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Fostering Resilient Aging with a Self-efficacy and Independence Enabling Robot (FRASIER)

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Fostering Resilient Aging with a Self-efficacy and Independence Enabling Robot (FRASIER)

A Major Qualifying Project Report Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Table of Contents

Table of Figures

Table of Tables

Glossary

- **3D Sensors** - Sensors with capability of capturing the environment in three dimension format, for example, the PrimeSense camera with depth image to produce rough sensing of the environment.
- **IR** - Infrared Proximity (IR) sensors are used for remote control detection with embedded little microchip with a photocell to listen to the infrared light transmitted also from the IR.
- **Modular Robotic Platform** - A robot platform can be used in the future development with all the hardware and software side to be easily integrated and seamless interface between future add-on devices.
- **Robotic Manipulators** - Simply refers to any robotic arm or automated mechanism to interact with environment such as pick and place objects to achieve user manipulating on the machine.
- **ROS-Hydro Environment** - A version of Robot Operating System software that provides many useful software tools to solve problems in robotics.
- **Sensors with control systems** - An integrated system with information feedback from sensors and information processing part to control the system.
- **RGB-D Cameras** – Red, Blue, Green, Depth Cameras are novel sensing systems that capture RGB images along with per-pixel depth information.

Authorship

This report is the collaborative effort of Lucine Bahtiarian, Cameron Canale, Loan Chau, Vanderlei Cunha, Helei Duan, Farhat Kohistani and Kristina Walker. Each section has a primary author, but the entire report was edited by all members.

Section:	**Author**
Title Page	K. Walker
Glossary	All
Authorship	K. Walker
Abstract	L. Bahtiarian
Acknowledgements	K. Walker
1. Introduction	All
2. Background	
2.1 Emerging Challenges on Aging	All
2.2 Physical, Cognitive, and Social Development	All
2.3 Assistive Technology	All
2.4 User-Acceptability	All
2.5 Societal Issues	All
2.6 Present Study	All
3. Design Requirements Development through User Studies	
3.1 Methodology	L. Chau
3.1.1 Study 1: Interviews with Assisted Living Community Residents and Independently Living Seniors	L. Chau
3.1.2 Study 2: Aging and Assistive Technology Survey	L. Chau
3.1.3 Study 3: User-Robot Interaction and Assisted Nursing Facilities	L. Chau
3.2 Results	L. Chau

8.1 Methodology	L. Bahtiarian
8.2 Results	L. Bahtiarian
8.3 Discussion	L. Bahtiarian
9. Conclusion	K. Walker
9.1 Future Work	All
10. References	All
11. Appendices	
11.1 Appendix A: Interview Questions	L. Chau
11.1.1 Appendix A: Study 1	L. Chau
11.1.2 Appendix A: Study 2	L. Chau
11.1.3 Appendix A: Study 3	L. Chau
11.2 Appendix B: Interview Results	L. Chau
11.3 Appendix C: Survey Results	L. Chau
11.4 Appendix D: Stakeholders	L. Bahtiarian and C. Canale
11.5 Appendix E: Needs Analysis	L. Bahtiarian and C. Canale
11.6 Appendix F: Technical Measures	L. Bahtiarian and C. Canale
11.6.1 Measures of Effectiveness	L. Bahtiarian and C. Canale
11.6.2 Measures of Performance	L. Bahtiarian and C. Canale
11.6.3 Typical Performance Measures	L. Bahtiarian and C. Canale
11.6.4 Key Performance Parameters	L. Bahtiarian and C. Canale
11.7 Robot Design Options	All

Table 1: Authorship Table

Abstract

With the percentage of the elderly population rapidly increasing as the Baby Boomer generation reaches retirement, the demand for assistive care will soon override the supply of caregivers available. Additionally, as most individuals age, the number of age-related limitations preventing them from completing everyday tasks independently may increase. Through FRASIER (Fostering Resilient Aging with a Self-efficacy and Independence Enabling Robot), the project team developed an assistive robot with a goal of providing a solution to this challenge.

The team determined the robot functionalities by conducting user studies through surveys and interviews of potential users. From these user study results, the team developed a mobile robot incorporating both aesthetic and companionship aspects. FRASIER will ultimately be able to interact with its environment and users through a robotic manipulator, cameras, and user interface.

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1 Introduction

Every individual goes through a series of physical, cognitive, and social changes in life, and one's perception of aging may be based on different cultural values, beliefs, and customs. However older individuals are regarded, as they reach an advanced age, their health, physical strength, and cognition may go through age-related changes, which may lead to age-related disabilities such as joint and bone issues, memory and cognitive declines, as well as physical function, that can limit independence.

Given the increased lifespan and the increased need for assistance outside the family due to families being separated by great distances, there has been a recent increase in the demand for supportive care in the home or community care setting (Berry & Ignash, 2003). Often times, this supportive care is intended to help individuals maintain independence and the ability to live in their own homes (Hoening, Sloan, & Taylor, 2003). One way that this can be achieved is through assistive technology, which is defined as any device that assists and helps retain a person's independence. The rise in assistive technology is applicable in many ways, especially for individuals who are aging and would still like to remain autonomous. This year, in conjunction with the Psychology Department and Robotics Engineering Program, our team of students designed and developed a personal assistance robot called FRASIER (Fostering Resilient Aging with a Self-efficacy and Independence Enabling Robot) that will serve those with age-related disabilities in assisted living facilities and in independent homes. This personal assistant robot was designed as an alternative solution for the increase in need for assistance as well as to help retain independence. The following sections will illustrate the need for assistive technology in today's society, existing technologies that aim at providing a solution to this problem, the steps taken by the team to design FRASIER as well as results obtained and recommendations.

The goal for this project is to develop a personal assistance robot that is able to aid individuals with age-related disabilities as well as support them to live independently. The aim was to increase user independence and reduce the need for human personal aides. The Major Qualifying Project (MQP) team faced an engineering challenge that required solving this problem with both technical and non-technical approaches. The MQP team followed various methods from different disciplines of social science and engineering. As a result, this integrated approach included:

- Three psychology-related user studies to determine needs of the users and functionalities of the personal assistant robot by interviews with potential users, online surveys related to aging and assistive technology, and user testing of the personal assistant robot.
- A gap analysis to identify possibilities and requirements for the project compared to the existing technology.
- Identification of needs and requirements for the robot in terms of functionalities and capabilities.
- A robot design including comprehensive technical approaches in order to meet the design requirements and other aspects of this project.

2 Background

The background highlights research that the MQP team conducted at the beginning of the project. This section details the psychology of aging, the growing aging population, existing robotic technologies and how they can be applied to assistive robots.

2.1 Emerging Challenges on Aging

Over the next few decades, the overall structure of the population is projected to change in relation to the age demographic. The percentage of the older adult population is rapidly increasing, in part, because there were 77 million individuals in the baby boomer generation, 1946 to 1964, (Ortman, Velkoff, & Hogan, 2014). According to the 2010 United States Census Bureau, between the years 2000 and 2010, the population of people ages 65 and over increased by 15 percent, while the total US population increased by 9.7 percent (Werner, 2010).

As seen in Figure 1, the 2010 baby boomer generation is now between the ages of 46 and 64. By the year 2030, the generation will shift into the advanced age rank, which in turn will move the age structure from 13% in 2010 to about 19% in the year 2030 (Ortman, Velkoff, & Hogan, 2014).

As individuals age, accompanying them are age-related issues that may prevent them from completing everyday tasks independently (Bayer, Bhattacharya, Knight, & Nigam, 2012). Therefore, there will be an increase in demand for caregivers. However, the increase in elderly population is overriding the number of caregivers available. Additionally, those who are unable to afford caregivers or to reside nursing homes, typically stay home and depend on their family members to get the assistance needed. Unfortunately it becomes very difficult for these family members to take care of an elderly relative given that a significant number of them have full time jobs and do not reside close enough to provide care, in addition to having other daily tasks. This makes it challenging to care for their elderly relative. At the same time, the nation faces a substantial increase of cost in the health-care sector. According to American Association of Retired Persons (AARP, 2007)), the average cost for a nursing home is more than $50,000 a year and still increasing (AARP, 2007). With assistive technology, robots become an alternative option for possibly reducing the yearly cost for caregiving services. Since employee's health insurances do not pay for nursing homes, about one third of the residents must pay for it themselves. As a result, this high cost of living in a nursing home may be considered as burdensome for both elderly and their loved ones. This is also in conjunction with the fact of the desire to stay at home rather than living in an assisted living facility. An alternative way should be developed in order to make sure that the elderly receive the care that is needed, while at the same time ensuring comfortability and affordability.

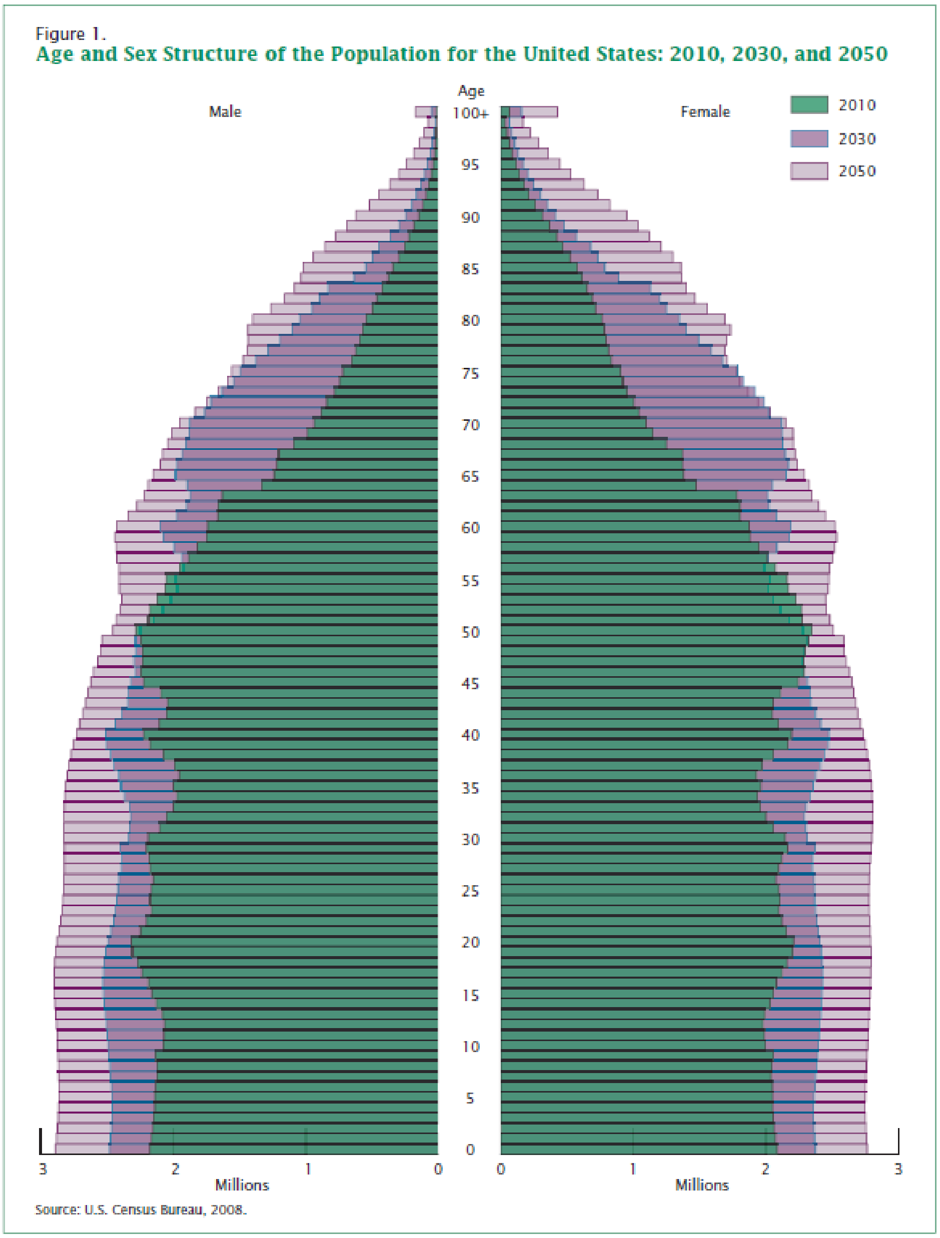

Figure 1: Age and Sex Structure of the Population for the United States: 2010, 2030, and 2050 (US Census Bureau, 2008)

