activity*". The same participant also concluded the category with this comment "*It is something that someone has to get used to. You must be very careful on how it is introduced, for both the client and the caregiver, it has to be their idea for a need, and it must be very attractive to use*".

d) Identify Unmet Needs

In the final category of questions, the participants were asked about their unmet needs and how the system could be modified, updated, or extended, in the future to help satisfy those needs. The first question asked in this category was to identify one activity that has been most impacted by their loved ones physical or cognitive impairment and one that they feel is a challenge to provide support or one where they have little or no support for. The answers provided by the participants are listed below.

- Bathing--lots of problems with falls (provided by two caregivers)
- Financial matters--no access (provided by paid caregiver)
- Transfer
- If bed ridden, a device to lift and move them
- Wandering during the night
- Hardest is to do my own personal things, take care of my health
- Time for personal activity

The next question was to identify what kind of assistive device they would want to build for themselves, if they were offered an opportunity to build one just for them and their loved one. They were asked to imagine that they have all the resources in the world – no constraints on money, expertise, practicality or time. The following are the different "dream" assistive devices they would like to build for themselves.

- A device to monitor the care recipient without me being physically present, just to identify how she does independently
- A device that could automate the process of transferring
- A device that could lift the body and rotate the leg over – for transferring
- Check for wandering
- Bathing

- Monitoring device so that the care recipient could be left alone and feel comfortable that she has this device and it could take care of her
- Location tracking, where she is and what she is doing

To identify their needs and expectations of a functional assessment system, a system which tracks activity performance by attaching sensors onto objects of daily use, we asked each participant for their needs. Their responses have been listed below.

- I expect the sensors to be hidden, not visible
- Longevity, light weight, different options (wrist, ankle)
- Track walking, stove
- Track how many times she wakes up during the night, how many times she moves, when she needs to change clothes, track their behavior, and sleep activity
- Something that could make my mom self-sufficient, do things on her own
- Track health status and location

Once they had listed the kinds of activities they would like to track, the next question was to identify their information needs. What kind of information they would like to see from the system if it were to track those activities. The information needs of some of the caregivers are listed below. The rest of the caregivers could not think of any new information to be displayed.

- Emotional state, while doing activities.
- Information about Stove, lights, door, conducive to their lifestyle

One participant mentioned "*More information would be excellent*" but did not specify further.

Only one participant said she would prefer a computer as her primary source for information to be delivered. All the rest of the caregivers said they prefer either a mobile phone or tablet. Everyone agreed that sharing the information the system has captured of their functional performance is useful and they would prefer that. Everyone also agreed that it will be helpful to them as well as their care recipients if they had suggestions from the system regarding their task performance through audio prompts. 75% of the participants said they preferred information to be sent to them every day while the remaining 25% preferred to monitor the tasks on a weekly basis. 25% of the participants said it might not be helpful for their care recipients if the system gave guidance in performing the tasks. One participant remarked "*She probably won't use it, the guidance will make her feel like she is losing independence*". While the rest 75% said it would be useful and helpful to have guidance for their care recipients.

Independence vs Privacy - 75% of the participants noted that independence is more important for their care recipients. While privacy accounted for the remaining 25%. This was an interesting observation since everyone was aware that as they get older, they have to let go either of privacy or independence (in most cases) or both (in some cases). Most preferred independence over privacy. When they have a caregiver, they are already in a state of mind where they have accepted lack of privacy however they wanted to still perform their tasks independently (provided they are physically and cognitively able to).

All except one of caregivers were favorable to having sensors embedded onto objects of daily use in their homes for tracking subtle cues of functional decline. The one person who was not comfortable said it does not work anymore as her mother was in the late stages of dementia and any level of technology would not help her at this stage. When asked about how we can improve the current system in their opinion, one caregiver remarked "*Make the data more colorful – icons, smileys etc. make toothbrush wireless, cameras hidden*". Another caregiver remarked "*Maybe a lock on the pillbox, controlling how many pills they can take*". The next question's focus was to identify what in their opinion, the system lacks that could help them take better care of their care recipient or loved ones. The following responses were given by the caregivers for the question.

- "*How to identify what pills they are taking and if they did take the pills? If there are multiple pills in a single box, how do you know if they took one pill? Reminder for prescription pills, reminder to tell you when you are out of pills, written not verbal*".
- "*More sensors to track more activities"*
- "*More activities to track*"
- "*They are only as good as the information they provide, they should be reliable"*
- "*Detect temperature of her body as well as the room, if she is cold, she does not do anything"*
- "*Maybe a way to help with incontinence by providing audio prompts"*

The interview concluded by asking them if they had any general comments and one caregiver gave the following comment "*What if they are not coffee drinkers? Have dentures? We want data to prove it and support caregivers. If the caregivers are not related, share it with the family / doctors. Care recipients lie so you need data to support it. It has to be a positive experience not a negative. Make them embrace it. Present it in a way that tells them that it is to help them and their family*".

7.1.4 Results Summary

From the results of the three studies, it is clear that the sensors used for this study are not sufficiently reliable for long-term home deployment, even though lab studies demonstrated their accuracy and short-term reliability. Real life in-home deployment present unique challenges and require creative solutions. There needs to be some way to monitor the status of the sensors within different objects, identify any problems that arise and fix them at the earliest opportunity, without seeking assistance or encumbering users at home. The process of identifying errors and rectifying them should be automated and should be done either by the researcher or by the system. Prior research shows that expecting caregivers or the care recipients to perform additional tasks is not a viable approach. With respect to the different activities investigated in these studies, medication was by far best received by the users and performed reasonably accurately compared with the other activities. The sensors were not 100% reliable for coffee making and teeth brushing activities. Dressing was used by only one participant and hence did not yield sufficient results for analysis, while skin conductance sensor's battery did not last for more than 2 days in these trials.

From the interviews with caregivers it was clear that to capture the perception of any product it is important to have prior experience with the product or a similar product or experience. Most caregivers mentioned that they do not use any assistive technology and would love to try these if given an opportunity. It was also found that the most important factor in technology adoption was to help the users (care recipients) use it. It is important to ensure that the choice of accepting to use a product was given to the care recipient rather than forcing them to use one. Also, another important concern among caregivers and care recipients alike was the need to be independent. If the technology gives them independence, they would be more than willing to give it a try. Almost all caregivers were against the placement of cameras with dressing activity, they were comfortable to have them if it was hidden from view. Similarly, most caregivers felt that voice guidance during activities would be helpful for their care recipients in performing their daily activities independently. With respect to unmet needs, the most common need was remote monitoring, tracking location and emotion state.

7.2 Data Analysis

7.2.1 Lab study

From the results of the lab study, it is quite clear that the sensors work well in a controlled lab environment. Both the x10 sensors (used in pillbox, coffee lid and drawer containing coffee powder) and the wireless sensors (used in toothbrush, and coffee maker) worked flawlessly without any problems under different conditions and the software developed to capture data from these sensors and display accurate information to the users worked well too. It is important to note that for the wireless sensors to work accurately, it needs to have a good wireless network and constant network connection. Similarly for the x10 sensors to work correctly, the antenna that is connected to the central server via a cable must always be connected. Both kinds of sensors work need a battery and it is important to check the status of the batteries regularly for efficient uninterrupted transmission.

7.2.2 Case Study

It was clear from the results of the case study with 4 healthy older adults that there are some environmental and behavioral challenges in making sure the system performs as intended and is being used to its full potential. The two challenges that were common among the participants are a) sensors losing signal from its receiver and b) sensors unable to communicate, rendering it useless. For the first situation, if we reset the sensor and re-connect it to the receiver, we can solve the problem. However for the second scenario, the sensor was completely dead and a new sensor had to be used. In the study with 4 people, one motion sensor and one moisture sensor was completely dead and a new one had to be purchased for further studies. The source of the problem could not be identified as both the sensors were supposed to be water proof and the participants were not aware of the problem until informed by the researcher. Other than this, there were other environmental problems as well. In participant 1's home, the router's setting prevented the REST service (the internet architecture parameter that was customized to enable logging of data to a server) from calling the custom URL, thereby preventing it from logging the data. In participant 3's home, the wireless network was disconnected a few times and this again prevented it from logging the data. Similarly, on some participant's home, the x10 sensors were dislocated from its original position for a few days and that prevented the system from detecting the user actions. In all the above scenarios, the participants were not aware of the problem and that resulted in loss of data. There was no problem with the battery on any of the sensors and they lasted for the entire duration of the study period on each participant's home.

Except one participant, all others declined to perform dressing activity as part of the study and be tracked for its performance. The two female participants declined at the onset due to the presence of video cameras on the dresser. While Participant 2 who initially was fine with performing dressing activity, declined to continue further unless the cameras were removed. In the two days when the dresser along with the video cameras were installed in his home (the cameras were not tracking anything and the study had not started yet), he felt an emotional response to the presence of those cameras and he felt a strong violation of his privacy which he had never thought he would experience before. Upon his request, the cameras were removed and dressing was removed from the list of activities being tracked for his participation. This is an important finding because it shows how our perception and emotion can change in a matter of a few days. The participant was well versed with technology, has experience building assistive technology for the disabled and had no trouble with video recording as well but his change of heart was shocking and surprising to him. This example shows that we should take extra care in designing technology for older adults considering their experience with technology, education, personality and their functional ability.

Another finding from the case study was that not everyone who participated in the study checked the user interface provided to them to monitor their activities. All participants inherently believed that they were not going to find anything new or important by monitoring their performance. They all agreed that it is important to have the resource to track their activity performance but not at this point and they would not do it on a daily basis. This is interesting considering that the expected answer to RQ6 "Does providing real time feedback on user's performance help stakeholders by increasing awareness and in providing timely interventions?" was YES, it helps to improve awareness and the feedback that we got from the participants was contradictory to the expected answer. They however wanted real time feedback through audio prompts if the system found something out of the ordinary (an anomaly) and then they could go to the resource and identify what was the anomaly and the reasons for it. This gives us valuable information in the way the information captured is presented to the user. Information delivery is an important aspect of any functional assessment system because if you cannot present the information at the right time and the right way, then the goal of the system will likely not be met.

One important aspect of the system was its ability to capture indicators of emotional state and compare that with the activity performance to identify if there is any correlation. However, the system failed to do so as the battery did not last for more than 2 days during the study. Since the software to capture skin conductance values has to be run continuously for 24 hours each day, it put enormous amounts of stress on the battery as the sensor is continuously communicating with the server for status. This was unexpected and prevented us from capturing more information about emotional levels during the activities. This is certainly an important constraint for the possibility of capturing emotional state to assess functional abilities in the future. There is huge potential and need for capturing emotional level of individuals as reported by caregivers of older adults (see section 7.2.3). However to be able to successfully use the technology, we need to improve the efficiency of the battery and make it last for several weeks (at the minimum).

Other than one participant, all the participants preferred independence over privacy. The two male participants did not like the idea of sharing the information captured about their functional ability with their loved ones, while the two female participants wanted their family to know if there was a problem with them so that they can help. This could be an initial limited indicator of a possible gender difference between the perception of male and female users and may warrant further investigation with respect to design of assistive devices for elderly populations.

7.2.3 Interviews with caregivers

To analyze the data collected from interviews with caregivers of older adults, the inductive analysis method was followed. The primary mode of analysis for inductive method is the development of categories. The categories resulting from the coding, have five key features as described by Thomas and David in 2006 [84]:

1. Category label**:** a word or short phrase used to refer to the category. The label often carries inherent meanings that may or may not reflect the specific features of the category.

2. Category description: a description of the meaning of the category, including key characteristics, scope, and limitations.
3. Text or data associated with the category: examples of text coded into the category that illustrate meanings, associations, and perspectives associated with the category.
4. Links: Each category may have links or relationships with other categories. In a hierarchical category system (e.g., a tree diagram), these links may indicate superordinate, parallel, and subordinate categories (e.g., "parent, sibling" or "child" relationships). Links are likely to be based on commonalities in meanings between categories or assumed causal relationships.
5. The type of model in which the category is embedded: The category system may be subsequently incorporated in a model, theory, or framework. Such frameworks include an open network (no hierarchy or sequence), a temporal sequence (e.g., movement over time), and a causal network (one category causes changes in another). To be consistent with the inductive process, such models or frameworks represent an end point of the inductive analysis. They are not set up prior to the analysis. It is also possible that a category may not be embedded in any model or framework.

Using this framework to analyze the above data, it is evident that the success of a functional assessment system depends largely on its adaptability and customization. There is no one size fits all with this technology. Each end user is different and unique in its own way and the design of assistive devices which can help them to perform their daily activities independently has to consider their personality, behavior, cognitive ability, education and their expertise with technology. Inductive analysis provides a convenient and efficient way of analyzing qualitative data and uncovers key themes that help inform a potentially generalizable model or initial framework. Specifically, the major categories that resulted from inductive coding are: User Experience, Concerns and Suggestions, Gender, Age and Cognitive ability considerations, Independence vs Privacy, Advantages of functional assessment and these will now be described in further detail here.

User experience

The success of any technology depends primarily on its design, ease of use, efficiency, and user's perception or in short its user experience. To improve the user experience of a functional assessment system, it is important to make the interaction simple and easy, make it attractive to use, make sensors blend into the environment and make it adapt to the user. One interview participant appreciated the usefulness of a functional assessment system and described the following:

> "*All of these things will be good if you could get them to use it. It will be good in the historical point of you. Did she take pills yesterday? Something like that. It does not work for people in the later stages of Alzheimer's. It will be quite helpful in the early stages.*"

Another interview participant explained the following about the possibility of her mother using visual aids:

> "*I think it would be ok for her because again it is something new for her to use and it would depend on the user friendliness. If it easy for her to use then it will be ok*"

Concerns and Suggestions

To design better, efficient, functional assessment systems, it is vital to incorporate user's feedback into the design and development of such systems. Some users have concerns with the way the current system is designed while others liked the idea but wanted to modify to adapt to their care recipient's needs or personality.

Concerns: One caregiver explains why guidance does not work with her husband and why one should consider the personality of the user in determining what level of assistance needs to be provided, she explains:

> "*I am not comfortable. No that is not going to work not with him anyway. I think it depends on the personality of the person who is older if they have dementia or not. He was paranoid when he was young. I mean he has always been paranoid*"

Suggestions: Another caregiver explains why it is necessary to consider the context and task at hand before providing guidance to users, this particular comment does overlap with the privacy category as well

> "*I think the audio prompts, you know what I mean or even just the visual prompts like a flashing light or it would depend on the device, like the dresser, audio one will be uncomfortable because you are in a room while coffee is in the kitchen. You will be exposed to more….you know the audio would be okay with the coffee but with the dresser no. you know what I mean because that is an invasion of the privacy and "whose talking to me, is that you God*"

Gender and Age considerations

In designing assistive technology for older adults, it is important to consider the differences in perception due to gender and age.

Gender: Gender plays an important part in how technology is received and used by older adults. This category overlaps with the user experience category because technology that was not designed with having gender differences in mind, tends to fail. As one caregiver explains the use of wearable devices:

"*Some yeah. Others might not. More females would use it than males. They have to wear devices like that in assistive homes so it might not be different*"

Age: Age is an important criteria in designing assistive technology for older adults. There are two different sections of older adults, a) baby boomers who are born between 1946 and 1964 and b) people who are born before 1945. Most people in the baby boomers category have some experience with technology and are comfortable using them while people who are older than 75 are not used to technology. As one caregiver puts it:

"*You know we are in our seventies and eighties if you had asked a young person may be even with dementia a machine told them to do something it might be a different story but you are dealing with a group that are not used to machines telling us what to do. I still get mad when I get that telephone call that says your pills are being shipped in four days*"

Cognitive Ability: Another participant noted that care should be taken to consider the cognitive ability of the user in designing efficient functional assessment systems. When asked about the use of voice prompts in guiding them perform daily tasks, she responded strongly saying:

"*Do you know, many people who have dementia hallucinate and they hear voices I am not sure how they would feel. If they hear voice from their dresser telling them to move into a certain place I am… mmm if it is dementia I am not sure that is going to work. I think you will scare the hell out of them*"

Independence vs Privacy

Having sensors, cameras and voice guidance are great for functional assessment from a technological perspective however you need to have a balance between independence and privacy. Some older adults prefer independence over privacy while others prefer the latter. This is extremely important for the success of the technology because if it violates this constraint then no matter how useful the technology is, the older adult is not going to use it.

Independence: When asked if they would use an assistive device for their daily activities, one caregiver reports:

> "*Yes. Again I would have to introduce it to her slowly. Allowing her the independence and letting her choose whatever she wants to. And that is one of the reasons I would come to my daughter's home for a few days because she would feel that I am not just living there and just taking care of her. I am just busy*"

Some comments overlap between multiple categories, such as the one below, where the focus is on user experience (how the technology is introduced to the user) as well as on the giving them independence in performing their daily activities.

> "*You know she might be especially if by the way it is presented to her, if she thought that she could function more independently then I think she might do it*"

Privacy: Similarly for the question of whether the user would be comfortable with having cameras attached to their dresser, the participant responded

> "*I think the dresser would be the biggest obstacle because of the camera and they would feel like they have lost privacy and you know being able to explain to them it is not taking pictures it is only going to be identifying what you are putting on and just having them should be ok with that. But I think the dresser part would be the biggest obstacle. Not the coffee or the tooth brush*"

Another participant noted that cameras are uncomfortable for the care recipients and also suggests a way to mitigate that.

"*Mainly for the dresser they would feel uncomfortable. One thing I would change is to make the sensors not visible to them maybe that would make them feel more secure. The cameras, they may not feel comfortable, they may not like it that they are being watched*"

Advantages of Functional Assessment System

It was pretty clear from the responses of caregivers who were interviewed that there are several advantages of using a functional assessment system and there were several suggestions on how to design or make changes to the existing system such that it helps people use it, especially those who are older than 75 and who have some kind of cognitive impairment.

One caregiver explains why the information is useful as follows:

"*It seems intuitive because it aids the care giver in giving the client factual information. It is not just the care giver's opinion. We have facts. And again it is an observation not an opinion. Right, so I am not giving my opinion. "No mom this is observing what you are doing and it is data and it is factual. Not just me "mom did you make coffee yesterday did you do it right near me. It is not my opinion its observation*"

Another caregiver explains why it is useful to have guidance to help their care recipient in performing daily activities:

"*Yes, it will truly benefit. They will be denial. So if it tells you they might listen and believe it since the system tells them*"

While some others believed that the technology is great for people who are healthy or in the early stages of dementia not for those who are in the later stages of dementia, as explained by a caregiver of a person in the late stages of dementia.

> "*You know what I was just thinking, if you know somebody in early stages of dementia or somebody living alone and you could track them, from your house, this would be absolutely fantastic. All of them would be fantastic. However that does not work with us*"

One caregiver explains why the information presented to them regarding their care recipient's functional performance is useful, even though it does not help her.

> "*Where my mother is at right now. Yes. However, for people that are on their journey earlier I don't think it would. And yes it would be a wonderful information for the people who are taking care of the people because they could better care where they are at.*"

Another caregiver sees value in the use of video cameras for dressing activity and how that could be a good diagnostic tool.

"*In some cases it can give clues to how they are responding to, whether they are doing well, having trouble, it could be a good tool diagnostically. I can see how it can be valuable. If you put it on early enough, there may be enough left that it could be a residual habit to individuals that they can carry on doing it even after they reach the later stages of dementia. It could also give you, perspective on the progress of Alzheimer's as a research point of view*".

Key Themes:

In summary, the four key themes identified through inductive analysis were:

1. User experience is key in deciding whether they use the technology or not

2. Design must consider gender, age, education, personality and cognitive ability of the user
3. Care should be taken to ensure it satisfies their independence and / or privacy needs
4. To maximize the usefulness of this technology, customization and adaptability to each individual user is vital

7.2.4 Analysis Summary

By analyzing data from the three studies conducted (lab study, case study and caregiver interviews), some common themes emerged which are synonymous with the key themes identified from caregiver interviews. The importance of focusing on user experience, catering to independence and/or privacy needs and adapting or customizing technology according to unique individual qualities of users are validated by both the case study results and interview results. It has also been found that the sensors used for this thesis are not sufficiently reliable for deploying long term in user's homes. The users have unanimously agreed that there is a need for this kind of technology and agree that this could help their loved ones in performing their daily activities independently and provide the caregivers with much needed respite. To be able to deploy and use this technology long term, efficient, reliable, and long lasting sensors are necessary. Similarly, intelligent software must be designed and built to identify when something goes wrong, find it and fix it in a timely manner without user intervention.

Another important finding that emerged from the case study was that healthy users tend not to review the user interface that was provided to track their task performance. Since they are healthy, they believe they would not benefit from tracking their task performance on a daily basis. Most preferred to do it once a month or once every 2 weeks. This was a contradiction to our initial hypothesis that real-time feedback was necessary and helpful in increasing their awareness of their functional abilities. However they all unanimously agreed that they would want to know if something out of the ordinary was detected by the system. Except one participant, all of them preferred to have audio prompts sent by the system to notify them of the anomaly. This is, in some sense, real-time feedback though only happens when something out of the ordinary happens. This is interesting because, even though they are quite confident that they are functionally stable, they also wish to be more aware of their functional abilities, especially if they start to decline. The difference in preferences between the males and females in this study was apparent in terms of the way they prefer information delivered to them. This bolsters the case for customization and adaptability to individual needs. The way information was shared with family/friends/clinicians was another issue that emerged. Males recruited for the case study preferred not to share their task performance information with anyone outside their home while females preferred to share the information with their family so that they could get the right support and care at the right time. This difference in perspective on information sharing also supports the case for systems that incorporate significant degrees of customization.

CHAPTER 8

DISCUSSION OF CASE STUDIES AND CAREGIVER INTERVIEWS

With the increase in the number of older adults, in the United States and globally, it has become increasingly important to develop an assistive technology that is objective, ecologically valid, easy to use and customizable to help older adults age in place independently in their own homes. These technologies can be both supportive and assist in monitoring health status. To date, existing functional assessment systems lack ecological validity. Technologies that have been developed to track functional abilities and conduct in-home assessments are not user friendly, do not focus on design, do not allow for customization and do not track ADL activities. Current research on functional assessment technologies tends to focus on the technology itself. The objective of this research is to explore and identify design, and technical challenges as well as inform opportunities for future investigation and advancement of these designs and technologies. This thesis explores a method to perform functional assessments in the homes of older adults to increase ecological validity. Through a combination of interviews with caregivers of older adults and case study with healthy older adults, three potential key qualities for long term deployment are highlighted: a) the need for explicit focus on user-centered design, b) importance and feasibility of tracking ADL and IADL activities in homes, and c) opportunities for adapt support that attends to user needs through customization. Each of these will now be discussed in detail.

Design: It was evident from the interviews with caregivers and case study participants that design is an important aspect in the adoption of any new technology. Their initial experience with any new technology makes or breaks it for them. How you present the technology to the users is also vital. The primary criterion for successful adoption of assistive technology for older adults with caregivers is whether it allows them to be independent. In that regard, user experience plays a crucial role in what they perceive of the technology and how it can help them in living independently and being able to perform their ALD and IADL activities on their own or with assistance.

ADL activities: The overall results of the case studies provide a promising indication that, not-withstanding several issues that still need to be addressed, it is possible to reliably track ADL activities. The sensor that was placed to track brushing was accurate and the sensors to track dressing well in the lab studies in a closed controlled environment. We were not able to get good data from the sensors for the dressing activity due to non-compliance of three of the four participants citing risk of privacy violation (because of the presence of video cameras in dresser). The success of brushing activity and the ease in which we can track this activity gives us the confidence to be able to include ADL activities for functional assessment. Dressing activity is technically possible but there is still some work needed to enable long-term deployment and unobtrusive experiences for users. Additional design effort is needed to make the sensors blend into the embedded dresser environment and make the experience as natural as possible for users.

Customization: It is also evident from the interview results that a technology that works well for one user may not be desirable or functional for another user. To enhance acceptability and functionality, it becomes crucial that the technology can be customized or adapted to the needs of the user. For example: One user might not prefer voice guidance during their activities while another user might find it very useful to have audio prompts to help with their daily activities. The results also show that assistive devices have to be adaptable to differences in age, gender, education (education does not matter so much for the use of assistive devices rather on the level of information to provide them), background, personality and cognitive ability to name a few. This was found from the interviews with caregivers, asking them feedback about the current system and other assistive devices they have used in the past. To be able to meet all those constraints, it needs to adapt to the user, or there should be provision to customize easily to cater to the different needs.

The purpose of this thesis is to design and develop assistive technology for people, who are healthy, and to provide them with a tool to monitor their functional ability and allow them to take appropriate interventions to prolong their independence. However if the design focuses only on this category of users, then the technology is not going to be viable for these individuals, in long term. As one gets older, it becomes increasingly likely that they will lose some of their functional ability and become dependent on a caregiver. The needs of healthy, independent older adults and older adults who are not healthy and dependent (on caregivers) to perform all or some of their daily tasks are huge. For example, privacy is extremely important when a person is independent and that caused some of the participants of the case study to remove dressing activity from their experience, for the duration of their participation in the study. However when a person is dependent and starts to lose some of their physical or cognitive ability, they are prepared to give up privacy (helped by someone or sharing information) in favor of aging in place. Some quotes from caregivers who express why independence is important over privacy for their care recipients,

About having video cameras - "*I don't think it will be a problem because we are the only ones there I mean it's only the family so I don't think so. And we need to help her any way so you lose the control over privacy if you need help*" and "*You can't have both independence and privacy. My mom she now allows me to do things which earlier she would have never allowed me to do two years ago*"

Notably the independent healthy older adults involved in this study were not particularly interested in tracking their activity performance on a daily basis. Most interviewed said they would do it once a week or once every two weeks, some even said they would not even look at it. This indicates that they are not interested in real time information rather they are more interested in the historical data, how they are performing over the course of time. This unexpected and differs from the initial hypothesis. The initial hypothesis was that providing real time information could help stakeholders by increasing awareness and in providing timely interventions. However, just as we learned this was not the case, we also learned that changing needs, as one gets older and becomes more dependent, can alter (increase) their acceptance of and desire for appropriately design supportive technologies.

We also learned that caregivers of older adults preferred to have real time information and wanted to monitor their loved ones on a daily basis especially on their ADLs. This is especially true for those who take care of people with cognitive impairment. As one caregiver put it, "*I would like to know what my wife is doing late in the night, is she sleeping or wandering? That would be useful. I don't care what she did last week, you are living in the now. I want to know what she is doing now*". They also appreciated the value in having historical data and the ability to share that information with clinicians. From the examples it is pretty clear that for the success of functional assessment system and to enable their use for long-term deployments, they need to have three key qualities a) the need for explicit focus on user-centered design, b) importance and feasibility of tracking ADL and IADL activities in homes, and c) opportunities for adapt support that attends to user needs through customization. Any functional assessment system that has these three qualities, will help caregivers (loved ones or family) and clinicians in helping older adult age in-place, by giving them as much independence and support as possible.

CHAPTER 9

CONCLUSION AND FUTURE WORK

Previous development on functional assessment systems have focused only on the IADL activities and the different kinds of data that could be captured and used for assessment, which does not work for everyone. These systems have not considered the importance of having a user-centered approach to their design, have not been able to track ADL activities efficiently and have not fully considered the opportunities to adaptively customize interfaces and experience to individuals' diverse and evolving needs. This thesis elucidates strategies for each of the following problems:

- Not focusing on design
- Not able to track ADL activities efficiently and use them for functional assessment
- Not able to customize / adapt to individual needs

By conducting user studies with older adults and caregivers of older adults, we were able to identify their needs, and challenges, and develop 3 key strategies to help guide the design of in-home functional assessments in the future. This thesis suggests that to solve most of the problems associated with current functional assessment systems, the focus should be more on design (having a user centered approach), should include tracking of both ADL and IADL activities, and allow for customization, to meet individual user needs.

9.1 Support for thesis

The goal of this thesis was to find answers for the following thesis statement (from section 1.3)

> How to design functional assessment systems for in-home monitoring of older adults and what are the challenges of deploying and using it in the real world?

The thesis statement can be divided into two sub-statements:

1. How to design functional assessment systems for in-home monitoring of older adults?
2. What are the challenges (design and technical) of deploying and using in-home monitoring for older adults, in the real world?

Support for thesis sub-statement 1 was provided by interviews with caregivers and healthy older adults (chapter 6). These 2 studies examined the needs of the users in using an in-home functional assessment system and what would they expect if they were to use it on a regular basis. From the results of the interview with caregivers, we were able to identify that there is no one size fits all. Every individual is different and the designer/developer should factor in the differences and uniqueness of the user when building systems. It was not surprising to know that the needs of those who are healthy and those who are not are different, however, what was revealed was that the differences are significant and varied.

For example, during interviews with caregivers, it was found that people who are older and dependent emphasize more on their independence and are willing to let go of their privacy if that allows them to be independent. This was different with healthy older adults, where they prefer to have both their privacy and independence intact. Similarly, healthy older adults preferred not to look at their performance data everyday rather prefer to monitor their performance once every 2 weeks or once a month. Which is contradictory to the requirements of the caregivers, where they prefer to monitor their loved ones on a daily basis or more frequently than healthy adults. This is because as one gets older and starts to lose their functional ability, their ADLs are very important to track and can provide cues to their functional performance. It then becomes important to track on a daily basis whether they are taking pills, taking bath, brushing their teeth and so on. Similarly, those who are older than 75 and are dependent on someone to perform their daily tasks cannot / do not want to get commands (voice guidance) from an automated machine (computer). Compared to healthy older adults, who preferred to have voice prompts if something is wrong with them rather than monitoring their performance themselves.

The studies also found certain other design needs such as making the user interface much easier to understand and navigate, making sensors attractive, and making sensors invisible. Design should also consider the age, gender, education, personality, and cognitive ability of the users to make it effective.

Support for sub-statement 2 was supported with data from the case studies and from the interviews with older adults and caregivers (chapter 6). One of the many technical challenges that were identified is the robustness and location of some of the sensors. For example, the motion sensor attached to the toothbrush was not comfortable to some users and it was dead well before its life cycle. Two sensors had to be replaced during the course of the case study and the reasons are unknown. These are waterproof sensors, which are designed to last for several years under normal circumstances (battery lasts for a year, but easily replaceable). Similarly, the skin conductance sensor’s battery did not last 2 days. The sensor was not stress tested before the study, as the normal usage of this sensor is only an hour a day (they were asked to wear only while performing the activities under test) under normal conditions. However, what we did not foresee is that the sensor was pinged constantly by the software to update information irrespective of whether it was worn or not. Similarly another technical challenge that we encountered is the problem of network connection in user home. In one case study participant's home, their router prevented the software (which is responsible to store the information captured from sensors) from writing information in log files locally. Even after getting help from customer support of the wireless sensor company, we could not isolate the problem. The same setup with the same set of sensors worked flawlessly without any problem in the subsequent case study with another participant.

Some of the design challenges that were encountered are a) one participant mentioned that the skin conductance sensor was uncomfortable and it was hard to keep it from slipping. He had to make it tight so that it does not slip but then it would get more uncomfortable wearing it. He felt it could be lighter and he was constantly worried about getting it wet. b) Some participants expressed the way the toothbrush sensor was designed and expressed that they were uncomfortable using the toothbrush and one participant was so worried that she would break the sensor attached to the toothbrush that she took extra care in brushing her teeth. One caregiver said that it would be much more comfortable and convenient for her loved one, if the sensor was wireless and blended into the toothbrush. c) Video cameras in dresser was a big design and technical challenge and most caregivers expressed their concern on having to use them and wanted to make it invisible so that their loved ones did not know it existed. While three out of four case study participants declined to perform dressing activity as part of the study because of the presence of cameras. It is also a technical challenge because for the current system to detect dressing activity, having a video camera is an integral part to it. The technology has not advanced to a point where the cameras are either completely removed or we hide the presence of cameras and make the markers on clothes invisible.

9.2 Contributions

This work makes contributions in three different disciplines: Human-Computer Interaction/Design, Computer Science, and Health Theory and Practice.

9.2.1 HCI / Design

The research described in this thesis has generated contributions in understanding user's needs, how people interact with their activity performance data, how to present data in a way that supports behavioral change, understanding people's perception on working with objects embedded with sensors and also a methodology for designing sensing systems that can adapt to individual needs.

9.2.1.1 Using Feedback to capture ground truth

Most sensing systems provide data based on what the sensors can capture. However the data captured through sensors may not reveal everything about the actions performed by the users or their lack of. The gap between actions users have performed and actions sensors think they performed, is a big one and a crucial one too. There is no way currently to predict the actual ground truth unless someone who watched them perform those actions, report the information. To fill in this gap, this thesis suggests a feedback mechanism where if the system finds an anomaly on a particular day, it sends a feedback questionnaire the next day to the caregiver or the user and asks them basic questions about the user's daily activities on the previous day. The questionnaire contains basic questions about their daily activities; such as did you take your pills yesterday? If they answered no, then gives them some predefined choices to select. The choices for this question would be a) forgot to take, b) out of pills, c) did not feel like taking it, d) went out and e) None of the above, other. Similarly, for other activities such as coffee making, brushing their teeth and their emotional status. The concept of trying to track emotional status is to find a correlation between emotional level and activity performance. If a person is frustrated, angry or agitated during an activity and makes a mistake during the activity, then the system tries to find correlations between these two and if it does, then discards the anomaly. This feedback mechanism is a simple method to capture close to ground truth without making someone watch the user perform all of their daily activities under test.

9.2.1.2 Identify information needs of stakeholders

By interviewing caregivers who take care of older adults who are not completely independent and older adults who are independent and healthy, we were able to get information needs from two completely different set of stakeholders. This is important because even though a functional assessment system is designed for older adults who are healthy to take care of themselves better before any potentially big event such as fall [80] or onset of cognitive impairment, once such an event occurs the system should be able to adapt itself for the changing needs or at the least, must be customizable to meet the changing needs. The current design allows for this level of customization and could act as an intelligent, automated assistant if the need arises. To this end, it is important to understand how their needs change from being independent to being dependent on a caregiver to perform some or most of their daily activities. Capturing their needs will help us to be in a better position to design future sensing systems that can be customized and be deployed long term for continuous in-home functional assessment.