With the rise in demand for caregivers, the robotics industry is looking into ways of creating robots that are able to aid the elderly with their daily tasks. Hoenig, Sloan and Taylor (2003) conducted a research study to determine if assistive technology could substitute assistive care. The results concluded that assistive technology such as motorized chairs, would be a way to improve the quality of life for such individuals, as opposed to completely replacing human assistance (Hoening, Sloan, & Taylor, 2003). One of the biggest benefits of assistive technology is that it requires less time to accomplish certain activities such as transferring from chair to bed or other areas, showering, and using the restroom. Robots may also be beneficial to the nurses because robots can help reduce the workload and physical demands on the nurses. This does not necessarily mean that everyone will agree with the use of assistive technology or robots. There are a number of older adults who are against the idea of robots and would rather have human interactions (Cornuet, et al., 2014).

2.2 Physical, Cognitive, and Social Development

Generally, aging can be defined as the gradual process of changes in one's life, whether physically, cognitively, or socially. Physiologically speaking, in the advanced aging stages of development, an individual's health may begin to experience changes (Bayer, Bhattacharya, Knight, & Nigam, 2012). Consequently, these changes also come with negative stereotypes. For example, many believe that as a person ages, their physical functions start to deteriorate. These stereotypes not only negatively impact views on aging, but it also affects the individual's development. However, applying strategies like enforcement of positive stereotypes regarding age has been shown to improve physical functioning and in turn weaken negative stereotypes about growing older (Levy, Pilver, & Slade, 2014). Thus, it is important to enforce and acknowledge positive stereotypes so as to increase prolonged physical functioning.

Accompanying physical changes in an aging individual, cognitive changes may also commonly occur (World Health Organization, 2015). For example, cognitive decline is common in aging individuals and consequences of this may result in supervision and reminders. Even though there is little cognitive decline in certain skills such as general knowledge and vocabulary, there are declines found in multitasking, reasoning, and memory (Albert, et al., 1995). As a result of this, decline of these skills may lead to interference with day to day tasks and living independently. However, given that cognitive decline is a common age-related change in aging individuals, it hides the fact that there are people who still possess the same or even better level of cognitive skill as they age. Young adults are known to interpret something analytically more than those who are older, but older adults are inclined to focus more holistically on a matter as well as its significance (Finucane, MacGregor, Peters, & Slovic, 2000). Additionally, older adults have shown to have a better capability of recalling and representing holistic altitudes of understanding (Finucane, MacGregor, Peters, & Slovic, 2000)). This emphasizes the fact that cognitive aging is not completely negative.

Accompanying the age-related changes in an aging individual's life is a stereotype that as a person ages, their emotional and social capacity lessens. This stereotype maybe due to the fact that residents in nursing or assisted living facilities have limited exposure to close relationships, as residents may not be able to see their family members often and the loneliness the elderly may experience poses as a risk factor for depression. The lack of access to close relationships and contact with family members may affect an individual's mental health (Adams, Auth, & Sanders). The aging individual may also experience the loss of friends and family members, and this may explain the desire to develop a stronger hold onto his or her relationships. Research also shows that a strong support network reduces the chance of becoming ill, therefore in the chance that the individual did become ill, recovery would be quicker with social support (Adams, Auth, & Sanders). In addition, research shows that through a life span analysis, emotion and social relationships become stronger as a person ages (Gross & Urry, 2010). With this being said, an assistive robot with a companionship ability would be a feasible way to aid individuals in performing daily tasks and regaining their independence while still giving them moral support, all while remaining in their own homes.

2.3 Assistive Technology

Traditional solutions for elderly care include assisted living communities and caregivers at individual's home. As previously discussed in Section 2.1, there is a rising demand amongst the elderly population for independent living, although homecare costs are substantially high. Given that technology is emerging in to today's society, there has been an increased focus on assistive technology for aging individuals. An example of applied assistive technology is the Care-O-Bot, the home assistant the carries out certain tasks in the user's home such as object carrying and retrieval, emergency detection, and environment perception (Fraunhofer, 2015).

With respect to the social aspect of assistive technology, the Jibo robot: a family-oriented companion robot, performs certain functions on demand such as record videos, snap photos, and engage in conversations. It also has entertainment, educational, webcam, intelligent reminder features, as well as telepresence capabilities. The features of the Jibo robot provide inspiration for the companion capabilities of the personal assistance companion robot due to its autonomous aspect (Jibo, n.d.). In addition to Jibo, there is also the Reeti, robot, which is the socially assistive robot originated in France. Reeti communicates with the user's technology in his or her home, has a graphical user interface, and displays emotional intelligence (Reeti Robot, 2015). Jibo, along with other assistive robots, has provided insight on how the group can integrate both an assistive and companion robot into one cost-effective robot.

2.4 User-Acceptability

Despite the rise in assistive robots for the aging population, there has been trouble introducing this technology to the public, specifically with the elderly. Studies show that user-acceptance relies on the quality of the assistive technology (McCreadie & Tinker, 2005). Typically, high quality assistive robots would be efficient, reliable, simple, safe, empathetic, trustworthy in appearance, as well as reasonably priced. It has been illustrated that depending on the task that the robot carries out, it must be customized to be able to accommodate to the user's needs and living environment, emphasizing the traits of a high quality assistive robot (McCreadie & Tinker, 2005).

User-acceptability success may be largely dependent on a robot's performance and appearance. A successful future robot that will share a home or community with humans should be able perform certain tasks or functions. In addition, it should perform them in a manner that is socially acceptable and that does not cause intimidation. Avoiding intimidation can be challenging, especially if the goal is to create a robot as close to human as possible. According to past research, if a robot is designed to resemble a human very closely in terms of natural human appearance and behavior but can still be identified as a robot, it causes discomfort among the human observers. Also when robot features look and move almost, but not exactly, like natural beings, it causes a response of revulsion among some observers; this is called an uncanny valley (Walters & Sydral, 2007). This enforces the fact that human-looking robots would contribute to users' resistance of using assistive robots.

2.5 Societal Issues

When developing a robot such as FRASIER, there are many societal considerations to account for. One of the biggest challenges in developing a robot focused on assisting the elderly is their perception of technology. Through interacting with potential users their fears regarding learning how to use a new technology and how it would function in their environment arose. Others highlighted the fact that there are concerns with caregivers loosing that role if robots become more accessible. The goal of this project is not to replace caregivers but to provide additional assistance and support the elderly who live independently or within assisted living facilities.

Introducing robots into daily lives presented another concern with the users. The concern of their safety was a top priority when developing FRASIER. In order to ensure the safety of the user various International Organization for Standardization (ISO) standards were considered throughout the design. The organization published a comprehensive standards on different personal care robots, including mobile service robots, exoskeleton wearable robots, and person carrier robots. By the project introduction and the technical design requirements above, FRASIER belongs to the class of mobile service robots. In the future, FRASIER will be used in assisted living facilities and other public environments. In order to realize the mass use of such robot, the team considers the available functions on the existing robot and compares them with all relevant safety requirements stated in ISO-13482 (International Organization for Standardization, 2014). This ISO for service robots safety standards are structured in three layers (Jacobs, Reiser, Hagele, & Verl, 2012). Top layer contains general requirements and are applicable for all machines. Second layer focuses on a certain safety function or a limited group of machines and third layer deals with a particular type of machine, service robot. For example, section 5.6.2 of ISO-13482 states that “sharp edges and points shall be avoided in the design of the personal care robot”. This directs our robot overall design not to have any sharp edges. Another example is 5.10.2.3, it states that “(robot should have) means to limit the velocity or range of the manipulator”. In the design of a robotic manipulator, joint rotational velocity and joint rotational range should be tunable and controllable by system or users.

2.6 Present Study

In collaboration with the Robotics Engineering Program and Psychology Department at Worcester Polytechnic Institute, the objective of this project was to develop and create a personal assistance robot that has companionship abilities such as conversation, emotional intelligence, games, communication with family and friends, and physical activity instruction, for elderly. The MQP team’s goal was to determine the needs of individuals with age-related disabilities and how they can be fulfilled with assistive technology, as well as to determine what aesthetics of the robot are required to determine what potential users may look for in a personal assistant robot. The team determined the robot needs, functionalities, and aesthetics by conducting user studies through surveys and interviews of potential users. FRASIER was developed in a way that serves both individuals with or without a wheel chair with ease. The team was able to develop a mobile robot incorporating both aesthetic and companionship aspects.

3 Design Requirements Development through User Studies

In order to obtain a better understanding of the psychological context in this project, the MQP team visited multiple assistive living communities and independent living seniors. These visits consisted of conducting interviews of individuals who are regarded as potential users for the robot.

3.1 Methodology

This interview process provided a real world assessment of the common needs for the project. These responses were then used as a guide to determine common themes that users found challenging to accomplish on their own, as well as to develop an online survey consisting of questions about daily physical (getting dressed, putting on brace, etc.) and cognitive (remembering appointments, events, etc.) tasks. As the project progresses, preliminary feedback on the current prototype will be assessed to examine and validate with the prototype of the robot, which will be explained in Study 3: User-Robot Interaction and Assisted Nursing Facilities.

3.1.1 Study 1: Interviews with Assisted Living Community Residents and Independently Living Seniors

Prior to starting the interview, participants learned that the researchers were conducting interviews on the individuals' daily lives. They were also informed that their responses would remain anonymous and that no identifying information would be collected or released. The interview was semi-structured in that all participants were asked the same questions in the same order, but the interviewer allowed for the individual to ask further questions and had the liberty of asking questions related to a particular response to learn more. At the end of the interview, the researchers revealed more information about the project and thanked the participants for their time and the valuable information they provided.

Participants

Participants consisted of residents in assisted living facilities as well as individuals living independently at home. Nine assisted living facilities throughout central Massachusetts were visited, and 40 residents (28 female; 12 male) were interviewed across these facilities. Residents were selected based on their interest and consent to participate in the interviews. Participation was voluntary. One individual living independently was also interviewed.