9.2.1.3 Real time versus Long term

This thesis investigated if real time feedback on user's performance helps in increasing awareness and in providing timely interventions. All the healthy adults who took part in the study as well as most of the caregivers who took part in the interviews did not care much about real time feedback. At least, not the way it was designed to help them. The system was designed to provide real time feedback on user's activity performance through a web interface and allowing them the flexibility to monitor when they wish to do so. Even the feedback mechanism used to help us identify "why" something happened in the context of functional assessment was designed to work unobtrusively. The system will not notify or instruct the user / caregiver to provide feedback as that could get annoying pretty soon but rather will be displayed in the web interface when the need / situation arises. Most people who were interviewed did not prefer real time information rather were more interested to track their progress or their loved one's progress once a week or once every two weeks. Except one participant, who was more interested in real time tracking of his loved one, everyone wanted to look at historical data, as they believed there would not be much change on a daily basis and there won't be any value in doing so. Some case study participants preferred to have audio prompts played in real time when something out of the ordinary happened so that they know what happened and then decide if they want to look further in the user interface or to ignore it.

The bigger disadvantage in relying on long-term data is that when you look back at the data and find something unusual, there is no proper way to identify why that happened. That's the problem feedback mechanism was designed to solve. By relying on long-term data, you lose the chance to potentially identify important cues of functional decline. There are obvious advantages to have long-term data though. Clinicians can use those historical data to predict how their functional abilities are changing over time and also suggest appropriate interventions if they find the need to do so. Designers of sensing systems must keep in mind the pros and cons between these two and prioritize based on user's needs.

9.2.2 Computer Science

This thesis provides technical contributions to the field of computer science and engineering.

9.2.2.1 Tracking ADL activities for functional assessment

This thesis describes the design, implementation and evaluation of a system, which can track activities of daily living and use the data captured for functional assessment. Specifically, this thesis describes a system, which can track dressing and brushing activity using sensors embedded onto dresser and toothbrush respectively. The DRESS system described in chapter 4 was designed to help people with cognitive impairment to dress through an intelligent automated sensing system. It uses fiducial markers, video cameras, x10 sensors and intelligent software to efficiently track how a user performs dressing in front of the dresser and be able to identify what state they are in with respect to dressing. This system has been extensively tested in the lab with younger healthy adults and results have been published. Similarly with the help of wireless sensor and intelligent software, the system used in this thesis can efficiently track brushing activity as well. Both have been deployed in user homes for a period of two weeks. While only one participant as part of the case study performed dressing, all four participants performed brushing and the results have been positive. Previous research in functional assessment has not included ADL activities in their assessment due to the inherent difficulty in tracking ADL activities. This thesis demonstrates that it's possible to reliably track ADL activities and paves the way for future development, testing and finally long-term deployment.

9.2.2.2 Context aware based monitoring

An important part of this thesis is to show the system's ability to use context awareness in tracking activity performance to identify events such as what actions were performed, when it was performed, and in what context. For example, when the user moves the toothbrush, the motion sensor logs this information. However it is important to identify if the user is actually brushing or just moving the toothbrush. It uses the time the sensor was moved and the time it took to go idle again and uses this information to identify the context. Based on their daily schedule, we can reliably predict if the user is brushing or not. If the sensor in the toothbrush changed from moved state to idle state in less than 10 seconds (just an example), we can predict that they user is not brushing. Anything close to the actual baseline is considered as proper data. Similarly, the system uses context to identify other daily tasks such as coffee making, medication adherence and dressing. This is extremely crucial because, the ability to predict context helps to eliminate false positives in the data.

9.2.3 Health Theory and Practice

In addition to contributions to human-computer interaction and computer science, this thesis also makes contributions to the health theory and practice. In particular, demonstrating how activity performance data can be used to support an individual's self-awareness and to help provide timely interventions. Furthermore, the system enables researchers and clinicians to see how individuals function in-place and to get objective, ecologically valid, functional assessment. It also identifies how user's perception of sensors affects their activity performance and / or behavior.

9.2.3.1 Support self-awareness and interventions through performance data

This thesis supports improving one's self-awareness by providing real time performance data as well as allowing caregivers to provide timely interventions using the same data. This is validated by the case studies and the interviews with participants. The participants agreed that having the ability to monitor functional performance is important in being self-aware and also gives caregivers an opportunity to provide the much needed independence to their loved ones. Most caregivers reported that having a system report functional performance or guidance is helpful, as they would be considered as facts rather than an opinion.

9.2.3.2 Identify how perceptions affect activity performance or behavior

Human perceptions are an important facet in the success or failure of any technology. How they feel about using it, what is their experience using it and is it positive enough to make them use the product again are important factors to consider. This thesis identifies through interviews how perceptions of users in working with objects embedded with sensors affect their task performance as well as their behavior. For example: one case study participant noted that she was very helpful in using her toothbrush during the period of the study because of the fact that there was a sensor attached to it. She did not want to break or damage the sensor and that increased her usual brushing time. This is an example of how their perception affects their performance. Similarly, 3 case study participants declined to perform dressing activity as part of the case study because of their pre-conceived perception of video cameras. Even though it was explained to the participants that the video cameras does not record any video nor capture any pictures, but is used only to track the markers attached onto clothing items, they were worried about their privacy. This is an example of how their perception is affecting their behavior. These are valuable data for researchers and clinicians because they can use these information to help build systems or provide interventions that benefits them without affecting their performance or behavior.

9.3 Limitations

Designing, building and evaluating embedded functional assessment technologies can be challenging for a number of reasons including the difficulty of tracking daily activities, designing it in a user friendly manner, presenting the information in an easy understandable format and the length of time required for evaluations and the unpredictability of how individual's perception, and behavior over time. This section describes some of the limitations of this work that address some of these challenges for embedded assessment.

The studies conducted as part of this thesis involved a small number of participants including 11 in the pilot study for DRESS, 8 for caregiver interviews and 4 for in-home case studies. The small sample size selected is statistically insignificant and does not allow for any statistical analysis on the data collected. However the real objective here is to perform an exploratory study (qualitative) rather a quantitative one. Another disadvantage of having a small sample size for the in-home study is the difficulty in testing all the sensors extensively if some of them failed. Another limitation is the selection of caregivers who were interviewed, most of the caregivers interviewed were taking care of someone who has a severe cognitive impairment. The care recipients do not represent the general population and most of them believed that no technology could help them at this point in their loved one's life. They all accepted that this technology is great and could be very helpful for people in the early stages of Alzheimer's or those who are healthy. Another major disadvantage is the fact that not even one case study participant monitored their activity performance using the resource (web user interface) provided to them. An important part of eliminating false positives is the creation of the feedback mechanism and no participant used them except at the end by two of the participants. Another limitation is the availability of limited data from dressing activity and from skin conductance sensor. Since only one participant volunteered to perform dressing as part of the study, there is not enough data to support the efficiency of the technology to track dressing. Similarly, due to poor battery life of skin conductance sensor, there was not enough data to find any correlations between emotional state and task performance.

9.4 Future Work and Recommendations

The findings from this thesis suggests there is value in focusing on design, and customizing the technology according to user's needs. However due to small sample size, the findings could not be generalized to the general older population. In future, more number of participants could be recruited for in-home assessments. There is evidence from our lab studies that we could reliably track dressing activity, however it needs some improvements and more testing before it could be deployed for long term studies. The bigger problem when working with sensors is its battery life, researchers in the future could find ways to replace the batteries on time by performing periodic checks or design the sensor in such a way that it could be easily recharged so that there is no loss of data due to loss of battery life. Once the sensors and all the daily activities are tested for reliability, efficiency and long-term usability, the future vision for the system should be to test with older adults with cognitive impairments. There is potential and opportunity to help the older adults live independently as much as possible at the same time provide the caregivers with the much needed respite.

Future evaluations of functional assessment systems could include more metrics to maximize the efficiency of these systems and to make them more reliable. The results from interviews with caregivers and case study participants demonstrate that there is a need for guidance using audio prompts. The current system has the capability to provide guidance built right in, future researchers could explore this functionality as this could benefit both the older adults as well as their caregivers. This thesis focused its usefulness of embedded assessment on caregivers, their care recipients and healthy older adults however it did not test the usefulness from a clinician standpoint. Future opportunities could investigate how data could be shared between data generators (older adults) and data consumers (care givers and clinicians) and how clinicians could provide care and interventions using the data.

Future opportunities could also explore adding other activities to track for functional assessment such as sleep, physical activity, and social interaction to name a few. There are multiple cheap trackers available for tracking sleep patterns and that data could easily be integrated for functional assessment, similarly most sleep trackers also track physical activity such as how many steps taken, distance, time etc. (ex. Jawbone, Fitbit etc.). As one caregiver reported that she would like to explore how her mother's social interaction benefits her functional ability. That's an interesting and promising area to explore. Another caregiver asked insightful questions such as what if the person is not a coffee drinker, what if they have dentures, what if they don't wear a watch or any wearable device. These are thought provoking questions because these present the need to customize the system to suit different needs. If future researchers we are not able to track brushing for ADL, they could rely on dressing or something else, similarly instead of coffee, it could be tea or water. Tracking how users perform their daily activities can give us valuable cues to track their functional ability and in providing them with the right care to prolong their independence.

9.4.1 Recommendations

This thesis provides recommendations to solve some of the challenges encountered during this thesis and how future researchers could use the recommendations to implement and deploy systems for long-term benefit. While dressing is one of the most challenging tasks to perform for older adults (75+), the current setup of having cameras creates privacy concerns for both the caregivers and the care recipients. Caregivers interviewed indicated that if the cameras are hidden, then it would lower care recipient's concerns. However, this may not be an appropriate way of dealing with this issue, and furthermore, the cameras still present privacy concerns for both the care recipients and care givers. To mitigate that, future researchers could use cameras that capture only infra-red images instead of images in the visual range. Since these are typically of lower resolutions they may be sufficient to detect clothing orientation why beneficially attending to some of the privacy issues. It is important for the end users to have options in terms of what technologies they may be dealing with. Demonstrating a camera that only captures infra-red images and does not store any of those images, may boost end-users' confidence and trust in the technology and help in advancing approaches for tracking dressing activity. Privacy concerns becomes a sub-category of a larger category called "Ethical Concerns" while working with older adults. Since the technology involves capturing personal data, there is a possibility for data misuse and strong ethical guidelines must be followed when in-home monitoring systems are deployed.

The concern with privacy and autonomy is understandable considering the wide range of sensors used in current technologies and the range of activities it tracks. Magnusson and Hanson [45] have discussed about ethical issues in research and technology to support older people in their own homes. They argue that ethical considerations and dilemmas which may arise in research involving older people are no different from those associated with any age group. They proposed a set of ethical guidelines which are relevant to research and technology projects involving older people. Some of the principles proposed included respect for human dignity, worth and fundamental rights, autonomy and privacy, confidentiality, informed consent, justice, non-maleficence, and truth telling. They also explain key ethical issues arising from applying those guidelines in real world projects especially those involving autonomy, independence, Quality of Life, security and privacy to name a few. To overcome these ethical issues, they used a user-focused approach i.e. the views and feedback of the families were given prime importance at all stages of their project. The authors explain with concrete examples the importance of privacy, security, disadvantages of focusing on technology itself rather than on the user, and concerns with location of the technology and use of video cameras with respect to privacy.

To highlight ethical issues in technology design, a new design methodology was proposed by Robertson and Wagner [74] called "Ethical design methodology". It is a combination of participatory design and democracy. They highlight the challenges in working with users, participants, ethical issues arising in monitoring, mobile technologies, and home care technologies to name a few. In addition to these, there are other studies dealing with ethical issues among elderly, although with slightly different perspectives, e.g. a generational perspective [9], a sensor technology based perspective [15], future perceptions perspective [27], medicalnperspective [92], and the significant other perspective [76]. There are other numerous studies on ethical issues and concerns on technology for older people which shows how important it is to follow ethical guidelines when designing and building technology for future researchers.

Another recommendation for researchers in other fields is to use consider the diverse needs these technologies might benefit. For example: the ability of the system to detect daily activities and provide audio interventions to complete the task correctly has a wide range of benefits. This technology could be used for people with physical disability to help with rehabilitation. It could be used as a personal coach in guiding them to perform tasks correctly. It could also be used for people with cognitive impairments (early stage) to act as a support center to help them perform daily tasks. As one of the caregivers pointed out, the technology could be used as a diagnostic tool as well, being able to monitor users' everyday tasks and their emotional state, it could serve to inform caregivers and clinicians on their progress. This thesis shows a glimpse of what these technologies can achieve in terms of providing respite for caregivers, too. Caregivers are in a lot of stress while taking care of their loved ones and it is important to attend to their health needs, too. The technology could be customized, tested, and adapted to help caregivers monitor loved ones remotely and also provide interventions remotely without them physically being present. Their voice could be recorded and when needed audio prompts provided to the care recipient, we could use caregiver's voice to simulate their presence and help the care recipient recover to their normal state. While there remains numerous challenges, the importance of the issues, needs of caregivers, and the possibilities for the use of these technology in aiding older adults live independently and have a healthier life are important, as they offer compelling opportunities for further advancement that may have a meaningful benefit to society.

REFERENCES

1. Abras C, Maloney-Krichmar D, Preece J. User-Centered Design. In: Bainbridge W, editor. Encyclopedia of Human-Computer Interaction. Sage; Thousand Oaks: 2004.

2. Administration on Aging (AoA), Administration for Community Living, U.S. Department of Health and Human Services. (2013). Profile of Older Americans.

3. Andersen, S. J., & Johnson, M. A. (1996). Caring for patients on the edge of decline. AJN the American Journal of Nursing, 96(12), 16B-16D.

4. Anderson, E. S., Winett, R. A., Wojcik, J. R., Winett, S. G., & Bowden, T. (2001). A computerized social cognitive intervention for nutrition behavior: Direct and mediated effects on fat, fiber, fruits, and vegetables, self-efficacy, and outcome expectations among food shoppers. Annals of Behavioral Medicine, 23(2), 88-100.

5. Apple Inc. www.apple.com.

6. Bankole, A., Anderson, M., Knight, A., Oh, K., Smith-Jackson, T., Hanson, M. A., Lach, J. (2011). Continuous, non-invasive assessment of agitation in dementia using inertial body sensors. Proceedings of the 2nd Conference on Wireless Health, San Diego, California. 1:1-1:9. doi:10.1145/2077546.2077548.

7. Barberger-Gateau, P., Fabrigoule, C., Helmer, C., Rouch, I., & Dartigues, J. (1999). Functional impairment in instrumental activities of daily living: An early clinical sign of dementia? Journal of American Geriatrics Society, 47, 456-462.

8. Barger, T., Brown, D., & Alwan, M. (2003). Health status monitoring through analysis of behavioral patterns. 8th Congress of the Italian Association for Artificial Intelligence (AI*IA) on Ambient Intelligence, 22-27.

9. Birkland, J. L. (2010). "What's so special about studying old people?" The ethical, methodological, and sampling issues surrounding the study of older adults and ICTs.

10. Brush, A., Lee, B., Mahajan, R., Agarwal, S., Saroiu, S., & Dixon, C. (2011). Home automation in the wild: Challenges and opportunities. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2115-2124.

11. Burleson, W., Newman, N., & Brotman, R. (2012). Empowering independent living for people with autism: Designing supportive, low-cost, interactive e-health environments. Proceedings of the 7th International Conference on Persuasive Technology: Design for Health and Safety, Sweden. 13-30. doi: 10.1007/978-3-642-31037-9_2.

12. Cook, DJ and Schmitter-Edgecombe, M and others. (2009). Assessing the quality of activities in a smart environment. Methods of Information in Medicine, 48(5), 480.

13. Cook, D. J., Youngblood, M., III, H. E. O., Gopalratnam, K., Rao, S., Litvin, A., & Khawaja, F.MavHome: An agent-based smart home. Proceedings of the First IEEE International Conference on Pervasive Computing and Communications, 2003. (PerCom 2003). 521-524.

14. Demiris, G., Parker Oliver, D., Dickey, G., Skubic, M. and Rantz, M. 2008. Findings from a participatory evaluation of a smart home application for older adults. Technology and Health Care, 16(2): 111–118.

15. Ding, D., Cooper, R. A., Pasquina, P. F., & Fici-Pasquina, L. (2011). Sensor technology for smart homes. Maturitas, 69(2), 131-136.

16. Edwards, W.K., and Grinter, R.E., "At Homewith Ubiquitous Computing: Seven Chal-lenges,"Ubicomp 2001: Ubiquitous Computing, Lecture Notes in Computer Science,vol. 2201, Springer-Verlag, Berlin, 2001, pp.256-272.

17. Fleury, A., Noury, N., & Vacher, M. (2009). Supervised classification of activities of daily living in health smart homes using SVM. International Conference on Engineering in Medicine and Biology Society, 6099. doi:10.1109/IEMBS.2009.5334931.

18. Floerkemeier, C., & Siegemund, F (2003). Improving the effectiveness of medical treatment with pervasive computing technologies. Proceedings of the UbiHealth 2003: The 2nd International Workshop on Ubiquitous Computing For Pervasive Healthcare Applications.

19. Fogg B.J. (1999). Persuasive technologies. Persuasive technologies (pp. 27-29)

20. Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. The Lancet Neurology, 3(6), 343-353.

21. Fried LP, Bandeen-Roche K, Chaves PH, & Johnson BA. (2000). Preclinical mobility disability predicts incident mobility disability in older women. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55(1), M43-M52. doi:10.1093/gerona/55.1.M43.

22. Fried, L. P., Herdman, S. J., Kuhn, K. E., Rubin, G., & Turano, K. (1991). Preclinical disability: Hypotheses about the bottom of the iceberg. Journal of Aging and Health}, 3(2), 285-300. doi:10.1177/089826439100300210

23. Gendron, M., & Levesque, L. (1993). Evaluating the functional autonomy of persons with alzheimer's disease: A tool for observing four activities of daily

living. American Journal of Alzheimer's Disease and Other Dementias, 8(Mar), 24-35.

24. Gorin, A. A., & A.A. Stone. (2001). Recall biases and cognitive errors in retrospective self-reports: A call for momentary assessments. Handbook of Health Psychology, 405-413.

25. Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. New England Journal of Medicine, 332(9), 556-562. doi:10.1056/NEJM199503023320902

26. Haigh, K. Z., Kiff, L. M., Myers, J., Guralnik, V., Krichbaum, K., Phelps, J., Toms, D. (2003). The independent LifeStyle assistant TM (I.L.S.A.): Lessons learned

27. Hayes, T. L., Hunt, J. M., Adami, A., & Kaye, J. A. (2006). An electronic pillbox for continuous monitoring of medication adherence. Conf Proc IEEE Eng Med Biol Soc,

28. Harrefors, C., Axelsson, K., & Sävenstedt, S. (2010). Using assistive technology services at differing levels of care: healthy older couples' perceptions. Journal of advanced nursing, 66(7), 1523-1532.

29. Intille, S. S. (2002). Designing a home of the future. IEEE Pervasive Computing, 1(2), 76-82.

30. Intille, S. S. (2003). "Ubiquitous Computing Technology for Just-in-Time Motivation of Behavior Change" in Proceedings of the UbiHealth 2003

31. Intille, S. S. (2004). A new research challenge: Persuasive technology to motivate healthy aging. Information Technology in Biomedicine, IEEE Transactions on, 8(3), 235-237.

32. Jeremy Birnholtz , McKenzie Jones-Rounds, Independence and interaction: understanding seniors' privacy and awareness needs for aging in place, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, April 2010

33. Jimison, H., Jessey, N., McKanna, J., Zitzelberger, T., & Kaye, J. (2006). Monitoring computer interactions to detect early cognitive impairment in elders. Distributed Diagnosis and Home Healthcare, 2006. D2H2. 1st Transdisciplinary Conference on, 75-78. doi:10.1109/DDHH.2006.1624801

34. Jimison, J., Pavel, M., Pavel, J., & McKanna, J. (2004). Home monitoring of computer interactions for the early detection of dementia. Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE, 2 4533-4536.

35. Kapoor, A., Burleson, W., & Picard, R. W. (2007). Automatic prediction of frustration. International Journal of Human-Computer Studies, 65(8), 724-736. doi:10.1016/j.ijhcs.2007.02.003

36. Katz, S. (1983). Assessing self-maintenance: Activities of daily living, mobility, and instrumental activities of daily living. Journal of the American Geriatrics Society.

37. Kaye, J., Hayes, T., Zitzelberger, T., & et al. (2007). Deploying wide-scale in-home assessment technology. Technology and Aging, 21, 17-26.

38. Kemp, N., Brodaty, H., Pond, D., and Luscombe, G., "Diagnosing Dementia in Primary Care: The Accuracy of Informant Reports" Alzheimer Disease & Associated Disorders, vol. 16, pp.171-176, 2002.

39. Kidd, C. D., Orr, R., Abowd, G. D., Atkeson, C. G., Essa, I. A., MacIntyre, B., Newstetter, W. (1999). The aware home: A living laboratory for ubiquitous computing research. Proceedings of the Second International Workshop on Cooperative Buildings, Integrating Information, Organization, and Architecture, 191-198.

40. Kientz, J. A., Patel, S. N., Jones, B., Price, E., Mynatt, E. D., & Abowd, G. D. (2008). The georgia tech aware home. CHI '08 Extended Abstracts on Human Factors in Computing Systems, Florence, Italy. 3675-3680. doi:10.1145/1358628.1358911

41. Korhonen, I., P. Paavilainen, & A. Särelä. (2003). Application of ubiquitous computing technologies for support of independent living of the elderly in real life settings. UbiHealth 2003: The 2nd International Workshop on Ubiquitous Computing for Pervasive Healthcare Applications,

42. Lawton, M. P., & Brody, E. M. (1969). Assessment of older people: Self-maintaining and instrumental activities of daily living. The Gerontologist}, 9(3 Part 1), 179-186. doi:10.1093/geront/9.3_Part_1.179.

43. Lee, M. L. (2012). Task-based embedded assessment of functional abilities for aging in place (Doctor of Philosophy (PhD)).

44. Lee, M. L. (2010). Embedded assessment of wellness with smart home sensors. Proceedings of the 12th ACM International Conference Adjunct Papers on Ubiquitous Computing - Adjunct, Copenhagen, Denmark. 473-476. doi:10.1145/1864431.1864490.

45. Magnusson, L., & Hanson, E. J. (2003). Ethical issues arising from a research, technology and development project to support frail older people and their family carers at home. Health & social care in the community, 11(5), 431-439.

46. Mahoney, D.F., Burleson, W., Lozano, C., Ravishankar, V., Mahoney, E. (2014). Development of a responsive emotive sensing system (DRESS) to aid persons with dementia dress independently. Gerontechnology, 13(2), 259.

47. Mahoney, D.F., Burleson, W., Mahoney, E. (2012). Context aware automated prompting for dressing: Concept feasibility. Gerontechnology, 11(2), 298.

48. Mahoney, D. F., La Rose, S., & Mahoney, E. L. (2013). Family caregivers' perspectives on dementia related dressing difficulties at home: The preservation of self-model. Dementia (London, England), doi: 101177/1471301213501821.

49. Mahoney, D. F., Purtilo, R. B., Webbe, F. M., Alwan, M., Bharucha, A. J., Adlam, T. D., Becker, S. A. (2007). In-home monitoring of persons with dementia: Ethical guidelines for technology research and development. Alzheimer's and Dementia, 3(3), 217-226. doi:10.1016/j.jalz.2007.04.388.

50. Matsouoka, K. (2004). Smart house understanding human behaviors: Who did what, where, and when. Proceedings of the 8th World Multi-Conference on Systems, Cybernetics, and Informatics, (3) 181-185.

51. Matteson, M. a. o. (1997). Functional assessment of the elderly. Nurse Practitioner Forum, 8(3) 91.

52. Mennicken, S., & Huang, E. M. (2012). Hacking the natural habitat: An in-the-wild study of smart homes, their development, and the people who live in them. Pervasive computing (pp. 143-160) Springer.

53. Microsoft Corporation. (2013). Kinect for windows. Retrieved from http://www.microsoft.com/en-us/kinectforwindows/.

54. Mihailidis, A., Boger, J., Canido, M., & Hoey, J. (2007). The use of an intelligent prompting system for people with dementia. Interactions, 14(4), 34-37. doi:10.1145/1273961.1273982.

55. Mihailidis, A., Carmichael, B., Boger, J., & Fernie, G. (2003). An intelligent environment to support aging-in-place, safety, and independence of older adults with dementia. In UbiHealth 2003: The 2nd International Workshop on Ubiquitous Computing for Pervasive Healthcare Applications.

56. Moen, A., & Brennan, P. F. (2005). Health@Home: The work of health information management in the household (HIMH): Implications for consumer health informatics (CHI) innovations. Journal of the American Medical Informatics Association, 12(6), 648-656. doi:10.1197/jamia.M1758.

57. Morrell, R. W. (2001). Older adults, health information, and the world wide web Psychology Press.

58. Morris, M., Lundell, J., & Dishman, E. (2003). Ubiquitous computing for mild cognitive impairment: A prototype for embedded assessment and rehearsal. Gerontologist, 43 393-394.

59. Morris, M., Intille, S., & Beaudin, J. (2005). Embedded assessment: Overcoming barriers to early detection with pervasive computing.3468, 333-346. doi:10.1007/11428572_20.

60. Morris, M., Lundell, J., Dishman, E., & Needham, B. (2003). New perspectives on ubiquitous computing from ethnographic study of elders with cognitive decline. (pp. 227-242).

61. Mozer, M. (2004). Lessons from an adaptive house.

62. Mynatt, E. D., Essa, I., & Rogers, W. (2000). Increasing the opportunities for aging in place. Proceedings on the 2000 Conference on Universal Usability, Arlington, Virginia, USA. 65-71. doi:10.1145/355460.355475.

63. Mynatt, E., & Rogers, W. (2001). Developing technology to support the functional independence of older adults. Ageing International, 27(1), 24-41. doi:10.1007/s12126-001-1014-5.

64. nTAG. (2004). nTag interactive.

65. Okonkwo, O., Griffith, R., Vance, D., Marson, D., Ball, K., and Wadley, V., "Awareness of Functional Difficulties in Mild Cognitive Impairment: A Multidomain Assessment Approach" J Am Geriatr Soc, vo1.57, pp.978-84, 2009.

66. Owsley, C., Sloane, M., McGwin Jr, G., & Ball, K. (2000). Timed instrumental activities of daily living tasks: Relationship to cognitive function and everyday performance assessments in older adults. Gerontology, 48(4), 254-265.

67. Patterson, D., Liao, L., Fox, D., & Kautz, H. (2003). Inferring high-level behavior from low-level sensors.2864, 73-89. doi:10.1007/978-3-540-39653-6_6.

68. Peters, C., Hermann, T., Wachsmuth, S., & Hoey, J. (2014). Automatic task assistance for people with cognitive disabilities in brushing teeth - A user study with the TEBRA system. ACM Trans.Access.Comput., 5(4), 10:1-10:34. doi:10.1145/2579700.

69. Philipose, M., Fishkin, K. P., Fox, D., Kautz, H., Patterson, D., & Perkowitz, M. (2003). Guide: Towards understanding daily life via auto-identification and statistical analysis. In Proc. of the Int. Workshop on Ubiquitous Computing for Pervasive Healthcare Applications (Ubihealth).

70. Philipose, M., Fishkin, K. P., Perkowitz, M., Patterson, D. J., Fox, D., Kautz, H., & Hahnel, D. (2004). Inferring activities from interactions with objects. IEEE Pervasive Computing, 3(4), 50-57. doi:10.1109/MPRV.2004.7.

71. Poh, M., Swenson, N., & Picard, R. (2012). A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. IEEE Transactions on Bio-Medical Engineering, 57(May), 1243-1252.

72. Pollack, M. E., Brown, L., Colbry, D., McCarthy, C. E., Orosz, C., Peintner, B., Tsamardinos, I. (2003). Autominder: An intelligent cognitive orthotic system for people with memory impairment.

73. Rantz M, Scott SD, Miller SJ, Skubic M, Phillips L, Alexander G, Koopman RJ, Musterman K & Back J, "Evaluation of Health Alerts from an Early Illness Warning System in Independent Living," Computers, Informatics, Nursing, 2013, 31(6):274-280.

74. Robertson, T., & Wagner, I. (2012). Ethics: engagement, representation, and politics in action. In Routledge Inter- national Handbook of Participatory Design (pp. 64–85). New York: Routledge.

75. Rogers, Y. (2006). Moving on from weiser's vision of calm computing: Engaging ubicomp experiences. UbiComp 2006: Ubiquitous computing (pp. 404-421) Springer.

76. Rosenberg, L., Kottorp, A., & Nygård, L. (2012). Readiness for Technology Use With People With Dementia The Perspectives of Significant Others. Journal of Applied Gerontology, 31(4), 510-530.

77. Skubic, M., Alexander, G., Popescu, M., Rantz, M., & Keller, J. (2009). A smart home application to eldercare: Current status and lessons learned. Technology and Health Care : Official Journal of the European Society for Engineering and Medicine, 17(3), 183-201. doi:10.3233/THC-2009-0551; 10.3233/THC-2009-0551.

78. Steele, Bonnie G and Belza, Basia and Cain, Kevin and Warms, Catherine and Coppersmith, Jeff and Howard, J and others. (2003). Bodies in motion: Monitoring daily activity and exercise with motion sensors in people with chronic pulmonary disease. Journal of Rehabilitation Research and Development, 40(5; SUPP/2), 45-58.

79. Stikic, M., Huynh, T., Van Laerhoven, K., & Schiele, B. (2008). ADL recognition based on the combination of RFID and accelerometer sensing. Pervasive Computing Technologies for Healthcare, 258. doi:10.1109/PCTHEALTH.2008.4571084.

80. Stone E & Skubic M, "Fall Detection in Homes of Older Adults Using the Microsoft Kinect," IEEE Journal of Biomedical and Health Informatics, 2015, 19(1):290-301.

81. Story, M. F. (1998). Maximizing usability: The principles of universal design. Assistive Technology, 10(1), 4-12.

82. Tapia, E. M., Intille, S. S., & Larson, K. (2004). Activity recognition in the home using simple and ubiquitous sensors. In Pervasive, 158-175.

83. Taylor, A. S., Harper, R., Swan, L., Izadi, S., Sellen, A., & Perry, M. (2007). Homes that make us smart. Personal and Ubiquitous Computing, 11(5), 383-393.

84. Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. American Journal of Evaluation, 27(2), 237-246.

85. Weiser, M. The Computer for the 21st Century. Scientific American, September, 1991.

86. WHO 2006. Disability and Rehabilitation WHO Action Plan 2006-2011

87. Wild, K. V., Mattek, N., Austin, D., & Kaye, J. A. (2015). "Are You Sure?" Lapses in Self-Reported Activities among Healthy Older Adults Reporting Online. Journal of Applied Gerontology, 0733464815570667.

88. Wilson, D., & Atkeson, C. (2004). Automatic health monitoring using anonymous, binary sensors. In CHI Workshop on Keeping Elders Connected,

89. Winzelberg, A. J., Eppstein, D., Eldredge, K. L., Wilfley, D., Dasmahapatra, R., Dev, P., & Taylor, C. B. (2000). Effectiveness of an internet-based program for reducing risk factors for eating disorders. Journal of Consulting and Clinical Psychology, 68(2), 346.

90. Wolinsky, F. D., Miller, D. K., Andresen, E. M., Malmstrom, T. K., & Miller, J. P. (2005). Further evidence for the importance of subclinical functional limitation and subclinical disability assessment in gerontology and geriatrics. Journals of Gerontology: Series B, 60(3), S146-S151.

91. Wolinsky, F. D., Miller, D. K., Andresen, E. M., Malmstrom, T. K., Miller, J. P., & Miller, T. R. (2007). Effect of subclinical status in functional limitation and disability on adverse health outcomes 3 years later. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences}, 62(1), 101-106.

92. Ziefle, M., Rocker, C., & Holzinger, A. (2011). Medical technology in smart homes: exploring the user's perspective on privacy, intimacy and trust. Paper presented at the Computer Software and Applications Conference Workshops (COMPSACW), 2011 IEEE 35th Annual.

APPENDIX A

IRB PROTOCOL DOCUMENT

Instructions and Notes:

- Depending on the nature of what you are doing, some sections may not be applicable to your research. If so, mark as “NA”.
- When you write a protocol, keep an electronic copy. You will need a copy if it is necessary to make changes.

1 Protocol Title

Include the full protocol title: *Identify design and technical challenges of using a functional assessment system in the real world with the help of a case study, interviews and controlled lab study*

2 **Background and Objectives**

Provide the scientific or scholarly background for, rationale for, and significance of the research based on the existing literature and how will it add to existing knowledge.

- Describe the purpose of the study.
- Describe any relevant preliminary data.

As people get older, it is important to assess their functional ability to determine if they can perform activities of daily living (ADL) tasks that are related to self-care and are fundamental for their functional lives and also those instrumental activities of daily living (IADL) tasks that are not fundamental to functioning but are helpful for independent living. Traditional functional assessment involves rating subjectively the social, occupational and psychological functioning of adults by clinicians or physicians either in clinics or in user's home. However, standardized tests have proven to be non-ecological, infrequent, expensive and, users tend to change their behavior during the tests. By embedding sensors onto objects of daily use and tracking users' performance and behavior unobtrusively, there is a better opportunity to get an ecologically valid assessment of their functional ability. Previous research by Lee [Lee, M., 2012] has shown how data from such a system could be useful in assessing functional ability. Having said that, how do you design a system that it is easier to use, does not alter the behavior of the user, capture different kinds of data, that is necessary to do a proper assessment, how do you present the data, how much data is sufficient, these are some of the questions that needs to be answered. A case study gives us more information on the design and technical challenges of deploying and using such a system and also about the user, which would guide us in building efficient functional assessment systems in the future.