Design and Procedure

Prior to interviewing residents, 15 questions were developed to evaluate the functions needed by potential users and aesthetic preferences for a personal assistance robot. The first set of questions assessed everyday tasks and activities that the individuals engaged in. These questions also determined whether the individuals needed assistance with these tasks and if they use any mechanical support devices (walkers, graspers, etc.). An example of these types of questions is "*Are there any types of objects you have trouble grasping?*" The next set of questions assessed attitudes, comfort, and familiarity with technology and robots. An example of these types of questions is "*Do you already use technology in your everyday life? i.e. iPad, tablet, iPod, cellphones, etc*." Participants were also shown pictures of the current robot design and were asked about their opinions. For example, "*Do you feel that the placement of the arm is appealing? Why or why not?*" To conclude the interview, the participants were given the opportunity to provide any additional ideas or comments on the project. The reasoning for these questions provided a basis of what features could be incorporated as well as what kinds of needs could be accommodated by specific features of the robot. For the full set of interview questions, please see Appendix A: Interview Questions.

3.1.2 Study 2: Aging and Assistive Technology Survey

Participants

Two hundred eighty-seven participants (154 male, 133 female) took part in this online study. Participant ages ranged from 18 to 50+. Eighty-four participants were enrolled in a psychology course at a private university and earned course credit for their participation. Two hundred twelve individuals participated through Amazon's Mechanic Turk, and were paid $1 for their time. All participants in this study were located within the United States.

Design & Procedure

Prior to completing the study, participants first read a short introduction that explained the purpose of the research and that their participation was anonymous. As with the interview, the 27-item survey assessed functions and preferences for a personal assistance robot.

The first set of questions determined any tasks that the participant might have trouble completing independently, whether they have care-giver assistance and if they use mechanical devices (canes, walkers, graspers, stools, etc.). An example of these types of questions is "*Are there any types of objects you have trouble grasping?*" The next set of questions asks participants about their use of technology, their comfort level with robots/advanced technology, and what robot designs appeal to them the most. An example of these types of questions is "*Do you already use technology in your everyday life? i.e. iPad, tablet, iPod, cellphones, etc.*". Another set of questions assessed the respondent's opinions on our current robot design, and an example of these questions is "*Do you feel that the placement of the arm is appealing? Why or why not?*" The last set of questions asked respondents about their demographic information. For the full survey, please see the Appendix A: Study 2.

After completing the survey, participants were debriefed with more detailed information on the project and thanked for their time.

3.1.3 Study 3: User-Robot Interaction and Assisted Nursing Facilities

Participants

Participants consisted of residents in assisted living facilities. Two assisted living facilities throughout central Massachusetts were visited, and 30 residents (36 female; 4 male) were interviewed across these facilities. Residents were selected based on their interest and consent to participate in the interviews. Participation was voluntary.

Design & Procedure

Prior to starting the demonstration and interviews, participants learned that the researchers were conducting a demonstration of the robot functions, followed by an informal group interview/feedback session. They were also informed that their responses would remain anonymous and that no identifying information would be collected or released. The interview was semi-structured in that all participants were asked the same questions in the same order, but the interviewer allowed for the individual to ask further questions and had the liberty of asking questions related to a particular response to learn more. At the end of the interview, the researchers revealed more information about the project and thanked the participants for their time and the valuable information they provided.

The interview consisted of approximately 15 questions, each evaluating the functions and aesthetics of the current prototype of the robot, as well as possible functions that could be integrated into the robot. The first set of questions assessed the aesthetics of the current prototype of the robot. An example of these questions is "*What did you think about the look of the robot?*" and *"Do you feel that the robot appeared friendly?"* The next set of questions assessed what the residents thought about the existing robotic functions. An example of these types of questions include "*Do you find that graphical user interface is useful?"* The next set of questions assessed attitudes of the robot itself. We asked questions such as "*Do you feel that this robot would affect your daily life?"* The last set of questions involved assessing their safety, what other functions could be integrated into the robot, and how much they would be willing to pay for a robot like this. An example of these questions is "*Is there anything else you think that the robot should do?"* For the full set of questions please see the Appendix A: Study 3.

3.2 Results

Outcomes from each of the user studies are examined in detail in the sections that follow. These results were analyzed in order to provide the team with feedback for the design process.

3.2.1 Study 1: Interviews

From the interview results, we were interested in understanding the different types of functions and features that the robot should have. In addition, we assessed different possible designs for the robot to see which design potential users preferred. Finally, we assessed the overall likelihood of using the robot and whether users would be willing to pay for a personal assistance robot.

Functionalities and Everyday Tasks

In order to get a sense of what kinds of needs can be assessed through the use of a personal assistant robot, we asked participants about their daily tasks and the difficulty of accomplishing them. Approximately 67.5% of the 40 interviewed participants stated that they did have difficulty accomplishing everyday tasks independently, while 32.5% of participants did not have difficulty or did not answer. We also asked about which types of everyday activities were most difficult to accomplish. As seen in Figure 36 in Appendix B: Interview Results, the most difficult tasks to accomplish independently were morning activities (15%), hygiene-related tasks (15%), and reaching/grasping (12.5%). These findings suggest that a personal assistive robot could be particularly helpful to independent living if it could help individuals with hygiene-related tasks (especially tasks related to the morning like getting out of bed, showering, other bathroom tasks) and if it could reach and grasp items.

In terms of reaching/grasping items, we followed up with participants to see if the issues arose from getting items that were located up high or down low. Based on the interviews, 72.5% of the participants reported having difficulties reaching objects located up high, and 7.5% reported difficulties in reaching objects that were located down low. Moreover, 17.5 % of participants indicated that small objects were especially hard to grasp, regardless if they were located up high or down low. For the types of objects that were hard to grasp, please see Figure 1Figure 37 in Appendix B: Interview Results. Given this data, we recommend that the robot have at least one functioning arm that can be able to reach up to higher places and the ability to detect and grasp smaller objects.

We also asked participants to indicate what features that they would like to see in a personal assistive robot. For the frequency of features that were commonly agreed upon, please see Figure 38 in Appendix B: Interview Results. Approximately 87.5% of participants preferred the robot to have a functional arm, 82.5% of participants preferred the robot to have voice activation , 80% of participants preferred that the robot did *not* look like an animal, 80% of participants preferred the ability to communicate with family members and medical staff , 72.5% of participants preferred the robot to have a cartoon face compared to a more human-like face, 67.5% of participants preferred the robot to assist with object retrieval, and 57.5% of participants preferred the robot to have safety monitoring capabilities. Thus, there is a wide range of features that could be integrated into a robot. But, again, one component that emerges is the ability to reach and grasp objects.

Finally, we specifically asked participants about different functions they would prefer to have in order to determine what features should get the most attention for a graphical user interface (GUI). Most popular activities included calendar events (35%), playing bingo (22.5%), taking trips (17.5%), computer games (17.5%), exercise (17.5%), reading (12.5%), board games (10%), arts and crafts (7.5%), and listening to music (7.5%). We conducted a chi-squared analysis to see if creating calendar events was significantly more popular than the other activities. When comparing calendar events (35%) and playing bingo (22.5%), there was no significant difference in terms of popularity, χ^2 (N = 40 = 2.72 p = .0.099). In other words, people equally want a robot that can help them make calendar events and that can play bingo with them. However, making calendar events (35%) was significantly more popular than taking trips (17.5%) χ^2 (N = 40 = 5.83 p = .0.016). Making calendar events (35%) was also significantly more popular than the ability to play computer games (17.5%), χ^2 (N = 40 = 5.83 p = .0.016). In addition, making calendar events was significantly more popular than exercise (17.5%), χ^2 (N = 40 = 5.83 p = .0.016). Thus, the two most popular features that should get integrated into the GUI are the ability to record and remind individuals about their calendar events and the ability to play bingo.

Aesthetics

The participants also evaluated three possible options of what the personal assistant robot could look like. The first robot had a short body with a wide monitor and an arm protruding in the middle. The second option has a long sleek body with a vertical and human face-like monitor on the top. The third option has a round base with a smiley cartoon-like face on the monitor. All three options had curved edges. As seen in Figure 40 in Appendix B: Interview Results, 45% of residents preferred the round base robot with the cartoon-like face (Robot Option C, please Figure 40 in Appendix B: Interview Results). The robot without an arm and that had a more human face on its monitor was the least preferred robot. We also directly asked participant if they preferred a human or cartoon face on the robot. Approximately 72.5% of residents prefer the robot to not have a human face. A chi square analysis shows that participants would prefer the human face (27.5 %) or a cartoon face (72.5 %) χ^2 (N = 36) = 33.6 p = <.001).

Acceptability

Another important factor to consider is how accepting the participants actually were of the idea of owning and using a personal assistant robot. Overall, 57.5% of the participants reported that they would be interested in using a personal assistive robot, and 42.5% of the participants reported not being interested in the robot. A chi-square analysis revealed that participants were just as likely to be interested in using the robot (57.5%) as were not interested in the robot (42.5%), χ^2 (N = 40) = 2.25 p = .0.134.

Cost

While interviewing residents about what functions that the personal assistant robot could have, they were asked on whether this is something that they would be willing to pay for, given that they had the funds. As reflected in the data of those who were interested in using the robot, half of the participants indicated that they would be willing to pay for the robot, and half of the participants indicated that they would not be willing to pay for the robot.

3.2.2 Study 2: Online Surveys

From the survey results we were interested in understanding the different types of functions and features from a broader distribution of ages. This way, we would be able to analyze what potential users would want now versus what potential users would want in the future. We also assessed the overall likelihood of using the robot based on age and living arrangements.

Age on Difficulty of Completing Daily Tasks Independently

We conducted a one-way ANOVA for each of the different daily tasks that participants rated in terms of difficulty. In particular, we were interested in whether age influenced how difficult different tasks were for individuals. Results show that there was a significant effect of age on: keeping track of appointments, $F(2,283) = 4.615$, p =.011, η_p^2 = .026, keeping track of medications, $F(2,282) = 3.115$, p =.046, η_p^2 = .067, and taking medications, $F(2,283) = 4.598$, p =.011, η_p^2 = .061. An LSD post-hoc test shows that those in age group 50+ years (M=4.14,SD= .92) are more likely than those in age group 18-29 years (M= 3.70,SD=1.06) to have difficulty keeping track of appointments, t(285)=29.292, p=.003. Those in age group 50+ (M= 4.16, SD=.93) are also more likely to have difficulty keeping track of medications than those in age group 18-29 years (M=3.83,SD= 1.05), t(284)=30.074, p=.024. And, those in age group 50+ years (M=4.29, SD=.799) are more likely to have difficulty taking medications than those in age group 18-20 (M=3.91, SD=.99) t(285)=33.278, p=.005.

These findings suggest that, as in Study 1, the robot should be able to reach items, especially those that are in high areas. Moreover, if we compare this with the interviews conducted in Study 1, older participants were less likely to report difficulty reaching low items than high items. Taking these results into account, suggestions would be to integrate a calendar event reminders function into the graphical user interface to help users keep track of appointments and medications, as well as integrate a function into the arm to help users take their medication.

Importance of Possible Robotic Functions

We wanted to determine what the highest rated functions were for the robot. Among the complete list of possible robot functions, some of the highest included emergency detection (*M*=5.93, *SD*=1.32), carrying heavy objects, (*M*=5.7, *SD*=1.32), monitoring user safety (*M*=5.55, *SD*=1.39), intelligence reminders (*M*=5.44, *SD*=1.48), voice activation (*M*=5.41, *SD*=1.53), and follow user (*M*=5.34, *SD*=1.48). In order to determine if the highest rated possible robotic function differed significantly from the lowest possible robotic function, a paired samples t-test was conducted. The highest rated function, emergency detection (*M* = 5.92, *SD* = 1.324), was significantly different from the lowest rated function, ability to display eBooks (*M*= 4.04, *SD* = 1.689), t (287) = 17.110, $p < .001$. The results suggest that more attention be put into emergency detection in the robot than the ability to read eBooks. T-tests conducted on each of these functions shows that there are significant differences between each function, and this reiterate that each one should be given consideration. This provides insight on what functions should be given more consideration than the other. In this case, emergency detection should be given more consideration for integration than the ability to display eBooks, as more users would find it more useful in a robot.