The goal of this study is to identify the design and technical challenges of developing, deploying and using functional assessment systems in the real world, which has not been thoroughly done before. Another important goal is to identify if performance of ADL tasks can be efficiently tracked in conjunction with IADL tasks for functional assessment.

We have developed an intelligent dressing system, which is unobtrusive, blends well with a wooden dresser and can monitor and capture performance data from dressing activity, a first of its kind. Preliminary demonstration of the system's effectiveness has been demonstrated in the following paper using a pilot study conducted at ASU [Mahoney et al, 2014]. We would be testing the system for its design and to also identify any technical challenges of using it in the real world. We have also developed intelligent sensing based systems for brushing, coffee making and medication taking activities.

The data will come from performance data, surveys, interviews, and lab controlled simulated data. Performance data would be gathered from the user (older adult), interviews and surveys would be gathered from both the users and caregivers while simulated data comes from a controlled lab experiment where we test the sensors for its robustness. Sensor data would be captured on four activities namely dressing, coffee making, brushing teeth and medication taking. The reasons for choosing them are 1) dressing and brushing teeth are one of the most common ADL activities and the only ADL activities we were able to reliably track, 2) coffee making and medication taking are the most common IADL activities, which are followed by most older adults and are easier to track compared to other IADL activities. Data would be collected from a wrist-worn device as well, which measures electro-dermal activity (electrical conductance of the skin) to predict their emotion while performing the four activities. There is a chance that the wrist-worn device could be uncomfortable for the older adult to wear, in such scenarios; it could be worn just above their ankle. Researchers won't tell patients their functional ability based on device. We will provide them with data captured from device and help them in understanding the data presented. The focus is more to identify the design and technical challenges of using such a system in the real world and how the data helps to assess functional ability rather than to accurately predict functional ability

Results of this study will be used to validate the effectiveness of using performance data to analyze functional ability and also to identify how performance data could be used to improve awareness and provide timely interventions. It could also help us identify how to design better functional assessment systems and how to better present the results. It could also help us to capture any potential technical challenges on working with sensors embedded onto objects of daily use. The study would also identify affective states while performing a task using a wearable skin conductance sensor (Burleson has demonstrated the use of wearable device to predict emotion [Kapoor et al, 2007]). Tracking these affective states will be used to better understand what tasks might be stressful for the user and ideally being able to anticipate when users are getting frustrated with the task so the system can provide relaxing interventions. The system developed not only helps the users to live independently by gaining awareness of one's own ability but also helps to improve the quality of life for them as well as for their caregiver.

References:

Mahoney, D., Burleson, W., Lozano, C., Ravishankar V., Mahoney, E.L., “Development of a Responsive Emotive Sensing System (DRESS) to aid persons with dementia dress independently”, ISG 2014

Lee, M., “Task based embedded assessment of functional abilities”

Kapoor A, Burleson W, and Picard RW, “Automatic prediction of frustration”, International Journal of Human-Computer Studies 65(8):724-736, 2007

The ECG
3 Inclusion and Exclusion Criteria Describe the criteria that define who will be included or excluded in your final study sample. If you are conducting data analysis only describe what is included in the dataset you propose to use. Indicate specifically whether you will target or exclude each of the following special populations: • Minors (individuals who are under the age of 18) • Adults who are unable to consent • Pregnant women • Prisoners • Native Americans • Undocumented individuals
The study targets three different groups: 1) healthy older adults; 2) healthy young adults; 3) family or friends' caregiving for older adults with impairments. The study plans to recruit 4 consenting, older adults aged 65 and over, who can perform most of their daily activities without any help. They should not have any cognitive impairment. This will be measured through the mini-mental state examination (score >23 will be included). Participants should also have physical mobility not in risk of falling (measured by the TUG test (score <12 seconds) attached). It is important and necessary to recruit participants without cognitive decline as the system is designed to help healthy adults capture potential future functional decline. By capturing their perception on the use of our system, their information needs, their feedback on how to improve the current system could help us design and build a better, efficient, useful system. To validate the system's ability to capture abnormal behavior through task performance, which are indicative of functional decline, we will conduct a controlled lab study where we would recruit healthy normal adults (aged 18+) perform different errors or mistakes on the activities under test. We will also recruit 8 caregivers who have taken care of at least one care recipient (aged 65+) in the last 12 months. The study will not include any of the special populations except Native Americans as a natural proportion of the population at Arizona. Older adults with heart conditions or psychiatric conditions or physical ailments (restricted movement in arms and legs or any physical injury that restricts them to perform most of their daily tasks) will be excluded from the experimentation as these would hurt the data gathered from the sensors. The sensors will not accurately monitor people with these conditions and we will not be able to make any reasonable analysis from the data it captures. The target sample will also not include any participant who has a history of panic attacks or experience a high level of stress. Certain participants may be more sensitive and getting stuck on any activity can increase stress or cause panic attacks which would affect the data captured through sensors. The study involves capturing indicators of emotion through a wearable device and participants who are sensitive can cause abnormal readings. If there were more than the 4 consenting individuals for the case study, 4 people would be selected based on the questionnaire, which enquires about their daily routine, their physical condition/ability (including the ones mentioned above) and their level of functional ability.

4 Number of Participant

Indicate the total number of participants to be recruited and enrolled*:* If there are more than 4 consenting participants who are willing to participate in the study, we would select 4 older adults for case study based on their responses to the questionnaire and chose them based on best fit. By best fit, the ideal candidate would be an older adult without any cognitive impairment and who is able to perform all the daily activities we are interested in on their own. If more than 4 older adults recruited meet this criteria then we will randomize the selection. We would also select 8 caregivers for Interviews and feedback. The selection criterion is that they should have cared for an older adult for a minimum of 12 months. Preference is given to those, whose care recipient has some kind of cognitive impairment. We would select 8 young adults for testing the sensors as well using a controlled lab study.

5 Recruitment Methods

- Describe when, where, and how potential participants will be identified and recruited.
- Describe materials that will be used to recruit participants. (Attach copies of these documents with the application.)

4 older adults, will be recruited using the recruitment letter and flyer to determine interest levels and their functional ability for the case study. Similarly we would recruit 8-12 caregivers and 8 younger adults for interviews and closed lab study respectively. Any person who expresses interest will receive a follow-up email / call containing an example of their appropriate recruitment letter (see attached).

6 Procedures Involved

Describe all research procedures being performed and when they are performed. Describe procedures including:

- Surveys or questionnaires that will be administered. (Attach all surveys, interview questions, scripts, data collection forms, and instructions for participants.)
- What data will be collected including long-term follow-up?
- Lab procedure and tests and related instructions to participants
- The period of time for the collection of data.
- Describe the amount and timing of any compensation or credit to participants.
- If the research involves conducting data analysis only, describe the data that that will be analyzed.

Part 1: Case Study for Older Adult Participants

Consenting participants for the case study will be first asked to fill out a questionnaire (attached), which asks details about their daily routine, their behavior and functional ability. Filling up the questionnaire should not take more than 10-15 minutes, this will be followed by a cognitive (MMSE) and physical ability test (TUG), and these should take no more than 15 minutes. More information on the selection criteria can be found in section 3. Based on their answers to the questions and their performance on the two tests, 4 participants would be selected for the case study. This will take place either at ASU (if participants can travel) or in participants home.

The study would be conducted in three phases.

Phase 1:
Before the start of this phase, the experimenter will review the study goals, what data would be collected, and study protocol (see phase 3 for reference). In the first phase, participants selected for the case study will be interviewed (document attached), which would take less than 2 hours. Participants would be interviewed again once at the end of 2 weeks (these interviews should take less than an hour, document attached). The interview questions would test the participant's perception of functional assessment systems, their information needs and how the use of wearable devices has changed over the course of the case study. Interviews would be audio recorded (if consented) for analysis purposes.

Phase 2:
In the second phase, the system will be installed in participant's home and training would be provided to the participant on how to use the system; both installation and training will be provided by the researcher and it would take 1-2 days depending on their availability and their comfort level in using the system. Participants will not be paid for installment and training. This installment and training period is separate from the 2-week experimental period.

Installing the system specifically would involve adding door sensors and video cameras to the participant's dresser, door / moisture / temperature sensor to coffee maker, door sensor to tooth brush, multiple door sensors to the pillbox and few more door sensors to the cabinets that contains coffee powder, coffee filter, pillbox and toothbrush (optional for pillbox and toothbrush). The function of door sensors attached to different parts of the objects mentioned above is to provide us with on/off or open/close functionality. All these sensors monitor for signals all day long and there is no need for user input for activation or deactivation. Video cameras would be attached only to the dresser and would be used for dressing activity alone. Still cameras will not be used for tracking task performance of any activity. For dressing, to protect participant privacy, they will be asked to put on the shirt and pants on top of the clothes they are already wearing. Once the activity is complete, they can remove the clothing provided. Participants will simulate dressing twice a day rather than following their daily routine, i.e. wear the shirts and pants provided, once in the morning and once in the evening. The system would provide audio prompts if the user makes any mistake, stays inactive or moves away from the dresser. The video camera attached to the dresser will start recording only when the user opens up the drawer containing the shirt / pants. It will stop recording once the drawer is closed. Users will have the control to switch it on/off to ensure privacy. In scenarios where the user is opening / closing the drawer when there are not performing the dressing activity, they can switch the video cameras off. How to turn the cameras on/off is described in the protocol document. Since dressing activity is performed with their clothes on, there is no risk of privacy being violated. We are not going to use the data from dressing for assessment rather for testing its efficiency and identifying design challenges. All activities would be performed for a period of 2 weeks. The entire installation should not take more than 2 days.

The training process involves explaining them about the different systems and sensors installed in their home and how to use them. Teaching them how to monitor task performance through a web based interface. Training would be provided to the users on how to monitor the sensors and system for proper functioning, contact information of the researcher would be provided for scenarios where sensors or system does not work properly. Users need to ensure the system is ON and working every day before they can perform the four activities. The "protocol – participants" document will be introduced and given to the participants for reference on what to do in the following phase of using the system. The entire tasks of installation and training should not take more than 2-4 days depending on their availability and their comfort level in using the system.

Phase 3:
In the third phase, the participant will be asked to follow this phase's protocol for a period of 2 weeks. They will be asked to read, ask any further questions. Immediately after, the participants would be asked to wear the wrist-worn sensor and keep calm to get a baseline of their electro-dermal activity. This data is used to establish baseline for the skin conductance sensor that the participants would be wearing during the case study. This step is necessary to understand their change in emotion so that we can adjust our parameters for effective interventions. They will be required to wear the skin conductance sensor every day before performing any of the four activities. Once they complete the activities, they can remove the skin sensor and repeat this process again the next day for a period of 2 weeks.

Researcher will be present to conduct interviews at the end of second week. Researchers will be present during all phases. Specifically for phase 3, where the researchers will conduct interview at the start of the 2-week study, and once at the end of 2nd week.

Participants for the case study will be able to choose to perform the activities on their own schedule. There is no requirement of a specific time on which these activities need to be performed. They can also choose to opt out of performing an activity on any particular day. Care is taken to ensure we do not interfere with their daily routine. Since these four activities are already part of their daily routine, they need not spend separate time for this case study with the exception of the simulated dressing for a week. The system would be passive and would monitor, track and capture data from sensors when activities are performed without disturbing the participant. One of the activities (dressing) will be video captured (if consented) as it is used to identify any design and technical challenges of using an automated dressing system with the target population, while data from the rest of the activities will be used for assessment. Dressing activity is video tapped to identify how people with dementia perform dressing activity, this will help us to improve the efficiency and identify any possible lapses in our intelligent dressing system.

The participants can withdraw from the case study at any point if they feel the need to do so. Each participant (care recipient) selected for the case study, would be paid $50 per week (for phase 3 alone) at the end for his or her participation. If for some reason, they chose to stop the study in between, they would be paid for the number of weeks they participated during phase 3. They would not be paid separately for the questionnaire, interviews, installation or training. After the completion of the study, de-installation of the system will take place. Based on convenient time for the participants, researchers will come to participant's home and remove all the equipment. This should not take more than couple of hours. The funds for the compensation are available to be used from the investigator's "Technology in home intervention to sustain dementia patients dressing abilities" grant, with account number CRS0472.

Part 2: Interviews
Interviews are conducted with caregivers to understand their information needs, their feedback on the current system and the user interface used to track performance data on daily activities. Their feedback goes a long way to design efficient usable systems. Interview would take a maximum of 3 hours. Only one interview would be conducted per caregiver.

Part 3: Controlled lab study
In the third part of our study, we will conduct a controlled lab simulation / study with healthy adults (potentially students at ASU) asking them to perform the 4 activities under test (brushing, dressing, coffee making and medication taking). This study is conducted to test the robustness and accuracy of the sensors. We will ask them to make mistakes / errors / delays in performing tasks and identify if the system is able to capture them. It is always hard to validate the system's accuracy in a real world setting, as it is hard to make all the mistakes. By simulation, we can ensure most of the common mistakes possible in a similar real world environment is tested within a closed lab environment.

Data collection and analysis:
Data collected from this study includes notes and audio recordings from the interviews, participant responses from questionnaires, performance data of participant's daily activities specifically those which are tracked (dressing, coffee making, brushing teeth and medication taking), electro-dermal activity data from the wrist-worn device and results from the standardized cognitive and physical ability test and, sensor data from controlled lab study. We will mainly use the performance data for analysis purposes and to identify how it affects perception, behavior and if it improves awareness of participant's functional ability for the users.

7 Risks to Participants
List the reasonably foreseeable risks, discomforts, or inconveniences related to participation in the research. Consider physical, psychological, social, legal, and economic risks.

Given participant's personal preferences, there is a slight risk of discomfort or skin irritation from wearing the wrist-worn device. In such scenarios, it could be worn just above their ankle to mitigate the discomfort or if it worsens, it could be removed altogether too. In any research, there is some possibility that you may be subject to risks that have not yet been identified.

8 Potential Benefits to Participants
Realistically describe the potential benefits that individual participants may experience from taking part in the research. Indicate if there is no direct benefit. Do not include benefits to society or others.

There is no direct benefit to the participant.

9 Prior Approvals
Describe any approvals – other than the IRB - that will be obtained prior to commencing the research. (e.g., school, external site, or funding agency approval.)

N/A

10 Privacy and Confidentiality
Describe the steps that will be taken to protect subjects' privacy interests. "Privacy interest" refers to a person's desire to place limits on with whom they interact or to whom they provide personal information.

Describe the following measures to ensure the confidentiality of data:

- Where and how data will be stored?
- How long the data will be stored?
- Who will have access to the data?
- Describe the steps that will be taken to secure the data (e.g., training, authorization of access, password protection, encryption, physical controls, certificates of confidentiality, and separation of identifiers and data) during storage, use, and transmission.

Although this study does not require any embarrassing or sensitive information to be revealed about the participants, it is recognized that some participants may not want anyone knowing they were a part of this experiment or knowing any results from their testing. In order to protect their identity, participants whose data will be reported individually will be given an ID. Also, all data that could be used to relate to the participants will be destroyed once the experimentation, analysis and reporting is completed.

All the data will be periodically stored in a database with a unique id for each participant and that is how we will track each participant's data. There will not be any personal information stored in the database other than their task performance data.

To prevent violation of privacy as the study involves tracking personal information, the data captured would be accessible only to the researchers involved with this study and no one outside of it would have access to it.

Anonymized data will be stored on an external drive, which would be safely locked at the research lab in ASU after the case study is over, taken out only by the lead research for data analysis. Once the dissertation is complete and approved, the data would be kept for a year (December 2015), after which the raw data will be destroyed, unless results are compelling in which case publication of the study may be sought. Only the people directly involved in the project will have access to the data (lead researcher, his advisor, his colleagues). Reporting of data and results will only include pseudonyms to protect participant's identity.

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11 Consent Process

Indicate the process you will use to obtain consent. Include a description of:

- Where will the consent process take place
- How will consent be obtained

Non-English Speaking Participants

- Indicate what language(s) other than English are understood by prospective participants or representatives.
- If participants who do not speak English will be enrolled, describe the process to ensure that the oral and/or written information provided to those participants will be in that language. Indicate the language that will be used by those obtaining consent.

Waiver or Alteration of Consent Process (written consent will not be obtained, required information will not be disclosed, or the research involves deception)

- Review the "CHECKLIST: Waiver or Alteration of Consent Process (HRP-410)" to ensure you have provided sufficient information for the IRB to make these determinations.

Participants who are minors (individuals who are under 18)

- Describe the criteria that will be used to determine whether a prospective participant has not attained the legal age for consent to treatments or procedures involved in the research under the applicable law of the jurisdiction in which the research will be conducted.

Consent will take place in two steps: 1) Recruitment Letter: Participants expressing interest will be sent a recruitment letter via email as well as mailed hard copies to their home, explicitly and briefly explaining purpose and procedure, and telling them they can withdraw from the study at any time. 2) Interview, Case Study and Controlled lab study would only begin after all participants are informed about the study and verify that they consent to participate by reading and signing the consent form. (See attached recruitment letter and informed consent forms). There are separate consent forms for each participant in each category of the studies. The consent process involves reading and consenting to instructions, knowing the risks and tasks involved with this study and consenting to audio/video recording as part of this study.

Participants would be informed verbally as well, that they could quit the study at any time with no penalty (e.g., they will be paid 50$ for each week they spent during phase 3 of the study. They will not be paid for participation during other phases of the study.). Caregivers (30$) and young adults (10$) who take part in Interviews and Lab study respectively would be compensated separately for their involvement.

12 Process to Document Consent in Writing

If your research presents no more than minimal risk of harm to participants and involves no procedures for which written documentation of consent is normally required outside of the research context, the IRB will consider a waiver of the requirement to obtain written documentation of consent.

(If you will document consent in writing, attach a consent document. If you will obtain consent, but not document consent in writing, attach the short form consent template or describe the procedure for obtaining and documenting consent orally.)

Consent will be gathered in writing and through reading an oral script prior to subject's participation (see attached consent form).

13 Training

Provide the date(s) the members of the research team have completed the CITI training for human participants. This training must be taken within the last 3 years. Additional information can be found at: http://researchintegrity.asu.edu/training/humans

Vijay Kumar Ravishankar 05/27/2014
Erin Walker

APPENDIX B

CONSENT FORM – CASE STUDY

Using case study to identify design and technical challenges in a functional assessment system

INTRODUCTION

The purposes of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

RESEARCHERS

Vijay Kumar Ravishankar, Doctoral student, Ira A. Fulton School of Engineering, has invited your participation in a research study. He is working under the direction of Erin Walker, Assistant Professor at Arizona State University and Winslow Burleson, Associate Professor at New York University's College of Nursing.

STUDY PURPOSE

The purpose of this case study is to identify the design and technical challenges of using functional assessment systems in the real world. A functional assessment is a multi-dimensional assessment to evaluate a person's functional ability. A specific evaluation of functional status is essential because functional impairment cannot be predicted on the basis of the number or the severity of medical diagnosis in an individual. Specifically, we will be examining the use of our functional assessment system, which is a suite of sensors embedded onto objects of daily use that captures your performance on daily activities such as dressing, coffee making, brushing teeth and medication adherence.

DESCRIPTION OF RESEARCH STUDY

Participants in this study must be 65 years or older without any cognitive impairment.

Participants must not suffer from:

- Heart conditions
- Psychiatric conditions
- Physical ailments such as restricted movement in arms and legs or any other physical injury that prevents you from performing daily tasks
- Panic attacks or high levels of stress

These conditions will cause incorrect sensor readings.

Study Phase 1:

Participants will be asked to complete a questionnaire on your daily schedule and wellbeing, perform a Mini-Mental State (cognitive) Examination, perform the Timed Up and Go (physical) Test. These tests will be conducted either at ASU (department of computer science) or in your home. Participants will spend approximately 30-45 minutes participating in proposed activities in phase 1 of the study.

Study Phase 2:

Participants may be invited to join a second part of the study, which involves a temporary installation of the functional assessment system technology in your home. Installing the system specifically would involve adding door sensors and video cameras to the participant's dresser, door / moisture / temperature sensor to coffee maker, door sensor to tooth brush, multiple door sensors to the pillbox and few more door sensors to the cabinets that contains coffee powder, coffee filter, pillbox and toothbrush (optional for pillbox and toothbrush). The function of door sensors attached to different parts of the objects mentioned above is to provide us with on/off or open/close functionality. All these sensors monitor for signals all day long and there is no need for user input for activation or deactivation. Video cameras would be attached only to the dresser and would be used for dressing activity alone. Still cameras will not be used for tracking task performance of any activity. For dressing, to protect your privacy, you are going to wear the shirt and pants on top of the clothes you are already wearing. You can remove the clothing provided once the activity is complete. You are going to simulate dressing twice a day rather than following your daily routine, i.e. wear the shirts and pants provided, once in the morning and once in the evening. The video camera attached to the dresser will start recording only when the user opens up the drawer containing the shirt / pants. It will stop recording once the drawer is closed. You will have the control to switch it on/off to ensure privacy. In scenarios where the user is opening / closing the drawer when there are not performing the dressing activity, you can switch the video cameras off. How to turn the cameras on/off is described in the protocol document. Since dressing activity is performed with their clothes on, there is no risk of privacy being violated. We are not going to use the data from dressing for assessment rather for testing its efficiency and identifying design challenges. All activities would be performed for a period of 2 weeks. The entire installation should not take more than 2 days. Researchers will train you on how to use the system, which will take 1-2 days of your time.

Study Phase 3:
The technology will be in your home for a period of 2 weeks, in which it will monitor your functional abilities while performing the four activities mentioned above. You will be asked to wear wrist worn sensor to measure affective states, like how you are feeling when performing tasks. We will capture baseline data initially to set up the sensor and adjust our parameters. To do so, we will ask you to stay calm and still. This will helps us to better gauge your affective state so that appropriate interventions can be provided. We will ask to interview you at the beginning and end of the study about sensors attached to your objects of daily use, your perception of using them, feedback on data and any problems that you may have with using the system. The interviews will last between 1-2 hours each. We will provide you instructions and detailed information about the study protocol in the form of a packet to read through before consenting to be a part of the study. Please ask us any questions you have.

IMAGE, VIDEO AND AUDIO RECORDING CONSENT
Phase 3 of the study involves the video recording of your performance in a simulated dressing activity. More information about this can be found in the protocol packet we gave you. Please ask us any questions you have. Finally we would like to be able to get audio recordings of our interviews with you. Parts of the recording of the session will be transcribed to written form, without identifying the user. The recorded media will be erased when all data from it have been reviewed and coded. Please let us know if you do not want to be audio or video recorded. You can change your mind after we start just let the researcher know.

RISKS

There could be a risk of skin irritation or uncomfortable feeling from wearing a wrist-worn sensor. In such scenarios, it could be worn just above your ankle to mitigate the discomfort or if it worsens, it could be removed altogether too. In any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS

There is no direct benefit to you for participating in this study. However, your participation in this study may help the improvement of technology that can track a person's functional performance in daily activities.

COSTS AND PAYMENTS

Participants invited to Phase 3 of the study will be compensated for the proposed activities in that phase of the study. Participants will be paid $50 per week for 2 weeks for their participation in the study during phase 3.

CONFIDENTIALITY

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, Mr. Ravishankar will keep all data on an external drive safely and locked in the research lab at ASU. Only a self-assigned ID will be used to keep track of your information. Your name will never be used, and as soon as your information is analyzed and reported, your information will be deleted from the data files to insure complete confidentiality.

WITHDRAWAL PRIVILEGE

Participation in this study is completely voluntary. It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. If you withdraw from the study, you will still be compensated for the amount of time spent in phase 3 activities. Once you withdraw from the study, we will come to your home to remove everything we have setup, which should not take more than 2 hours.

VOLUNTARY CONSENT

Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Vijay Kumar Ravishankar, (480) 270-9625, vravisha@asu.edu. You can also contact Dr. Erin Walker at erin.a.walker@asu.edu

If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk; you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965 6788.

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given (offered) to you.

Your signature below indicates that you have read the consent form and protocol packet, and you consent to participate in the above study.

____________________	_________________________	____________
Subject's Signature	Printed Name	Date
____________________	_________________________	____________
Legal Authorized Representative (If applicable)	Printed Name	Date

By signing below you are agreeing to be video and audio recorded, and to have selected images of your home, video and audio recorded.

___________________	_________________________	____________
Subject's Signature	Printed Name	Date
___________________	_________________________	____________
Legal Authorized Representative (If applicable)	Printed Name	Date

INVESTIGATOR'S STATEMENT

"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answer any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided (offered) the subject/participant a copy of this signed consent document."

Signature of Investigator ____________________ Date __________

APPENDIX C

CONSENT FORM – CAREGIVER INTERVIEW

Identify design and technical challenges of using a functional assessment system

INTRODUCTION

The purposes of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

RESEARCHERS

Vijay Kumar Ravishankar, Doctoral student, Ira A. Fulton School of Engineering, has invited your participation in a research study. He is working under the direction of Erin, Walker, Assistant Professor at Arizona State University and Winslow Burleson, Associate Professor at New York University's College of Nursing.

STUDY PURPOSE

The purpose of this study is to identify the design and technical challenges of using functional assessment systems in the real world. A functional assessment is a multi-dimensional assessment to evaluate a person's functional ability. A specific evaluation of functional status is essential because functional impairment cannot be predicted on the basis of the number or the severity of medical diagnosis in an individual. Specifically, we will be examining the use of a functional assessment system, which is a suite of sensors embedded onto objects of daily use that captures your care recipient's performance on daily activities such as dressing, coffee making, brushing teeth and medication adherence.

DESCRIPTION OF RESEARCH STUDY

If you decide to participate, you will join a study involving an interview about caregiving and feedback about our system. Your participation is limited to answering questions during the interview and, providing feedback about our system and resource to track information. You should have some familiarity with helping someone (could be your loved one) perform any of their daily activities.

Your participation will last for about 2-3 hours in total. There will be a screening process to select the right candidates for our study. If you did not meet our requirements, you will not be able to participate in this interview and you will not be compensated.

The interview will be about your background, your experience in providing care and using technology including sensors or/and assistive devices for your care recipient, your information needs, your perception and feedback on our system, and our resource for tracking activity performance to name a few.

RISKS

There are no risks from taking part in this study. In any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS

There is no direct benefit for participating in this study. However, your participation in this study may help the improvement of technology that can track a person's functional performance in daily activities.

CONFIDENTIALITY

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, Mr. Ravishankar will keep all data on an external drive safely and locked in the research lab at ASU. Only a self-assigned ID will be used to keep track of your information. Your name will never be used, and as soon as your information is analyzed and reported, your information will be deleted from the data files to insure complete confidentiality.

WITHDRAWAL PRIVILEGE

Participation in this study is completely voluntary. It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time.

COSTS AND PAYMENTS

There is a 30$ compensation for your participation in this study.

IMAGE AND AUDIO RECORDING CONSENT

This study involves taking audio recordings of our interviews with you (if consented). Please let us know if you do not want to be audio recorded. You can change your mind after the interview starts just let the researcher know. Parts of the recording of the session will be transcribed to written form, without identifying the user. The recorded media will be erased when all data from it have been reviewed and coded.

VOLUNTARY CONSENT

Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Vijay Kumar Ravishankar, (480) 270-9625, vravisha@asu.edu. You can also contact Dr. Erin Walker at erin.a.walker@asu.edu.

If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk; you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965 6788.

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given (offered) to you.

Your signature below indicates that you consent to participate in the above study.

______________________ ___________________________ __________

Subject's Signature Printed Name Date

______________________ ___________________________ __________
Legal Authorized Representative Printed Name Date
(If applicable)

By signing below you are agreeing to have selected to be audio recorded.

_______________________ ___________________________ ___________
Subject's Signature Printed Name Date

_______________________ ___________________________ ___________
Legal Authorized Representative Printed Name Date
(If applicable)

INVESTIGATOR'S STATEMENT

"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answer any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided (offered) the subject/participant a copy of this signed consent document."

Signature of Investigator _________________________ Date ___________

APPENDIX D

CONSENT FORM – CONTROLLED LAB STUDY

Identify design and technical challenges of using a functional assessment system

INTRODUCTION

The purposes of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

RESEARCHERS

Vijay Kumar Ravishankar, Doctoral student, Ira A. Fulton School of Engineering, has invited your participation in a research study. He is working under the direction of Erin Walker, Assistant Professor at Arizona State University and Winslow Burleson, Associate Professor at New York University's College of Nursing.

STUDY PURPOSE

The purpose of this study is to identify the design and technical challenges of using functional assessment systems in the real world. A functional assessment is a multi-dimensional assessment to evaluate a person's functional ability. A specific evaluation of functional status is essential because functional impairment cannot be predicted on the basis of the number or the severity of medical diagnosis in an individual. Specifically, we will be examining the use of a functional assessment system, which is a suite of sensors embedded onto objects of daily use that captures your care recipient's performance on daily activities such as dressing, coffee making, brushing teeth and medication adherence.

DESCRIPTION OF RESEARCH STUDY

If you decide to participate, you will join a study involving simulation of daily tasks under closed controlled lab environment. Your participation is limited to performing daily tasks such as making coffee, taking pills and brushing under researcher supervision and, providing feedback about our system and resource to track information.

Your participation will last for about 20-30 minutes in total. In order to participate you need to be 18 years or older and without any physical or cognitive impairment that impedes your performance on daily tasks mentioned above.

RISKS

There are no risks from taking part in this study. In any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS

There is no direct benefit for participating in this study. However, your participation in this study may help the improvement of technology that can track a person's functional performance in daily activities.

CONFIDENTIALITY

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, Mr. Ravishankar will keep all data on an external drive safely and locked in the research lab at ASU. Only a self-assigned ID will be used to keep track of your information. Your name will never be used, and as soon as your information is analyzed and reported, your information will be deleted from the data files to insure complete confidentiality.

WITHDRAWAL PRIVILEGE

Participation in this study is completely voluntary. It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time.

COSTS AND PAYMENTS

There is a 10$ compensation for your participation in this study.

IMAGE AND AUDIO RECORDING CONSENT

There is no image, audio or video recording for this study.

VOLUNTARY CONSENT

Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Vijay Kumar Ravishankar, (480) 270-9625, vravisha@asu.edu. You can also contact Dr. Erin Walker at erin.a.walker@asu.edu

If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk; you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965 6788.

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given (offered) to you.

Your signature below indicates that you consent to participate in the above study.

____________________	____________________________	____________
Subject's Signature	Printed Name	Date
____________________	____________________________	____________
Legal Authorized Representative (If applicable)	Printed Name	Date

INVESTIGATOR'S STATEMENT

"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answer any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided (offered) the subject/participant a copy of this signed consent document."

Signature of Investigator ________________________ Date __________

APPENDIX E

QUESTIONNAIRE - CASE STUDY

Directions: This questionnaire asks you questions about your personal daily routine, behavior and about your physical and functional ability. You should provide either a short answer, or circle a rating number within a 7-point scale. Your responses will help us identify a perfect match to conduct the case study.

1. Have you ever had a major stroke? (YES / NO)

2. Have you ever had a minor or mini stroke? (YES / NO)

3. Have you ever had a major physical injury in the last 10 years? (YES / NO)

4. Do you have any physical /cognitive impairment that prevents you from performing any of your daily activities on your own? (YES / NO)

5. Do you have a history of panic attacks or experience a high level of stress while performing daily activities or while using wearable devices? (YES / NO)

6. Can you perform dressing activity on your own without any external help?

Never Sometimes Always

7. Can you make a pot of coffee on your own without any external help?

Never Sometimes Always

8. Can you brush your teeth on your own without any external help?

Never Sometimes Always

9. Can you take your pills on your own without any external help?

Never Sometimes Always

10. Do you need help on performing some other daily activity? (YES / NO)

If YES, please specify which one ______________________________________

11. How often do you forget performing an activity or steps from your daily routine?

Never | Sometimes | Always

If more than once, please specify which activity ________________________________

12. Are you comfortable asking for help in performing any of your daily activities?

Never | Sometimes | Always

13. Would you be comfortable if a computer helps with your daily activities instead of a person?

Not at all | Maybe | Absolutely

14. Do you use any wearable device? (YES / NO)

If YES, please specify ____

15. How comfortable would you be in using a wrist-worn device for the study?

Not comfortable | can try | No problem

16. How important is it for you to live independently and perform all your activities on your own?

Not important | not sure | Very important

Personal Questions

1. What is your age?

☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ 70-79 ☐ 80 or older

2. What is your height?

3. Are you left handed or right handed? ☐ Left ☐ Right

4. Do you use the chair for wearing pants in your home? (YES / NO)

5. Are you comfortable working with a system that uses camera to monitor / track tasks?

☐ Yes ☐ No ☐ Sometimes

6. Are you concerned with privacy when working with such a system?

☐ Yes ☐ No

7. What is your usual order of dressing (shirt then pants / pants then shirt)?

8. How often do you mistakes while dressing?

☐ Very often ☐ Sometimes ☐ Very rare ☐ Never

9. Are you comfortable with using computers? (Checking email online?)

☐ Yes ☐ No

APPENDIX F

QUESTIONNAIRE – CAREGIVER INTERVIEW

Directions: This screening questionnaire is used to screen participants for the Interviews. You should provide either a short answer, or select an option from the list. Your responses will help us identify a perfect match to conduct the interview.

Participant # ______________ Date: ________________

To see if you might be eligible to participate in this project, I would like to take about 10 minutes of your time to ask you some questions. Is this a convenient time?

<u>If yes</u>: Before we begin, let me assure you that anything you say is strictly confidential. Also, there is no cost to participate in this project. Are you ready to begin?

<u>If no</u>: When would be a better time for me to call you back?

Date: __________________________

Time: __________________________

INTRODUCTION: I would first like to ask some questions about you, as a caregiver. Then I would like to ask some questions about the care recipient (CR). Is this OK?