Age and Importance of Possible Robotic Functions

While we know the overall functions that everyone believed were important, we wanted to know more specifically what functions those 50+ thought were important. Therefore, a one-way ANOVA was conducted to test whether there was a significant difference of age as a main effect on importance of each individual robotic function. Results show that there was a significant main effect of age on the ability to push elevator buttons/handicap doors $F(2, 261) = 12.035$, $p < .001$, $\eta_p^2 = .084$, the ability to switch lights on and off $F(2, 261) = 6.349$, $p = .002$,

η_p^2 = .046, the ability to open and close doors $F(2, 261) = 5.732$, $p = .004$, η_p^2 = .042, and the ability to dispense medication $F(2, 261) = 7.112$, $p = .001$, η_p^2 = .052.

Does older adults living situation influence how comfortable they are with using a personal assistive robot?

To investigate this question, we only looked at the participants who were 50+ years. We conducted a one-way ANOVA to see if their living situation ("living alone", "living with a roommate not related to me", "living with spouse/partner", "living with other family members", and "other") influenced how comfortable they were using the robot. The results indicate that older adults living situations influenced how comfortable they would be using a robot, $F(2, 277) = 9.426$, $p < .001$, η_p^2 = .064. An LSD post-hoc analysis shows that those 50+ years living alone (*M*= 3.80, *SD*=1.803) are less likely than those living with a spouse or partner (*M*= 4.86, *SD*=1.517), to be comfortable with using a personal assistant robot, $p = .012$. Those living alone are also less likely than those living with other family members (*M*= 5.50, *SD*=1.092), $t(75)= 11.43$, $p=.002$.

Age on level of appeal of current robot design

To determine whether there is an effect of age on the level of appeal on the current design, we ran a one-way ANOVA. The ANOVA shows that there was a significant effect of age on level of appeal of the current robot design $F(2, 285) = 5.552$, $p = .004$, η_p^2 = .038. A LSD post-hoc test shows that those in age group 50+ (*M*=4.32, *SD*=1.64) find the robot more appealing than those in age groups 18-29 years (*M*=3.65, *SD* = 1.34), $t(287)=21.51$, $p = .002$ and 30-49 (*M*= 3.74, *SD* = 1.43), $t(287)=21.505$, $p=.008$. There was no significant difference in age groups 18-29 years and 30-49 years on rating the appeal of the current robot design ($p = .671$).

Likelihood of Usability

Finally, we wanted to understand who was likely to use our robot. First, we determined whether age had a main effect on likelihood of using the robot. Results from a one-way ANOVA show that there was a significant main effect of age on likelihood of usability $F(2, 279) = 6.355$, $p = .002$, η_p^2 = .044. In a LSD post-hoc test, results show that those in age group 50+ years (*M*=4.41, *SD*=1.913) are more likely to use the robot than those in age group 18-29 years (*M*=3.47, *SD*=1.697), $p<.001$ and those in age group 30-49 years (*M*=3.74, *SD*=1.769), $t(281)=17.728$, p=.015. Thus, this data indicates that individuals 50+ would be likely to use the personal assistance robot.

In addition, we also wondered if one's living situation influenced how likely they were to use the robot (e.g., lived alone versus lived with someone). Upon exploration of the data, we noticed that only one participant indicated that they lived with a caretaker and given the small sample, their data was excluded for this analysis. We conducted a one-way ANOVA to examine if there was a significant effect of participants' current living situation on their likelihood to use the robot. The ANOVA showed a significant main effect of current living situation on likelihood of using the robot $F(6, 276) = 3.09$, $p = .006$, $\eta_p^2 = .063$. A LSD post hoc test shows that those who live in 55+ communities (M=5.75, SD=1.50) are more likely than those living in an apartment (M=3.78 , SD=1.689) to use the robot p=.031, those in 55+ communities are more likely to use a personal assistant robot than those living in a house, M = 3.97 , SD= 1.804, p = .048, those living in a house are more likely to use a personal assistant robot than those living in a condominium, M=2.57, SD=1.813, p=.041, those living in 55+ communities are more likely to use a personal assistant robot than those living in a dormitory, M=3.37, SD=1.832, p=.011, those living in a dormitory are less likely to use a personal assistant robot than those living in a townhouse, M=5.25, SD=.957, p=.045. This suggests that the robot could be designed for homes in 55+ communities.

We also wanted to explore whether gender had a main effect on likelihood of using the robot. A one-way ANOVA was conducted to determine whether there was a significant effect of gender on likelihood of usability. Results show that there is a significant main effect of gender on likelihood of usability $F(1, 279) = 5.005$, $p = .026$, $\eta_p^2 = .018$. Females (M=4.08, SD=1.838) were more likely to use the robot than males (M=3.59, SD=1.776). This may suggest that the robot can be designed more for women.

3.2.3 Study 3: User-Robot Testing

Appeal

Our goal was to determine whether the appeal of the robot was pleasing to the participants and what they thought of its size, shape, and color. All participants agreed that the look of the robot was pleasing. They also reported that it was not too big, they liked the shape, and they enjoyed the color.

Arm

We also wanted to determine whether the arm was placed in an aesthetically pleasing way and if it was a feature that potential users found useful. All participants thought that the placement of the arm was aesthetically pleasing. In addition, participants believed that the arm's intended function (object recognition and retrieval) was useful. Participants also suggested that the arm of the robot should be able to crush pills, pour a glass of water, and reach objects in high locations.

Features

We wanted to determine whether the current features and features that would be integrated in to the future will be useful to the user. All participants agreed that calendar events were very useful, especially reminding of appointments and scheduled medications. Participants also expressed that they would like to also see pill-dispensing and medication reminders as features.

Cost

We wanted to determine whether a personal assistant robot is something that they would pay for given that they had the funds. All participants voiced that they would pay for a personal assistant robot, if health insurance covered a part of the cost, reducing the overall price. Two participants showed concern about the cost being too high.

3.3 Discussion

With the expected rise in the baby boomer population, the number of those needing assistive care will soon override the amount of caregivers available (Super, 2003). While there are services to accommodate and care for those with age-related disabilities, such as in-home care and assisted living facilities, the use of assistive technology may be something that will help facilitate the user's quality of daily life. Therefore, the current project aimed to develop a personal assistance robot that could meet the users' needs. To do this, we conducted two studies prior to the development of FRASIER to determine features that would be important to implement. After the prototype of FRASIER was complete, we assessed feedback from users on the prototype.

To assess user's needs, we conducted two studies. In one study, we interviewed individuals living in assisted living or nursing home facilities. In the second study, we surveyed individuals from all age groups. Both studies were conducted to determine the potential design and functionalities that the personal assistant robot could have as well as determine the amount of acceptability there may be among individuals from a wide range of ages. From these two studies, we discovered that the most difficult activities to accomplish were morning activities (such as getting out of bed), hygiene-related tasks (such as getting to the bathroom), and reaching/grasping tasks. In particular, participants reported that reaching/grasping objects in high or low places was especially challenging. Moreover, participants reported that they commonly used a gripper, a mechanical device to reach and grab objects. These challenges highlight the need for a robotic arm to be able to help reach, grasp, and carry objects.

One challenge that became more evident in the survey than with the interviews was that individuals who are 50 years in age or older had difficulty keeping track of their medications, especially in comparison to those aged 18-29. This finding is in alignment with past research that finds that as individuals age, their bodies may need more assistance from outside resources to maintain their health, for example, taking medication (Balakrishnan, 1998). Participants in the survey also indicated that having a robot that could detect emergency situations would also be very helpful.

In addition, we looked into features that could keep individuals active, engaged, and maybe even feel like the robot was a companion. The results from both studies shows that user's preferred a robot that could assist with making calendar events, playing bingo, exercising, and reading aloud. Therefore, we were able to provide recommendations for features that the Graphical User Interface (GUI) should have.

We also wanted to design a robot that was aesthetically pleasing and not intimidating. Therefore, we showed participants several possible prototypes and assessed their perceptions of these prototypes. We predicted that residents would prefer the robot not look too human-like, especially in the face, because past research shows that when robots are look and sound human it causes revulsion, and that this is especially prominent for older adults (Fassert, Rigaud, & Wu, 2012). Our results confirm this hypothesis. Participants preferred a robot that looked less human and more cartoon-like.

Finally, it was also important to assess just how accepting or willing individuals, especially older individuals, might be to use a personal assistance robot. From the interviews, we found that just as many people were likely to want to use the robot as those who were unlikely to use the robot. Common themes of the responses from those who were resistant to the idea of assistive robots involved the deeper philosophical implications of technology, such as the fact that they fear that robots will take over the world and that robots have no soul and will not be able to emotionally connect with the user. However, the survey results showed that those who are 50+ years reported being more comfortable to have a robot in their home than those who are 18-29 years. Thus, our results are inconsistent with how accepting and comfortable individuals would be with a personal assistance robot. This may reflect a general mistrust that older individuals have for robots and technology (Giuliani, Scopelliti, & Fornara, 2005), or it may indicate a change in attitude. Future work needs to look more into acceptability and methods that may help make potential users more comfortable with a personal assistance robot.

We wanted to determine what design would be non-threatening and ease the user-robot interaction. Participants from interviews voiced that they enjoyed the robot with the animated face and a smooth curved design. After designing our robot, we wanted to include it in the survey to get feedback to solidify our design. Results show that 50+ years were most likely find the robot most appealing. This suggests that the design we have now will appeal to potential users now.

Our goal was to take FRASIER to assisted living facilities after development. We were able to visit a couple of facilities and interview the participants as a group. The goal was to evaluate users' thoughts on overall appeal, functions, cost, and whether it would affect their daily lives. We were able to visit two assisted living facilities and get valuable feedback.

As the majority of participants voiced that the overall look of the robot was aesthetically pleasing. The participants enjoyed the color of the robot. Even though the covering of the robot was temporary, the participants still liked the color and covering. This implies that the robot's shape and color is acceptable to users. We also asked participants what they thought about the size of the robot. Many participants expressed that they would use a robot of that size and that it will be able to work around their living space. A couple of participants from both assisted living facilities wondered why the robot was that particular size. After explaining to them, they thought that the reasoning was valid. Taking into consideration the opinions of the participants, the appeal of the robot is acceptable.

We also wanted to determine whether participants would pay for a personal assistant robot. Participants expressed that cost was a concern. This shows that cost is a big factor in whether or not the individual would purchase and use the robot. Suggestions include having health insurance cover a portion of the cost to reduce the price of the robot.

We wanted to have participants evaluate the current and future features of FRASIER. The participants found that the current features of the robot (calendar, appointment reminders, medication reminders, object recognition, autonomous driving) would be useful for a person living at home alone or living in an assisted living facility. Several participants agreed that features that should definitely be integrated into the robot include pill dispensing and emergency detection. For example, one participant's daughter voiced that she must be at home during her father's scheduled medication times in order to administer them to him, thus pulling her away from work. This implies that pill dispensing and emergency detection should be features to be integrated into the robot.