1. What is your age?

☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ 70-79 ☐ 80 or older

2. Gender: ___________ (this will be filled in by the interviewer, not asked)

3. What is the highest level of education you have obtained?

____ Some High School
____ High School
____ Some College/University
____ Completed College/University
____ Post Graduate Studies
____ Other ___________________

4. How long have you been a caregiver for? ________________________

5. Have you been a caregiver in the last 12 months?

☐ YES ☐ NO

6. What is the relationship with the person you are caring for?

☐ Spouse ☐ Daughter ☐ Son

☐ Daughter in-law ☐ Son in-law ☐ Grand Daughter / Son

☐ Other ___________________

7. Approximately how much time do you spend with him/her each day?

Hours per day: _____________

8. Is your loved one: ☐ Male ☐ Female

9. What is the age group of your loved one?

☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ 70-79 ☐ 80 or older

10. Do you have any physical /cognitive impairment that prevents you from performing your caregiving duties?

☐ YES ☐ NO

If YES, please specify ____

11. Do your loved one / person you cared for has any physical / cognitive impairment?

☐ YES ☐ NO

If YES, please specify ____

12. I would like to get an idea of your familiarity and comfort level with technology.

a) Do you use a computer? Yes No
b) Do you use a cellphone? Yes No

c) On a scale of 1 to 5 please rate how comfortable you are using or trying some sort of technology?

1__________2__________3_________4__________5

1. Not comfortable at all
2. Not very comfortable
3. Neutral
4. Somewhat comfortable
5. Very comfortable

13. I would like to get a sense of your loved one's level of functioning. Please answer by saying 'yes' or 'no' to the following statements and provide any comments or examples as necessary.

Impairment	YES	NO	COMMENTS/EXAMPLES
Problems with memory – can remember new things (STM) and can't remember past (LTM)			
Disorientation – to person, place or time; visual / spatial disorientation, inability to interpret environmental cues			
Personality changes – irritability, poor temper control, anxiety, inappropriate mood or behavior, withdrawal from social interaction, decreased ability to function in social interactions			
Communication difficulties – absent or impaired language abilities, difficulty with word finding and expressing needs, etc.			

APPENDIX G

CAREGIVER INTERVIEW QUESTIONS

Caregiver #: _________________ Conducted By: _____________

Date: ___________________

Hi _____________. It's nice to meet you! Thank you for letting me come to your home today.

I appreciate your help and co-operation for this study. This interview is to capture how you use sensors and/or assistive devices in your home or in your loved one's home and how that has changed your perception of them. This interview is also to capture your information needs, feedback of our system and how you can help us make it better.

Do you have any questions for me so far?

I am going to start the interview now. If there is a question you do not understand, let me know and I will repeat the question or if there is a question you don't feel comfortable answering, we can skip over it. If you have any questions or comments during the interview don't hesitate to ask me at any time.

Participant #: ____

Part 1 – Identifying and Describing Assistive Devices Used

I am now going to ask you some questions about various categories of devices you or your loved one may use to help with day- to-day life. For each device that you do use, I am going to ask you some follow-up questions.

i. MEDICATION REMINDERS

Do you or your loved one use any **medication reminders** to provide support for medication management? These devices help people who have difficulty remembering to take their medication at the correct time.

IF NO/UNSURE: For example, medication reminders may include pillboxes, automatic pill reminders or automatic pill dispensers)

If YES: What is the name of the medication reminder you use?
____

(*If many assistive devices are named for this category, ask for the most commonly used for category and continue with follow up questions)*

a) Who uses this **medication reminder**?
___ Myself ___ My loved one ____ Both of us

b) Who would you say is the primary user? (If **you** use medication reminder, please only consider your use if it is to help with care giving role and not if it is for your own day-to-day use.)
___ Myself ___My loved one

Can you describe/show me how it is used?

(Proceed with Caregiver questions and/or Care Recipient Questions where applicable)

CAREGIVER QUESTIONS

If it is to help with care giving- What care giving activity do you use it for?

c) How frequently do you use this **medication reminder** to help with care giving?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

- For how long have you been using it?
- Has your use changed over time? If so, how?

d) How helpful do you find this **medication reminder**?

1 2 3 4 5

1 –Very unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very helpful

-Is there anything you like about this **medication reminder**? What?
-Is there anything that makes it easy to use? What?
-Is there anything you do not like about this **medication reminder?** What? -Is there anything that makes it difficult to use?

e) How comfortable are you using this **medication reminder**?

1 2 3 4 5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

CARE RECIPIENT QUESTIONS

For this set of questions, I would like you to think about your loved one's use of the medication reminder. Please try to answer the best you can while considering their perspective.

-Have you ever seen your loved one use the **medication reminder** on his/her own?

f) How frequently does your loved one use this **medication reminder**?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long has your loved one been using this **medication reminder** to help with any cognitive difficulties?

-Has your loved one's/your use changed over time? If so, how?

g) How helpful would you say this **medication reminder** is for your loved one?

1 2 3 4 5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

-Is there anything your loved one likes about this **medication reminder**? What?

-Is there anything that makes it easy to use for your loved one? What?

-Is there anything your loved one does not like about this **medication reminder**? What?

-Is there anything that makes it difficult to use for your loved one? What?

h) How comfortable is your loved one using this **medication reminder**?

1 2 3 4 5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

IF NO (Does not use this category of device):
-What are the reasons for you and your loved one NOT using a **medication reminder**? You can choose more than one of the following responses.

_____ Haven't heard of it
_____ Does not apply to my care giving role
_____ Does not apply to loved one
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other ______________________

-How useful do **medication reminders** sound to you?

-If one of these **medication reminders** was given to you or your loved one, would you use it? Why/why not?

iii**. REMINDER SYSTEMS (or Memo Minders)**

Does your loved one use, or have you provided your loved one with **memo minders or reminder systems**? This group of devices helps people who have difficulty remembering to carry out tasks and/or remembering to stop a task.

IF NO/UNSURE:
This is a large category of devices. For example, auto shut off kettles or stove minders fall under this category, as do devices that play a short recorded message that can give prompts and reminders. More sophisticated memo minders can play messages when movement is detected (for example, if placed by the front door can it remind person to lock the door or to not leave the building). Do you use anything that sounds like this?
If YES:
What is the name of the device you use?
____

(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) Who uses this **reminder system**?
   ___ Myself ___ My loved one ____ Both of us
b) Who would you say is the primary user? (If **you** use a reminder system, please only consider your use if it is to help with care giving role and not if it is for your own day-to-day use.)
   ___ Myself ___My loved one

Can you describe/show me how it is used?
(Proceed with Caregiver questions or Care Recipient Questions where applicable)

CARE RECIPIENT QUESTIONS
For the next set of questions, I would like you to think about your loved one's use of the **reminder system**. Please try to answer the best you can while considering their perspective.

-Have you ever seen your loved one use the **reminder system** on his/her own?

f) How frequently does your loved one use this **reminder system**?

1 2 3 4 5

1 – Less than once a month
2 – Once a month

3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long has your loved one been using this **reminder system** to help compensate for any cognitive difficulties?

-Has your loved one's/your use changed over time? If so, how?

g) How helpful would you say this **reminder system** is for your loved one?

1	2	3	4	5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

-Is there anything your loved one likes about this **reminder system**? What?

-Is there anything that makes it easy to use for your loved one? What?

-Is there anything your loved one does not like about this **reminder system**? What?

-Is there anything that makes it difficult to use for your loved one? What?

h) How comfortable is your loved one using this **reminder system**?

1	2	3	4	5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

-How did you hear about this **reminder system**?
___ Occupational Therapist
___ Physical Therapist
___ Social Worker
___ Physician
___ Friend
___ Family Member
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):
-What are the reasons for you and your loved one NOT using a **reminder system**?

You can choose more than one of the following responses.
____ Haven't heard of it
____ Does not apply to my care giving role
____ Does not apply to loved one
____ Too expensive
____ Too complicated/too hard to learn
____ Not available
____ Not interested
____ Other ______________________

-How useful do **reminder systems** sound to you?

-If one of these **reminder systems** were given to you or your loved one, would you use it? Why/why not?

iv. **SIGNS, NOTICES and OTHER ENVIRONMENTAL AIDS**
Do you or your loved one use **signs or notices** around your home – these are simple visual aids that can help remind people to do things.

IF NO/UNSURE: For example, signs, labels, whiteboards, bulletin boards, and pictures throughout your home can be used to trigger your loved one's memory.

If YES: What is the name of the device you use?
____

(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) Who uses these **environmental aids**?
   ___ Myself ___ My loved one ____ Both of us
b) Who would you say is the primary user? (If **you** use an environmental aid, please only consider your use if it is to help with care giving role and not if it is for your own day-to-day use.)
   ___ Myself ___My loved one

Can you describe/show me how it is used?
(Proceed with Caregiver questions and/or Care Recipient Questions where applicable)

CARE RECIPIENT QUESTIONS
For the next set of questions, I would like you to think about your loved one's use of the **environmental aid**. Please try to answer the best you can while considering their perspective.

-Have you ever seen your loved one use the **environmental aid** on his/her own?

f) How frequently does your loved one use this **environmental aid**?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long has your loved one been using this **environmental aid** to help compensate for any cognitive difficulties?

-Has your loved one's/your use changed over time? If so, how?

g) How helpful would you say this **environmental aid** is for your loved one?

1 2 3 4 5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

-Is there anything your loved one likes about this **environmental aid**? What?

-Is there anything that makes it easy to use for your loved one? What?

-Is there anything your loved one does not like about this **environmental aid**? What?
-Is there anything that makes it difficult to use for your loved one? What?

h) How comfortable is your loved one using this **environmental aid**?

1 2 3 4 5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

-How did you hear about this device?
___ Occupational Therapist
___ Physical Therapist
___ Social Worker
___ Physician
___ Friend
___ Family Member
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):
-What are the reasons for you and your loved one NOT using a sign or notice to help prompt memory? You can choose more than one of the following responses.
_____ Haven't heard of it
_____ Does not apply to my care giving role
_____ Does not apply to loved one
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other ______________________

-How useful do these **environmental aids** sound to you?
-If one of these **environmental aids** were given to you or your loved one, would you use it? Why/why not?

Part 2 – Identifying Occupational Performance
Now I would like to focus on your loved one's occupations or daily activities. I have a list here for you that describes various everyday activities that your loved one may or may not have difficulty with (See Appendix G). I will give you a few moments to look it over and then I will ask you some questions.

I. I would like you to first identify one important activity that is the most difficult for your loved one to perform.

Activity: __________________________
Do you or your loved one use any tools or devices to help with _________, in order to do it with more ease and/or to increase his/her safety?

If YES:
What is the name of the device you use?
____
(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) Who uses this device?
   ___ Myself ___ My loved one _____ Both of us
b) Who would you say is the primary user? (If **you** use this device, please only consider your use if it is to help with care giving role and not if it is for your

own
day-to-day use.)
___ Myself ___My loved one

Can you describe/show me how it is used?
(Proceed with Caregiver questions or Care Recipient Questions where applicable)

CARE RECIPIENT QUESTIONS
For this set of questions, I would like you to think about your loved one's use of the device. Please try to answer the best you can while considering their perspective.

-Have you ever seen your loved one use this device on his/her own?

f) How frequently does your loved one use this device?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long has your loved one been using this device to help compensate for any cognitive difficulties?

-Has your loved one's/your use changed over time? If so, how?

g) How helpful would you say this device is for your loved one?

1 2 3 4 5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

-Is there anything your loved one likes about this device? What?

-Is there anything that makes it easy to use for your loved one? What?

-Is there anything your loved one does not like about this device? What?

-Is there anything that makes it difficult to use for your loved one? What?

h) How comfortable is your loved one using this device?

1 2 3 4 5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

-How did you hear about this device?

___ Occupational Therapist
___ Physical Therapist
___ Physician
___ Friend
___ Family Member
___ Social Worker
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):

-What are the reasons for you and your loved one NOT using any device to help with this activity? You can choose more than one of the following responses.

_____ Haven't heard of anything
_____ Does not apply to my care giving role
_____ Does not apply to loved one
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other ______________________

-Do you think it would useful you or your loved one to have something to help with _________ activity?

-If one you or your loved one were given a device to help with this activity, would you use it? Why/why not?

ii. Looking over this list again, I would like you to identify one activity that you, as a caregiver, are having the most difficulty with providing support to your loved one.

Activity: ________________

Do you use any tools or devices to help provide support for your loved one while doing _________ (activity?)

If YES:

What is the name of the device you use?

____

(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) Who uses this device?
___ Myself ___ My loved one ____ Both of us

b) Who would you say is the primary user? (If **you** use this device, please only consider your use if it is to help with care giving role and not if it is for your own day-to-day use.)
___ Myself ___My loved one

Can you describe/show me how it is used?
(Proceed with Caregiver questions and/or Care Recipient Questions where applicable)

CAREGIVER QUESTIONS
If it is to help with care giving- What care giving activity do you use this device for?

c) How frequently do you use this device to help with care giving?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long have you been using it?
-Has your use changed over time? If so, how?

d) How helpful do you find this device?
1 2 3 4 5

1 –Very unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very helpful

-Is there anything you like about this device? What?

-Is there anything that makes it easy to use? What?

-Is there anything you do not like about this device? What?

-Is there anything that makes it difficult to use?

e) How comfortable are you using this device?

1 2 3 4 5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

CARE RECIPIENT QUESTIONS

For this set of questions, I would like you to think about your loved one's use of the device. Please try to answer the best you can while considering their perspective.

-Have you ever seen your loved one use this device on his/her own?

f) How frequently does your loved one use this device?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long has your loved one been using this device to help compensate for any cognitive difficulties?

-Has your loved one's/your use changed over time? If so, how?

g) How helpful would you say this device is for your loved one?

1 2 3 4 5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

-Is there anything your loved one likes about this device? What?

-Is there anything that makes it easy to use for your loved one? What?

-Is there anything your loved one does not like about this device? What?

-Is there anything that makes it difficult to use for your loved one? What?

h) How comfortable is your loved one using this device?

1	2	3	4	5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

-How did you hear about this device?

___ Occupational Therapist
___ Physical Therapist
___ Physician
___ Friend
___ Family Member
___ Social Worker
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):

-What are the reasons for you and your loved one NOT using any devices to help with this activity? You can choose more than one of the following responses.

_____ Haven’t heard of anything
_____ Does not apply to my care giving role
_____ Does not apply to loved one
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other _______________________

-Do you think it would useful you or your loved one to have something to help with _________ activity?

-If one of these devices were given to you or your loved one, would you use it? Why/why not?

iii. Looking over the list one last time, please identify one activity that your loved one is performing successfully either independently or with minimal assistance.

Do you or your loved one use any tool or device to help perform _________ activity with more ease and/or to increase safety during this activity?

If YES:
What is the name of the device you use?
____
(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) Who uses this device?
___ Myself ___ My loved one ____ Both of us
b) Who would you say is the primary user? (If **you** use this device, please only consider your use if it is to help with care giving role and not if it is for your own day-to-day use.)
___ Myself ___My loved one

Can you describe/show me how it is used?
(Proceed with Caregiver questions and/or Care Recipient Questions where applicable)

CARE RECIPIENT QUESTIONS
For this set of questions, I would like you to think about your loved one's use of the device. Please try to answer the best you can while considering their perspective.

-Have you ever seen your loved one use this device on his/her own?

f) How frequently does your loved one use this device?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

-For how long has your loved one been using this device to help compensate for any cognitive difficulties?

-Has your loved one's/your use changed over time? If so, how?

g) How helpful would you say this device is for your loved one?
1 2 3 4 5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

-Is there anything your loved one likes about this device? What?

-Is there anything that makes it easy to use for your loved one? What?

-Is there anything your loved one does not like about this device? What?

-Is there anything that makes it difficult to use for your loved one? What?

h) How comfortable is your loved one using this device?

1	2	3	4	5

1. Very Uncomfortable
2. Uncomfortable
3. Neutral
4. Comfortable
5. Very Comfortable

-Can you explain your reasons for choosing this response?

-How did you hear about this device?

___ Occupational Therapist
___ Physical Therapist
___ Physician
___ Friend
___ Family Member
___ Social Worker
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):

-What are the reasons for you and your loved one NOT using any devices to help with this activity? You can choose more than one of the following responses.

_____ Haven't heard of anything
_____ Does not apply to my care giving role
_____ Does not apply to loved one
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other _______________________

-Do you think it would useful you or your loved one to have something to help with _________ activity?

-If one of these devices was given to you or your loved one, would you use it? Why/why not?

Part 3 – Identifying usage of 1) sensors - ones embedded onto objects of

daily use and those, which are wearable and 2) information provided.

a. Sensors attached onto objects

1. Did you think there would be any discomfort for your loved one with using objects that are attached with sensors? Like coffee machine, pillbox and your drawers YES / NO

If Yes, please explain?

2. Have you seen any object attached with sensors? YES / NO?

- If YES, please explain and what do you like about them?
- What is one thing that you don't like about using objects attached with sensors?

3. If you were given an opportunity to change one thing about the sensor(s) or the way they are used now, what would you change?

4. What do you think about sensors being attached to your dresser? Do you think it will bother your loved one? YES / NO

If YES, please explain why?

5. Are you comfortable with having a video camera attached to the dresser? YES / NO

If NO, please explain why?

6. Are you concerned about your loved one's privacy with having a video camera attached to the dresser? Please explain.

7. If you were given a choice to change something with the way the dresser is designed now, what would it be? [Show them a picture of its design]

8. Would your loved one have any discomfort standing / sitting in a confined space to dress?

9. Do you think it would benefit your loved one if the system gave guidance (audio prompts) to perform activities of daily living? Especially the following (dressing, brushing, coffee making and pill taking) YES / NO

If No, explain why?

b. Wearable Sensors

11. What do you think about the wearable sensor? Is it comfortable to wear for the participant? YES / NO [show them the wearable sensor]

If No, explain why?

12. Would it be comfortable to wear it on a different part of your body, maybe on their ankle? YES / NO / Maybe

Please explain why?

13. If you were given a choice to change one thing with the wearable device, what would it be? Explain?

c. Information provided to you

14. What do you think about the resource that was provided to track information?
Is it intuitive?
Is it easy to use?
Is it easy to understand?

14. Did you find the information provided to you useful? YES / NO?
    Explain why?

15. Does the information provided to you overwhelm you? YES / NO? Explain

16. What would you like to see apart from what was displayed?

17. If you were given a choice to change something what would it be?

18. Any general comments about the system / sensors / resource provided?

Part 4 – Identifying Unmet Needs
We are now nearing the end of the interview. So far we have discussed what devices you use in care giving and what devices your loved one use to help with daily activities and to increase safety throughout the home. I would like to learn more about what you wish existed or what you need help with.

I would like you to think of an activity you or your loved one has to carry out that has been the most impacted by their physical / cognitive impairment, that you feel is a challenge or that you feel you have little or no support for. What is this?

Now I want you to take a minute to imagine that you have been offered the opportunity to have an assistive device made just for you and your loved one. You have all the resources in the world – no constraints on money, expertise, practicality or time.

What would this device be able to do to help you or your loved one with the problem you mentioned above?

Now I want you to think about a system which tracks activity performance by attaching sensors onto objects of daily use.

- What do you expect from such a system?
- What kind of information do you expect to see from it? What data it should capture? How detailed?
- Do you prefer the information to be displayed in a browser (computer/tablet) or mobile?
- Would it be helpful if there were an easy way to share the information that you get from the system?
- Would it be helpful if the system gives you suggestions?
- Would it be helpful if the system can present information on activity performance every day to you?
- Would it be useful / helpful if it can guide the care recipient in performing tasks through audio / video prompts?
- Which is more important to the care recipient in your opinion, privacy or independence? Assuming the system captures data / video only to help the care recipient and does not share the information with others.
- Are you comfortable with sensors monitoring activities of daily living for subtle clues of functional decline?
- Do you think the care recipient would be comfortable with using objects attached with sensors and wearing a wrist-worn sensor?
- How can we improve our current system?
- What does this system lack in your opinion that could help you in taking care of your loved one better? Please explain?

- What does the system lack in your opinion that could help your loved one perform their daily activities better? Please explain?

Is there anything else you want to share with me?

That concludes the interview! Do you have any questions for me?

Thank you very much for allowing me to come to your home today and for showing me the devices that you and your family member use. I will send you the results of the study if you wish – would you like that? (If YES- Would you like the study results mailed or emailed to you?) If you have any questions in the meantime, please feel free to contact me using the contact information provided. (Provide email address and phone number)

Participant #: _______________ Date: ____________________

APPENDIX H

PRE-CASE STUDY INTERVIEW QUESTIONS

Participant #: ________________ Conducted By: _________________

Date: ________________

Hi ______________. It’s nice to meet you! Thank you for letting me come to your home today.

I am conducting a research study to find out how to best develop a computerized aid, which can help older adults track in their daily activities specifically with dressing, brushing, coffee making and taking medications. I am here now to ask you few questions to better understand how you perform these daily activities so that I can use the information to make the aid more useful.

Do you have any questions for me so far?

I am going to start the interview now. If there is a question you do not understand, let me know and I will repeat the question or if there is a question you don’t feel comfortable answering, we can skip over it. If you have any questions or comments during the interview don’t hesitate to ask me at any time.

Participant #: ____

Part 1 – Identifying information on the four activities involved in the case study

a. MEDICATION ADHERENCE

Do you need help in taking your medications?

If yes, what kind of help? And how often you need them?

Do you use a medication reminder?
If Yes:
Do you like it?
What do you like about it?
What do you don't like about it?

If No:
Would it be helpful if you had a medication reminder?

Would you be comfortable if sensors were attached to the pillbox for tracking your medication adherence?

b. COFFEE MAKING

Do you need help in making a pot of coffee?
If yes, what kind of help? And how often you need them?

Do you ever forget to turn off the coffee machine?
If yes, how often?

Do you use a reminder system or a visual aid for this activity? These devices help people who have difficulty remembering to carry out tasks / steps to compensate for cognitive difficulty.

If Yes:
Do you like it?
What do you like about it?
What do you don't like about it?
If No:
Would it be helpful if you had a reminder system / visual aid?

Would you be comfortable if sensors were attached to the coffee machine and the cabinet for tracking how well you perform this activity?

c. BRUSHING TEETH

Do you need help in brushing your teeth?

If yes, what kind of help? And how often you need them?

Do you use a reminder system or a visual aid for this activity?

If Yes:
Do you like it?
What do you like about it?
What do you don't like about it?

If No:
Would it be helpful if you had a reminder system / visual aid?

Would you be comfortable if sensors were attached to the toothbrush and the cabinet for tracking your brushing teeth activity?

d. DRESSING

Do you need help in dressing up?

If yes, what kind of help? And how often you need them?

Do you use a reminder system or a visual aid for this activity?

If Yes:
Do you like it?
What do you like about it?
What do you don't like about it?

If No:
Would it be helpful if you had a reminder system / visual aid?

Would you be comfortable if sensors were attached to the dresser and inside your room for tracking your dressing activity?

Would you be comfortable if cameras were used to find out how well you dress and also to help if you get stuck in the middle of dressing?

Part 2 – Identifying Occupational Performance

Now I would like to focus on your daily activities. I have a list here for you that describes various everyday activities that your loved one may or may not have difficulty with (See Appendix G). I will give you a few moments to look it over and then I will ask you some questions.

i. I would like you to first identify one important activity that is the most difficult for you to perform.

Activity: __________________________

Do you use any tools or devices to help with ________, in order to do it with more ease and/or to increase your safety?

If YES:
What is the name of the device you use? ___________________________________
(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) How frequently does your loved one use this device?

1	2	3	4	5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

For how long have you been using this device to help compensate for any difficulties?

Has your use changed over time? If so, how?

b) How helpful would you say this device is for you?

1	2	3	4	5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

Is there anything you like about this device? What?
Is there anything that makes it easy to use for you? What?
Is there anything you do not like about this device? What?
Is there anything that makes it difficult to use for you? What?

c) How comfortable is it for you using this device?

1	2	3	4	5

6. Very Uncomfortable
7. Uncomfortable
8. Neutral
9. Comfortable
10. Very Comfortable

Can you explain your reasons for choosing this response?

How did you hear about this device?

___ Occupational Therapist
___ Physical Therapist
___ Physician
___ Friend
___ Family Member
___ Social Worker
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):
-What are the reasons for you NOT using any device to help with this activity? You can choose more than one of the following responses.

_____ Haven't heard of anything
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other ______________________

-Do you think it would useful for you to have something to help with ________ activity?

-If you were given a device to help with this activity, would you use it? Why/why not?

ii. Looking over the list again, please identify one activity that you are performing successfully either independently or with minimal assistance.

Do you use any tool or device to help perform ____________ activity with more ease and/or to increase safety during this activity?

If YES:
What is the name of the device you use? ____________________________________
(*If many assistive devices are named for this category, ask the most commonly used in category and continue with follow up questions)*

a) How frequently do you use this device?

1 2 3 4 5

1 – Less than once a month
2 – Once a month
3 - Once a week
4 - Two to three times a week
5 – Daily

For how long have you been using this device to help compensate for any difficulties?

Has your use changed over time? If so, how?

b) How helpful would you say this device is for you?

1	2	3	4	5

1 –Very Unhelpful
2- Unhelpful
3- Neutral
4- Helpful
5- Very Helpful

Is there anything you like about this device? What?
Is there anything that makes it easy to use for you? What?
Is there anything you do not like about this device? What?
Is there anything that makes it difficult to use for you? What?

c) How comfortable are you using this device?

1	2	3	4	5

6. Very Uncomfortable
7. Uncomfortable
8. Neutral
9. Comfortable
10. Very Comfortable

Can you explain your reasons for choosing this response?

How did you hear about this device?

___ Occupational Therapist
___ Physical Therapist
___ Physician
___ Friend
___ Family Member
___ Social Worker
___ Internet
___ Saw in store
___ Advertisement
___ Other ___________

IF NO (Does not use this category of device):
What are the reasons for you NOT using any devices to help with this activity? You can choose more than one of the following responses.

_____ Haven't heard of anything
_____ Too expensive
_____ Too complicated/too hard to learn
_____ Not available
_____ Not interested
_____ Other _______________________

Do you think it would useful for you to have something to help with _________ activity?

If one of these devices were given to you, would you use it? Why/why not?

Part 3 – Identifying Unmet Needs

We are now nearing the end of the interview. So far we have discussed what devices you use to help with daily activities and to increase safety throughout the home. I would like to learn more about what you wish existed or what you need help with.

I would like you to think of an activity that is now most challenging to do. What is this? Do you get help to do it?

Now I want you to take a minute to imagine that you have been offered for free the opportunity to have a special device made just to help you do this activity.

> What would this device be able to do to help you with the problem you mentioned above?

Now I want you to think about an activity system, a system which tracks activity performance by attaching sensors onto objects of daily use. Here is an example (show picture of current system)

- What do you expect from such a system?
- What kind of information do you expect to see from it? How detailed?
- Where do you prefer the information to be displayed?
- Would it be helpful if there were an easy way to share the information that you get from the system?
- Would it be helpful if the system gives you suggestions?
- Would it be helpful if the system can present information on activity performance every day to you?
- Would it be useful / helpful if it can guide you in performing tasks through audio / video prompts?
- Which is more important to you, privacy or independence? Assuming the system captures data / video only to help and does not share the information with others.
- Are you comfortable with sensors monitoring activities of daily living for subtle clues of functional decline?
- Would you be comfortable with using objects attached with sensors and wearing a wrist-worn sensor?

Is there anything else you want to share with me?

That concludes the interview! Do you have any questions for me?

Thank you very much for allowing me to come to your home today and for showing me the devices that you use. I will send you the results of the study if you wish – would you like that? (If YES- Would you like the study results mailed or emailed to you?) If you have any questions in the meantime, please feel free to contact me using the contact information provided. (Provide email address and phone number)

Participant #: _______________ Date: _________________

APPENDIX I

POST-CASE STUDY INTERVIEW QUESTIONS

Participant #: __________________ Conducted By: ______________

Date: ____________________

Hi ______________. It's nice to meet you! Thank you for letting me come to your home today.

Congratulations for completing 2 weeks of this case study. I appreciate your help and co-operation provided for this case study. This is the final interview to capture how your perception and usage of sensors and assistive devices has changed over the course of this case study. This interview is to capture that information.

Do you have any questions for me so far?

I am going to start the interview now. If there is a question you do not understand, let me know and I will repeat the question or if there is a question you don't feel comfortable answering, we can skip over it. If you have any questions or comments during the interview don't hesitate to ask me at any time.

Participant #: ____

Part 1 – Identifying usage of 1) sensors - ones embedded onto objects of daily use and those, which are wearable and 2) information provided.

a. Sensors attached to objects

1. Are you comfortable with using objects that are attached with sensors? Like coffee machine, pillbox and your drawers - YES / NO

If No, please explain why?

2. What is one thing that you like about using objects attached with sensors?

3. What is one thing that you don't like about using objects attached with sensors?

4. If you were given an opportunity to change one thing about the sensor(s) or the way they are used now, what would you change?

5. What do you think about the sensors attached to your dresser? Does it bother you? YES / NO

If YES, please explain why?

6. Are you comfortable with having a video camera attached to the dresser?
YES / NO

If NO, please explain why?

7. Are you concerned about your privacy with having a video camera attached to the dresser? Please explain.

8. If you were given a choice to change something with the way the dresser is designed now, what would it be?

9. What do you feel about standing / sitting in a confined space to dress?

10. Would you be comfortable if the system gave you guidance (audio prompts) to perform activities of daily living? Especially those that are monitored now (dressing, brushing, coffee making and pill taking) YES / NO

If No, explain why?

b. Wearable Sensors

11. What do you think about the wearable sensor? Is it comfortable to wear? Would you be willing to wear it every day? YES / NO

If No, explain why?

12. Would it be comfortable to wear it on a different part of your body, maybe your ankle? YES / NO / Maybe
Please explain why?

13. If you were given a choice to change one thing with the wearable device, what would it be? Explain?

c. Information provided to you

14. What do you think about the resource provided to track information?
Is it intuitive?
Is it easy to use?
Is it easy to understand?

15. Did you find the information provided to you as useful? YES / NO?
Explain why?

16. Does the information provided to you overwhelm you? YES / NO? Explain

17. What would you like to see apart from what was displayed?

18. If you were given a choice to change something with the information provided what would it be?

19. Any general comments about the system?

Part 3 – Identifying Unmet Needs

We are now nearing the end of the interview. I would like to learn more about what you wish existed or what you need help with.

20. Considering all the resources and information you had over the last 2 weeks, what do you think is the most important resource / information that you wished you could have had?

21. How can we improve our current system?

22. What does the system lack in your opinion that could help you perform your daily activities better? Please explain?

APPENDIX J

STANDARDIZED COGNITIVE TEST - MMSE

Participant ID: DATE: Time: AM/PM

<u>Time Orientation</u>

Ask:
What is the year?
What is the month of the Year?
What is the day of the week?
What is the season of the year?
What is today's date?
Give one point for each correct answer. 5

<u>Place Orientation</u>

Ask:
Where are we now? What is the state? 5
What is the city?
What part of the city are we in?
What part of the building are we in?
What floor of the building are we on?
Give one point for each correct answer.

<u>Registration of Three Words</u>

Say: *Listen carefully. I am going to say three words. You say them after I stop. Ready? Here they are*: (wait one second between giving each word)
Horse
Penny
Orange
Ask: *Now what were those words?*
Give one point for each correct answer. 3

<u>Serial Seven as a Test of Attention and Calculation</u>

Say: Subtract 7 from 100 and continue to subtract 7 from each subsequent remainder until I tell you to stop. What is 100 take away 7?
Keep going....
Stop the patient after five calculations.
Give one point for each correct calculation 5

<u>Recall of Three Words</u>

Ask: What were those three words I asked you to remember?
Give one point for each correct answer 3

<u>Naming</u>

Ask: What is this? Show
A pencil
A watch
Give one point for each correct answer. 2

<u>Repetition</u>

Say: Now I am going to ask you to repeat what I way. Ready?
"No ifs, ands, or buts." Now you say that.
Give one point for correct repetition 1

<u>Comprehension</u>

Say: Listen carefully because I am going to ask you to do something. Take this paper in your left hand. Fold it in half.
Put it on the floor.
Give one point for each correct action, for a total possible score of 3. 3

Reading

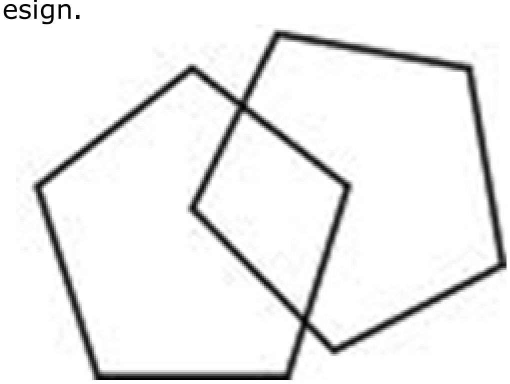
Say: Please read the following and do what it says, but do not say it out loud.
Show the patient the following words on a piece of paper:
Close your eyes.
Give one point if the patient closes his or her eyes without speaking. 1

Writing

Say: Please write a sentence
If the patient does not respond, say:
Write about the weather.
Give one point if the patient writes a sentence. 1

Drawing

Say: Please copy this design.



Give one point for a correct copy of the diagram. 1

APPENDIX K

STANDARDIZED PHYSICAL TEST - TUG

Patient ID: Date: Time: AM/PM

The Timed Up and Go (TUG) Test

Purpose: To assess mobility

Equipment: A stopwatch

Directions: Patients wear their regular footwear and can use a walking aid if needed. Begin by having the patient sit back in a standard arm chair and identify a line 3 meters or 10 feet away on the floor.

Instructions to the patient:

When I say **"Go,"** I want you to:

1. Stand up from the chair
2. Walk to the line on the floor at your normal pace
3. Turn
4. Walk back to the chair at your normal pace
5. Sit down again

On the word **"Go"** begin timing.

Stop timing after patient has sat back down and record.

Time: __________ seconds

An older adult who takes ≥12 seconds to complete the TUG is at high risk for falling.

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