Limitations and Future Research

Through this study we were able to obtain feedback from those in assisted living facilities and online survey takers to get a wider age distribution. Given the time restraint, we were not able to visit those living in independent homes. Future research could involve reaching out to more participants living independently at home to get a wider range of feedback for the robot.

Although preliminary feedback was obtained for the current prototype of the personal assistant robot, future research should involve more in-depth user-robot interaction feedback after the robot has gone through more development in terms of aesthetics and features.

This study investigated the needs of individuals of age-related disabilities that could be fulfilled by the personal assistant robot through interviews, online surveys, and user-interaction studies implemented in the 2014-2015 school year time frame. Through research and the studies implemented, we were not only able to obtain information for the development of the personal assistant robot, but we learned to become more sensitive to the needs of the population reaching advanced age. According to results from all three studies, the personal assistant robot is something that will definitely be in demand due to the growing population and decline of health care assistance in the near future. With this in mind, future research should focus on interviewing more residents from assisted living facilities, reach a wider number of participants of all ages through surveys, and obtain more user-robot interaction feedback after the completion of the robot.

4 Robot Design

This sections details existing assistive care robots as well as the technical needs and requirements for the design of the robot. A comparison between the first iteration of WPI's personal assistant robot and FRASIER was also conducted.

4.1 Gap Analysis

Based on the insight gained from the user studies, a gap analysis was conducted. Under this project's scenario, current available commercial products and research projects were ideal candidates to explore. Focusing on the functionalities of several robotic systems, the gap analysis provided what each product was lacking in terms of supporting and assisting users. Also, before further identifying the needs and developing design aspects for this project, it was necessary to examine the available robotic platforms and existing research projects relative to this MQP.

4.1.1 Assessing Currently Available Technology

Analyzing previous related projects has helped to identify some of the potential challenges associated with developing an assistive care robot with companionship abilities. One of these challenges was to autonomously follow a user and navigate an open area. To accomplish this, modern robots use simultaneous localization and mapping (SLAM) to map areas and place the robotic system within the created map. The QC Bot, developed by Vecna Technologies, is a delivery robot used in medical and manufacturing environments (Vecna Technologies, n.d.). The QC Bot is able to navigate hallways and open areas by using proximity sensors and 3D vision systems. However, this robot does not provide assistance nor does it have any companionship components.

Another challenge faced in robotic design is an increasing desire for a robotic system to be able to anticipate the needs of the user and to provide companionship. Jibo is a robotic system that focuses on intuitive interactions between families (Jibo, n.d.) Jibo can converse with users, recognize user voices and faces, alert others when given commands, hold messages, and act as a voice activated web browser (Jibo, n.d.). While Jibo has achieved the companion aspect that the QC Bot lacks, Jibo is a stationary robot.

A third challenge was the ability of the robotic system to manipulate its environment. One robot that successfully achieved this was iRobot's PackBot. The PackBot was designed as a bomb defusing robot. It has a 3-link arm with 8 degrees of freedom that can hold a small payload (iRobot). The PackBot is a great example of a robot that can navigate over harsh and rugged terrain (much more rugged than an Assisted Living facility or residential home) and manipulate objects; however, it does not interact with a user or provide companionship. While the PackBot's intended use has no direct ties to personal assistive care, it has been presented as an example of an effective modular based robot with a manipulator.

Of the three robots reviewed, two can navigate their environments. The PackBot has the ability to manipulate the environment and the QC Bot can provide interaction with the user. However, none of these current systems meet the requirements for the current personal assistance robot. By the end of the five year project, FRASIER will be able to move around, perform various functions, interact with the user, and provide companionship.

Most of the research projects relative to supporting elderly are referred to as Assistive Robots (ARs). Currently, ARs are mainly task-oriented robots with dedicated functions to help users. In addition to the goals stated in the above gap analysis, other projects that focus on personal assistance for the elderly include the mutual care robot HOBBIT (Fischinger, et al., 2013), Partner Robot (TOYOTA, 2012), TWENDY-ONE (Iwata, Sugano, & IEEE, 2009), Care-O-bot 4 (Fraunhofer, 2015). Table 2 examines the basic functionalities of these projects.

Project Title	Main Functionalities of Each AR
HOBBIT (est. 2011)	1. Voice control on the robot. 2. Clearance of the objects on the floor. 3. Object retrieval to elderly and learning new objects. 4. Fall detection and helper functions. 5. User Entertainment and Social Connectedness.

Partner Robot (est. 2009)	1. "Pick-up" which allows the robot to grasp objects like papers or cards by small vacuum installed in the hand. 2. "Fetch" which controls the robot using voice commands or touchscreen GUI by simple communications with users. 3. "Manual Control" which is defined beyond the capabilities of this robot while having telepresence for caregivers and other.
TWENDY-ONE (est. 1998 originally named as WENDY)	1. Sitting-up motion support to boost elderly out of bed. 2. Transferring motion to move elderly onto wheelchair. 3. Fetching multiple objects and dexterous handling of small objects. 4. Carrying and pick-n-place tray with food on it. 5. Following elderly by user touching or handling the robot arm.
Care-O-bot 4 (est. 1998)	1. Modular base that allows user to switch out sections based of cost and desired activities. 2. Two manipulators to interact with the environment. 3. Assists humans in their daily lives with household tasks or other services such as delivering room service or working in warehouses. 4. Cameras, microphones, speakers and a GUI control and allow Care-O-bot 4 to interact with humans. 5. Growing use in elderly assistive care.
GiraffPlus (est. 2012)	1. Monitors activities in the home using sensors. 2. Connection to healthcare professionals and family to allow continued involvement in the daily life of the user. 3. Tele-presence robot focused on social interactions with a "Skype-like interface".

Table 2: Summarization of Functionalities of Various Assisted Robots

From Table 2, most of the functions belonged to the category of supporting the users as the main control input. These robots, already under research development are fair examples to compare FRASIER with, but many of them lack the combination of features that FRASIER strives to accomplish. Several of these examples lack a companion component that the MQP team achieved, such as calendar reminder, the ability to skype and play games, help users with exercise and physical therapy, measure heart rate and emergency alarm. Robots that had these capabilities differed from FRASIER in other ways of not having any manipulators to interact with the environment or more focused as helper in the home rather than an assistant for elderly care.

4.1.2 Technical Needs Analysis and Requirements

Built on the gap analysis, the integrated approach evaluated possible users and organizations that are involved with the project either directly or indirectly to provide their needs or feedback on the project. The MQP team interviewed and emailed active stakeholders (Appendix D: Stakeholders). These stakeholders included, but were not limited to, nursing home administrators, assisted living residents, caregivers, and individuals who require assistive care but are living independently in their own home. The MQP team also obtained needs (Table 11: Stakeholder Analysis

Appendix E: Needs Analysis) from stakeholders involved with the research of the project. Stakeholders involved in the different fields expressed a large variety of needs. Table 3 below shows three major stakeholders that have primary influence on the project.

ID	Title	Description	Role	Priority	Communication
SH.01	User	Individuals who will use FRASIER	Define needs, provide feedback	1	Interviews, email
SH.02	National Science Foundation	Government agency that promotes scientific research	Funding	1	Proposal
SH.03	International Standard Organization (ISO) -13482	Standards for robotic devices	Safety requirements for personal care robots	1	

Table 3: Key Stakeholders

In Appendix E: Needs Analysis, most needs are grouped into categories to better explain the overall needs for the robotic system. These needs were created by the MQP team representing a broader group of stakeholders. These needs ensured that standards were met along with determining the size and weight. For example, FRASIER should be able to carry larger objects placed on it (for example, food trays) and should remain powered after 8 hours of operation.

A comprehensive evaluation of all possible stakeholders and their needs result into a list of requirements for the robot as shown below.

- Basic interaction with static objects in the environment.
- A user-interactive Graphical User Interface (GUI) that allows basic realistic communications between the user and the robot.
- Drive autonomously when tracking and following the user.
- Remind the user of daily activities, including scheduled medications and events.
- Alert nurses or authorities in the case of an emergency. For example, by an alarm sound or flashing light.

To meet all possible needs, the MQP team validated each requirement. Most requirements were validated by the creation of sub-systems which will be explained in the section below. A subsystem was added to FRASIER after it was validated by the major stakeholders and other relevant parties. Combined with the technical measures, use cases Appendix F: Technical Measures covered major tasks and ensured the integrated approach results in all crucial requirements to achieve project goals.

4.2 Methodology

This sections focusses on the changes made to PARbot in order to develop a robot based off the results from various user studies. Feedback from these studies lead the team to make improvements to PARbot's base. To allow for these improvements supporting modifications were also made.

4.2.1 Robot Overall Design

The main focus of the project is to design and realize a personal assistance robot that is able to assist individuals, especially those with age-related disabilities. While capability of the robot is very important, special attention was also given to the aesthetics. It was important to make sure that this prototype was appealing and non-threatening to users to ensure an easy user-robot interaction. FRASIER was developed by a previous MQP team called PARbot (Burns, Godani, Hugal, & Orszulak, 2014). Although, PARbot had some great functions, it lacked easy user-robot interaction. Based on discussions with potential users, it was concluded that PARbot, looked intimidating and the interface was not user friendly. PARbot was built using a large cubic base that had two large wheels in front of the robot. It also had sharp edges that needed to be removed, based on ISO guidelines (International Organization for Standardization, 2014).

Revisions necessary from the previous project were considered when designing FRASIER. Table 4 details problems, solutions and criteria for assessment for FRASIER subsystems. The assessment criteria field contains items that needed to be considered in the design phase in order for the subsystem to be successful.

	Robot Design	Arm Design	Wheel Base	End Manipulator
Problem	Deciding the design of the robot frame and options for storage space.	How the arm should be designed to meet the requirements.	Determining the sturdiest drivetrain for robot requirements.	To determine the best end effector for the arm.
Candidate Solutions	• Translational Design • Arm on Top • Arm on Side • Stick with original design • Hyperbolic shape	• Homemade Design • Homemade Design with commercial hand • JACO • PhantomX	• 2 wheel, 1 caster • 2 wheel, 2 caster • Holonomic • Segway	•Gripper •3 Finger Hand •Pointer finger •Homemade end effector
Assessment Criteria	• Work Envelope • Storage Capability • Aesthetics • Manufacturability	• Easy ROS integration • Tactile Sensors • 3DOF • Light weight • Compact • Carrying Load	• Turns on center of rotation • Sturdy • Capable to go up ramps	• Cost • ROS Integration • Tactile sensors • Size • Gripping load

Table 4: Problems and Suggested Solutions for Subsystems

PARbot's Update to FRASIER

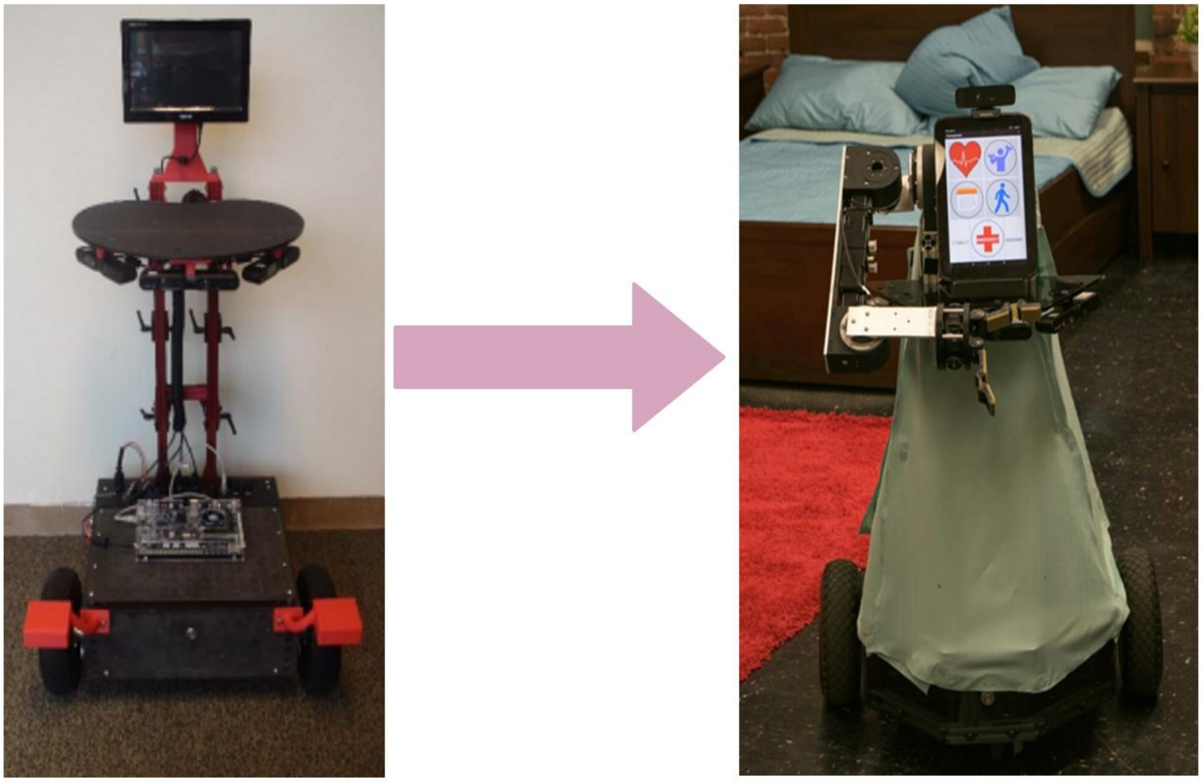

Figure 2: PARbot to FRASIER

Based on the user studies, several design changes and supporting modifications needed to be implemented to update the old PARbot system. The most obvious addition was adding a robotic manipulator. To successfully do this, the team would need to make the robot sturdier, widen its polygon of stability, and change upper tray design. Additionally, because of its front wheel locations, the PARbot system had a tendency to tip over forward when decelerating. This is because the front mounted wheels would act as a fulcrum, and the momentum of PARbot would cause it to tip over and crash forward onto the ground. The FRASIER team would need to move the driving wheels to a better location on the robot, and add casters to prevent the robot from tipping over.

4.2.2 Base

Several aspects were considered while designing the base, including drive system, turning capability, stability, and design aesthetics. The considerations stem from design requirements based on the Technical Needs Analysis and Requirements. There are many different ways to drive a mobile robot; however, previous work on PARbot helped guide drive system considerations. A differential drive system was chosen as FRASIER's drive system. A differential drive system provides an easy and inexpensive drivetrain where the driven wheels are directly connected to a motor on the sides of the robot.

With a differential drive system, the robot has a zero turning radius with the center of turning located in the middle of the drive axis. The center of turning is represented by the red origin in Figure 3. In addition to simple design, a differential drive system is relatively easy to control for path planning. Based on the rotational velocity of each wheel, the robot can travel in a wide range of arcs ranging from zero radius (turning in place) to an infinite radius (driving straight).

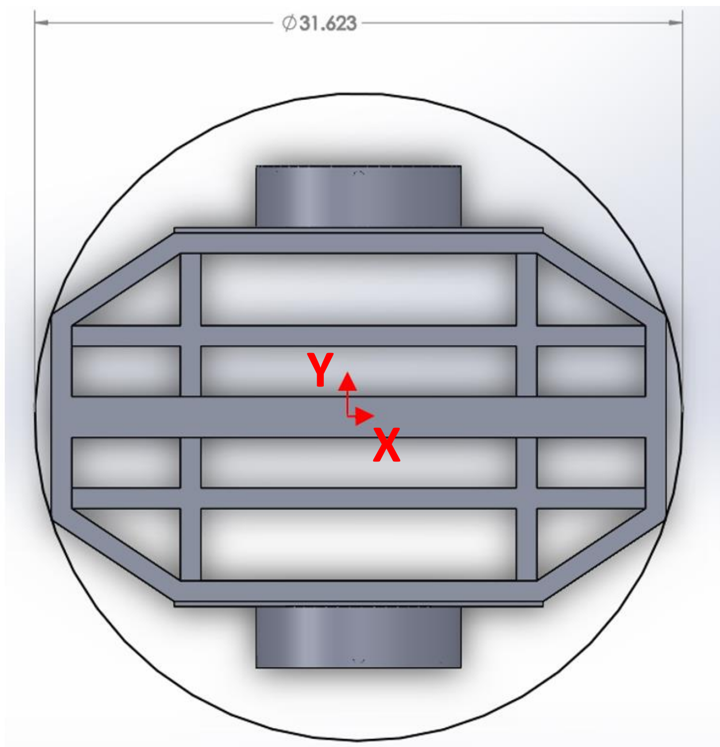

Figure 3: Base of FRASIER

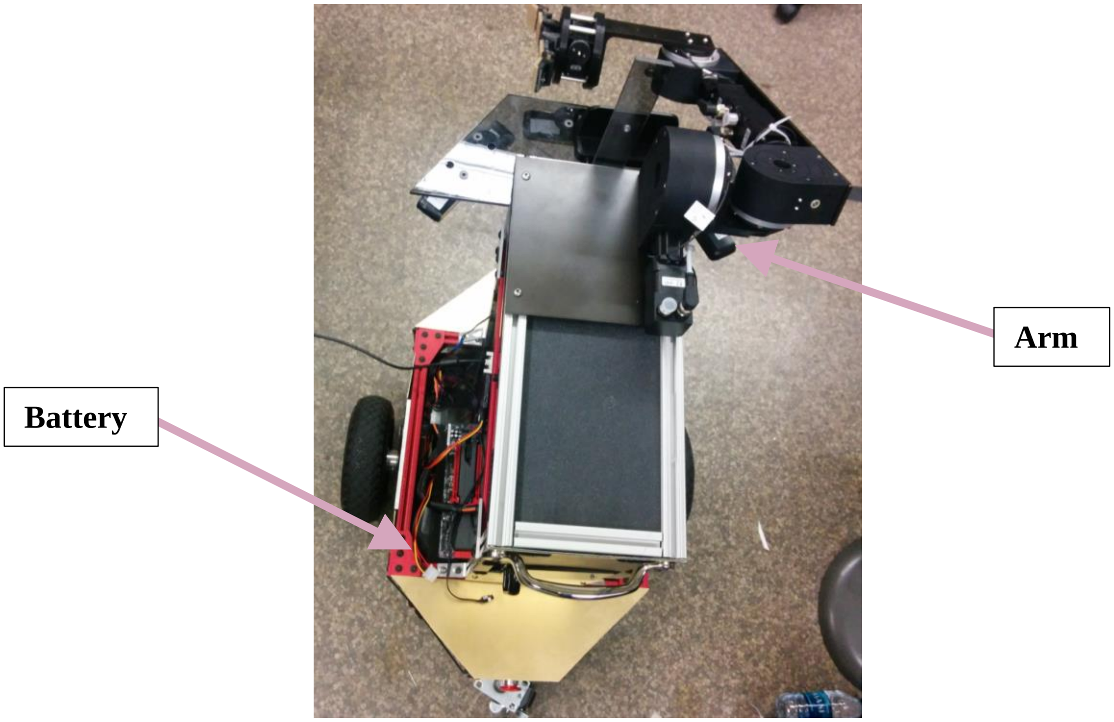

Figure 4: Battery Location vs. Arm Location

The addition of an arm increases the likelihood of the robot tipping over, caused by the change in the center of gravity when in use. To reduce this effect, a large area of stability was needed and the battery placement was used to help counter-balance any moment created by the robot arm (see Figure 4). The area of stability is between the places where FRASIER comes into contact with the ground. The electrical components in the base were restructured to ensure weight distribution.

4.3 Results

To ensure that the robot is versatile and easy to use for everyone, including people with or without wheelchairs, the MQP team took into consideration the average height of men and women in the United States as well as the average height of people in wheel chairs. Based on the data, the team decided on a height of 24.5 inches for the robot, that is comfortable and easy to use for everyone, whether seated in a wheelchair or standing. This way the user can interact with the robot and the tablet without having to struggle or reach for it.

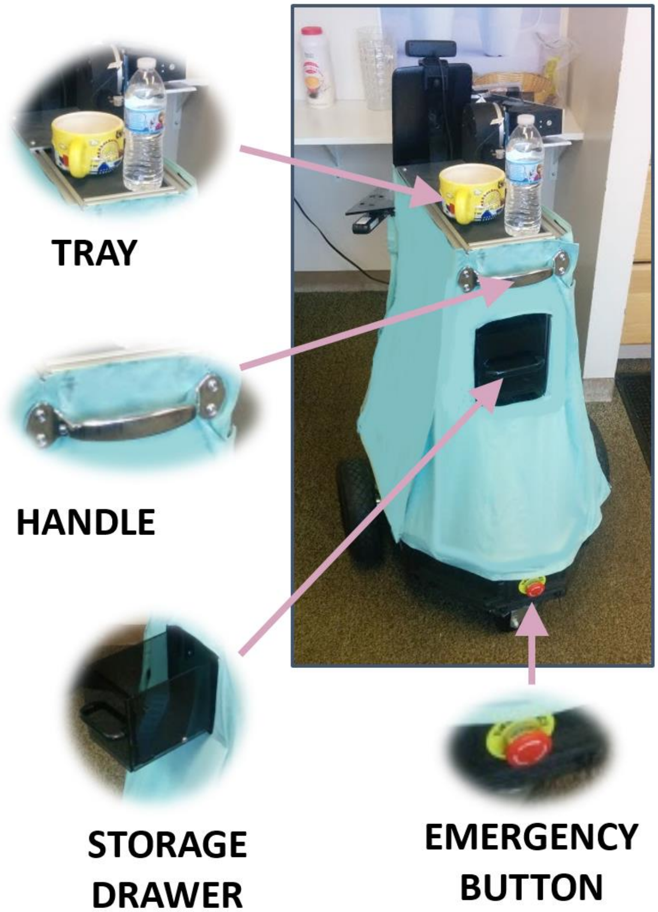

Figure 5: Additional Features

The robot also has a tray on top, a drawer, a handle and an emergency stop button all located in the back, see to Figure 5. The tray can be used to carry food, glasses, cups, and other small objects that can fit on the tray. The tray has a layer of sandpaper to prevent objects from slipping off. During the visits to the nursing homes, it was mentioned that, they would like the robot to help them carry certain objects so that they can have a free hand and also to help take the load off from them. Therefore the team decided to include a drawer. The drawer can be used as a storage compartment that can help carry certain personal belongings such as bags, pill dispenser, and groceries among other things.

The handle of the robot can be used to help the user stand when seated, and can also be used to push or pull the robot when needed, for example if the robot runs out of charge and the user needs to move the robot, they can easily pull or push the robot with the use of the handle.

For extra precaution the team has included an emergency stop button in the back of the robot. The button is fairly large and very easy to accesses. Although the robot has been engineered to insure safety, for extra caution the emergency stop button has been placed in the back to prevent the robot from any issues that may occur. Due to time constraints, testing was not conducted to ensure the robot stops within ISO standards for stop button response time, however, the team believes that the this emergency stop adds to the safety of the robot and future teams could better fulfill the ISO stakeholder's needs.

4.4 Discussion

For the robot shell, we recommend that future teams use expanded polystyrene foam (EPS) as the main material for the Shell. Since the foam is white, it would be easier to paint over to implement various designs, it's also cheap and easy to work with. If EPS is utilized, we recommend to hard coat the shell in order to give it extra strength, make it water resistant, and help prevent dents. EPS shells can either be ordered from a custom manufacturer or cut using a heated wire.

The base performs well in an indoor environment. Adding the casters to the front and back of the robot increased its stability greatly. However, because the driven wheels are in the middle of the robot, the robot can encounter times when its driven wheels lose contact with the ground. This can happen during drastic slope changes on the ground, like a wheelchair ramp. The team knew this problem would occur during the design, but accepted the decrease in possible terrain because the robot was designed to stay on a single floor of a home. If future teams wish for the robot to be able to handle changes in the ground slope, the FRASIER team recommends a spring/damper suspension system for the caster to allow them to compress so the driven wheels always remain in contact with the ground.

The robot base incorporated several different features to increase everyday usability of the robot. The modular nature of the extruded aluminum allowed the team to quickly adapt to stakeholder needs developed during the user studies conducted at the beginning of the year. Items like the drawer, pill dispenser, and handle were not originally in the preliminary design for FRASIER, however, because of the adaptability and modularity of the design, these additions were quickly incorporated into the design. With the extra space in the robot, it will be easy for future teams to add additional features to the system.

5 Navigation

Navigation for indoor mobile robots encompasses a versatile variation of robotics disciplines and technologies that are synthesized to convey a robust system that performs in a socially acceptable manner. Functionally, navigation systems tailored to social robots focus on decisive factors such as: safety, reliability, and flexibility and robust robot mobility to efficiently carry out complex missions and tasks in indoors environment autonomously (Thrun & Bucken, 1996). Such tasks are accomplished by algorithms that convert high-level specifications (tasks) given by humans into low-level descriptions on when and how to move.

5.1 Methodology

In order to design an appropriate navigation system for FRASIER, the accuracy to which it needs to navigate (i.e. resolution of navigation) must be determined and parameterized. These requirements allow validation of the systems to be performed during the debugging and testing process.

5.1.1 Motion Planner

Motion planners for indoor navigation systems are commonly discretized into three physical scales: global navigation, local navigation, and personal navigation. *Global Navigation Planner* encompasses an overall trajectory formulation that determines the position of the robot in an absolute or map-referenced term, thus, generating a path from robot's current location to a target area. *Local Navigation Planner* is referred to as the "object avoidance" planner since it determines the robot's position relative to objects (static or dynamic) in the environment, which allows the robot to properly interact with it. Lastly, *Personal Navigation Planner* involves the robot's self-awareness and anything in contact with it. This project only makes use of global, local planners, and simple straight-line path generation.

The focus of this project is not to develop a complex path-planning algorithm, but to synthesize FRASIER's new features with the existing navigation stack. However, a basic problem in motion planning for mobile robots is to automatically compute a path that doesn't collide with obstacles.

Thus, in order to ensure that FRASIER can reach designated targets in its workspace to perform an assigned task given by the user, several environment and navigation assumptions were implemented and parameterized. These assumptions are summarized below:

- FRASIER is a single point in space that can move freely in any direction (holonomic)
- FRASIER only navigates in known environments (structured environments)
- FRASIER must navigate in a static world
- FRASIER’s workspace (environment) is 2D with polygonal obstacles
- FRASIER is controlled by sending desired velocity commands to achieve in the form of:
    - x_velocity
    - y_velocity
    - theta_velocity
- FRASIER’s operates in a mock Home Environment that mimics a real-world scenario
- FRASIER only interacts with rigid objects
- FRASIER navigates in a collision-free path from target to target

A mock home environment that mimics a real-world scenario is used to validate FRASIER’s navigation performance. Figure 6 depicts FRASIER’s workspace, robot and obstacle geometry represented in 2D, of the home environment.

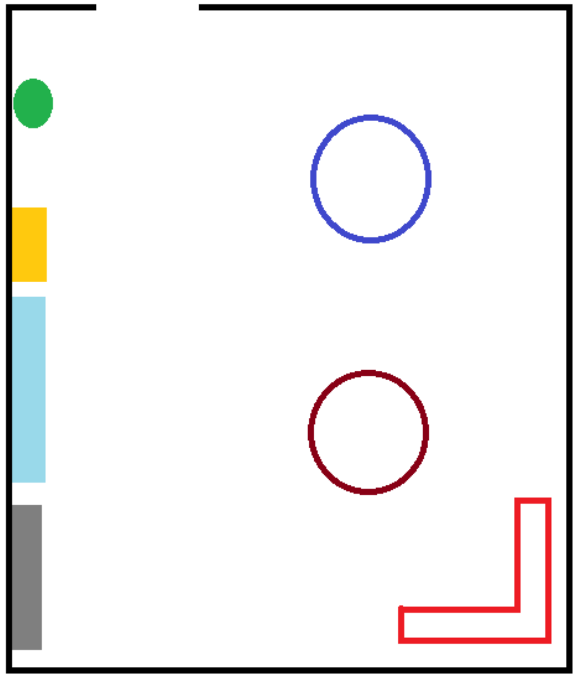

Figure 6: Static Home Environment workspace depicting all of the possible obstacles

A simple motion planner was utilized to generate straight-line paths to navigate FRASIER from an arbitrary (but known) target in the workspace to another known target. These path generations are bidirectional, meaning FRASIER can navigate back and forth from targets. FRASIER uses its existing A* planner to generate global path paths to targets, and since in this scenario paths are assumed to be collision-free no local planner is necessary. Here, the workspace is composed of three known targets – door, table, and kitchen countertop. Figure 7 shows the three path trajectories generated for this scenario, corresponding to the three desired targets.

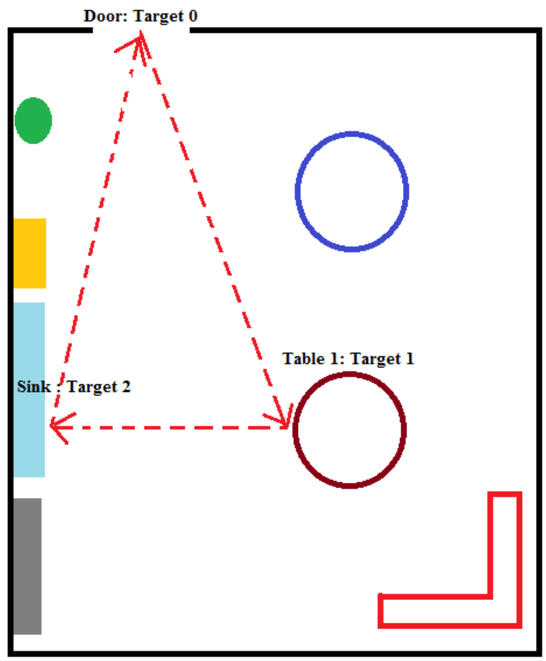

Figure 7: Three path trajectories between desired targets

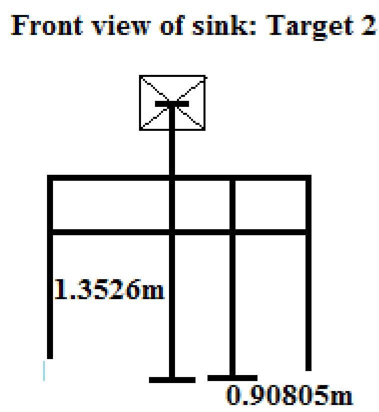

Figure 8: Front view of sink: Target 2

FRASIER path planner and trajectory generation are composed of common and standardized algorithms. However, in order to capitalize on FRASIER's new features and capabilities, FRASIER needed to be positioned at very precise locations in the vicinity of desired targets. Previously, FRASIER utilized SLAM for exploration and localization; however, given the necessity of precise positioning of the robot with respect to its target, an alternative localization method was implemented in FRASIER's navigation package.

5.1.2 Localization

Fiducial Marker Localization method was adopted for FRASIER's task of approaching a designated targets and positioning its self at precise locations in a close-quarter environment. This method incorporates Augmented Reality. Augmented Reality (AR) is visualization technique that makes use of superimposing virtual objects in the user's view of the real world, allowing task plans and mobile robots motions visualization in workspace of the human operator (Gaschler, Springer, Rickert, & Knoll, 2014). For the purposes of this project, AR applications include; real-time marker tracking, multiple frame registration between fiducial makers and FRASIER's *base_link*. This will allow

FRASIER makes use of *ar_track_alvar* package, which is a ROS wrapper for the **Alvar** C++ software library that creates virtual and augmented reality applications. This package is a high-performance, robust, and intuitive library used for tracking multiple bundles of fiducial markers in a workspace. The ar_track_alvar package has four main functionalities (Liebhardt, 2015):

1. Generating arbitrary-size, resolution, and data/ID AR tags
2. Identifying and tracking pose of individual AR tags with respect to the frame that the published Cartesian locations of the AR tags will be relative to – i.e. /*base_link*
3. Identifying and tracking pose of "bundles" of tags in the same field-of-view. This functionality allows for more stable pose estimation, robustness of occlusions and tracking of multi-sided objects/targets.
4. Monocular or Stereo camera images to calculate *spatial* relationship between tags in the workspace.

The first step in AR tag tracking is camera calibration. This is a necessary step in 3D computer vision in order to extract metric information from 2D images. In this case, camera calibration produces a projection equation linking known coordinates of a set of 3D points and their projections to solve for intrinsic and extrinsic camera parameters. This project makes use of the camera calibration pipeline provided by ROS to obtain rectification and distortion compensation parameters. It is important to note that no work can be accomplished with an un-calibrated camera, unless the workspace relies solely on what is being seen perfectly at the center of the camera.

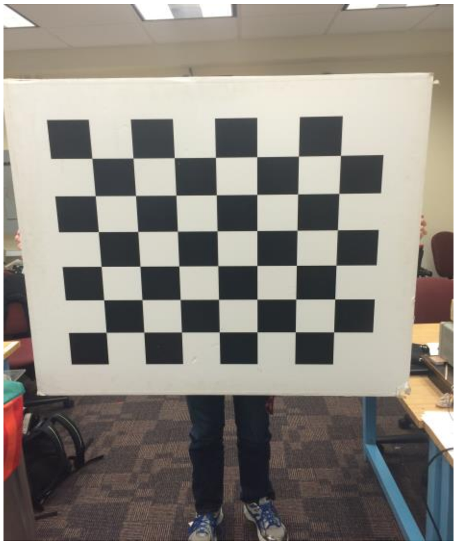

Figure 9: 7x5 Checkerboard Calibration Target

Calibration was performed on the *Creative Senz3D Camera* (monocular RGBD image modality) using a checkerboard calibration target. The calibration target is composed of an internal 7x5 grid checkerboard with a square width of 10.7cm; camera image topic was taken from the Creative API. See Figure 9.

The second step was generating the tags with its arbitrary parameters. This is done by running the following command on the terminal and following the instructions describing the multiple options: **$ rosrun ar_track_alvar createMarker.** Once the tag(s) are generated the following command line parameters must be instantiated.

Augmented Reality Tag Parameterization	
Parameters	**Description**
1.Marker Size (data type: **double)**	Width of one side of the black square marker boarder in centimeters
2.Max New Marker Error (data type: **double)**	Threshold determining when new marker can be detected under uncertainty
3.Max Track Error (data type: **double)**	Threshold determining how much tracking error can be observed before a tag is no longer visible/track-able
4.Camera Image Topic (data type: **String**)	Camera topic that provides camera frames for detecting AR tags – i.e. mono, rgb, unrectified image
5.Camera Info Topic (data type: **String**)	Camera topic that provides the camera calibration parameters so that image can be rectified

6.Output Frame (data type: **String**)	Name of Frame that the published Cartesian locations of the AR tags will be relative to

Table 5: Table of AR Tag Parameterization

The AR Marker setup was formatted to the following parameters:

- Tag_Marker_Size: 11.5 cm
- New_Marker_Max_Error: 0.08 cm
- Max_Track_Error: 0.1 cm
- Camera_Image_Topic: /softkinetic_camera/rgb/image_mono
- Camera_Info_Topic: /softkinetic_camera/rgb/camera_info
- Output_Frame: /base_link

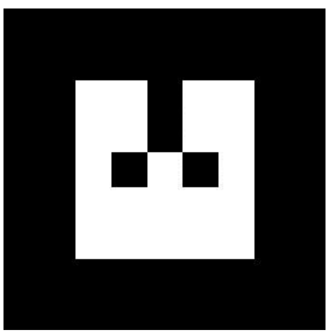

Figure 10: Marker 0 - Table

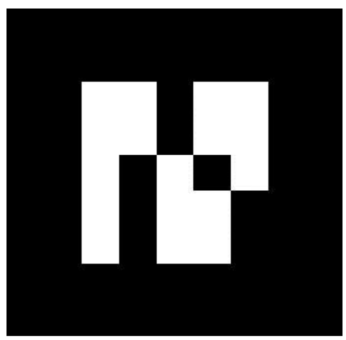

Figure 11: Marker 1 - Door

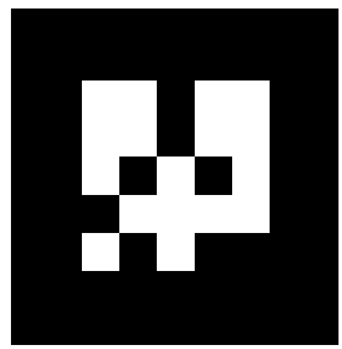

Figure 12: Marker 2 - Sink

In order for FRASIER to localize in its mock Home Environment, three tags were generated using the preceding parameters.

NOTE: The markers were placed at arbitrary locations around the vicinity of the targets in order for them to be in the field of view of the camera. This prompted offsets from center of the marker to desired targets to be hard coded in the navigation package. As seen in Figure 13 and Figure 14, the tags were placed in arbitrary locations through the process of trial-and-error - i.e. ensuring that the tags were in the field of view of the Creative camera as FRASIER approached a target.

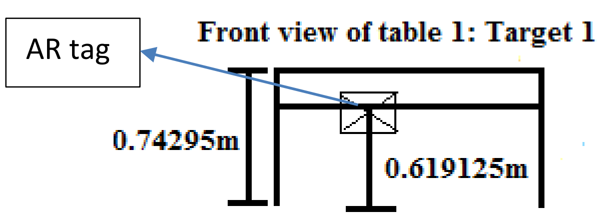

Figure 13: Front view of table 1: Target 1

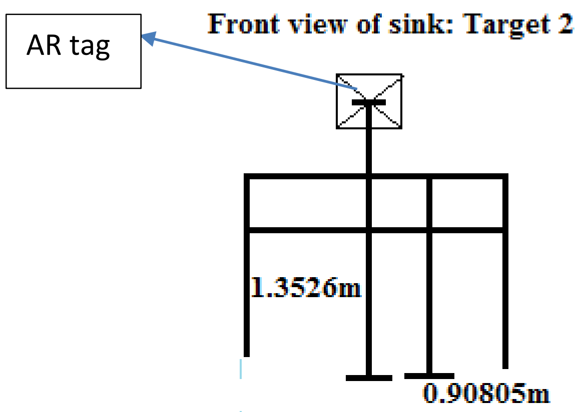

Figure 14: Front view of sink: Target 2

5.2 Results

This section features figures of the navigation validation in a testing environment. While the testing for these systems were done independently, they have been designed for an easy integration with the system for future work. Figure 15 showcases FRASIER's ability to detect multiple tags in the same field of view, and distinguish the markers from each other.

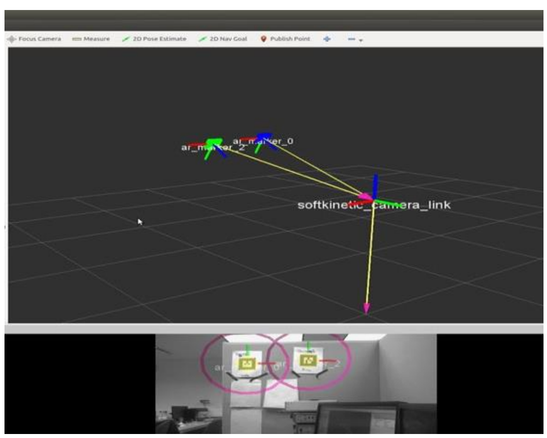

Figure 15: Multiple AR Tag tracking the same field of view

In Figure 16, a target tag is detected at the table height as previously parameterized. As FRASIER approaches the target, the tag is kept in its field of view till precise robot location is achieved.

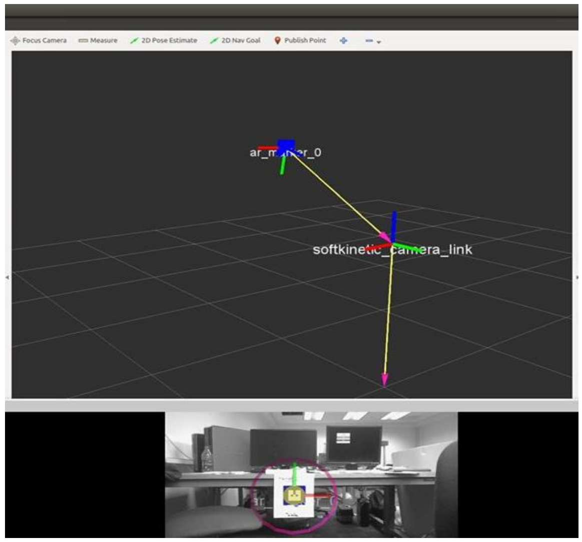

Figure 16: Single AR Tag tracking with pose estimation

Internally, the transformation between the robot's base_link and center of the AR tag are computed and displayed in the terminal output as Figure 17 shows. The output gives the 6 degrees of freedom of the AR tag with respect to a point on the robot.

```
FRAISER: ~
  frame_id: ''
markers:
  -
    header:
      seq: 0
      stamp:
        secs: 1430376440
        nsecs: 101884756
      frame_id: /base
    id: 0
    confidence: 0
    pose:
      header:
        seq: 0
        stamp:
          secs: 0
          nsecs: 0
        frame_id: ''
      pose:
        position:
          x: -0.320104755823
          y: -1.50433916943
          z: 1.31307055673
        orientation:
          x: 0.876555474253
          y: -0.0108882781764
          z: -0.00116730791916
          w: -0.481176249775
  -
```

Figure 17: Transformation pose output from AR Tag w.r.t base_link

5.3 Discussion

The navigation planner used by FRASIER in this scenario is trivial by nature since its workspace is a controlled environment where FRASIER navigates in an obstacle collision-free path. However, one major issue with the navigation stack was motor control. The planner did not take into account accelerating and decelerating as the robot approached the arbitrary targets. This caused FRASIER to either bump into the targets or stop too far from the targets. As this project evolves in the coming years, a more complex and robust navigation system should be implemented. The navigation planner should enable FRASIER to move efficiently and smoothly with groups of people in a populated environment. Selecting individuals that move towards the robot's desired goal could accomplish this. Global planners such as RRTs or PRMs are strong, robust, and holistic planners for this mode of motion planning. Navigating through crowded environments in human-like motion behavior is an important feature for FRASIER to possess since FRASIER must ultimately operate in a highly dynamic environment.

The localization method of ARTags utilized in this project has proven to be accurate and easy to implement. It reduced computational cost since the only camera needed for this localization was the Senz3D. As long as the AR tags were in the field of view of the Senz3D, FRAZIER could calculate a trajectory to follow the marker. However, there were a lot of problems with FRASIER not knowing where it was when the markers were out of the field of view. A solution for that was to have FRASIER spin around on its zero motion line slowly till it could locate the markers again. This, however, is not a very good re-localization method. Using AR Tags proved to be very precise, intuitive, and accurate for getting a robot to move from one point to another, which was all it needed to do in this project. Overall, FRASIER's navigation and localization system needs to be better developed and tested for user-interaction satisfaction.

6 Computer Vision

This section addresses a discipline of engineering that deals with the development of methods, algorithms and image processing operators that are used to implement a perceptive autonomy for FRASIER – this is commonly referred to as computer vision.

6.1 Methodology

Computer vision augments a robot's ability to: self-localize, avoid obstacles, track and recognize people, and learn how to recognize and interact with objects. This section of the report capitalizes the feasibility of an automated perception-decision-action controller for FRASIER by enabling the robot's ability to process and understand the environment based on sensory data. While it is necessary for FRASIER to use robust controller methods, the choice of hardware, software, and drive control loops are important for the robot's efficacy. The computer vision for FRASIER utilizes a robotic framework with a number of capabilities. These include determining locations of "pre-selected" objects within the robot's workspace (10 inches in front of the robot) through means of autonomous exploration, dense real-time localization and mapping, object detection, path planning and motion control (Kaess, Leonard, Whelan, & Finman, 2013).

For this project, FRASIER's computer vision approach was accomplished by benchmarking off the methods adapted by Finman, Whelan, Kaess and Leonard (2013). As a result, FRASIER's computer vision explored the efforts to develop an object-based semantic perception understanding of the robot's environment to interact with definite-geometric shape objects. FRASIER utilizes two image modalities (cameras), the *PrimeSense* and *Creative Senz3D Depth* and *Gesture Recognition Camera.* Currently, FRASIER utilized the PrimeSense cameras exclusively for robot navigation/localization, obstacle avoidance and mapping. The Creative Senz3D has recently been augmented to FRASIER as a means of short-range camera with RGBD frame sync. This specific camera's field of view ranges between 0.5ft and 3.25ft and it uses a USB 2.0 interface. It is commonly utilized for high-precision computer vision algorithms but its close range depth tracking, facial analysis and speech recognition (via dual-array microphones).

FRASIER is able to perform compliant manipulations according to the actual state of the environment. This is accomplished through the development and fusion of existing algorithms that convert high-level specification into low-level descriptions on how to move and perform object recognition tasks. These algorithms include the use of a pass through filter, Euclidean cluster extraction, model segmentation. The model segmentation algorithm returns the normal of the objects, which is used to determine the position of the object. Figure 18 illustrates the steps that were taken in order for FRASIER to be able to achieve object recognition and detection.

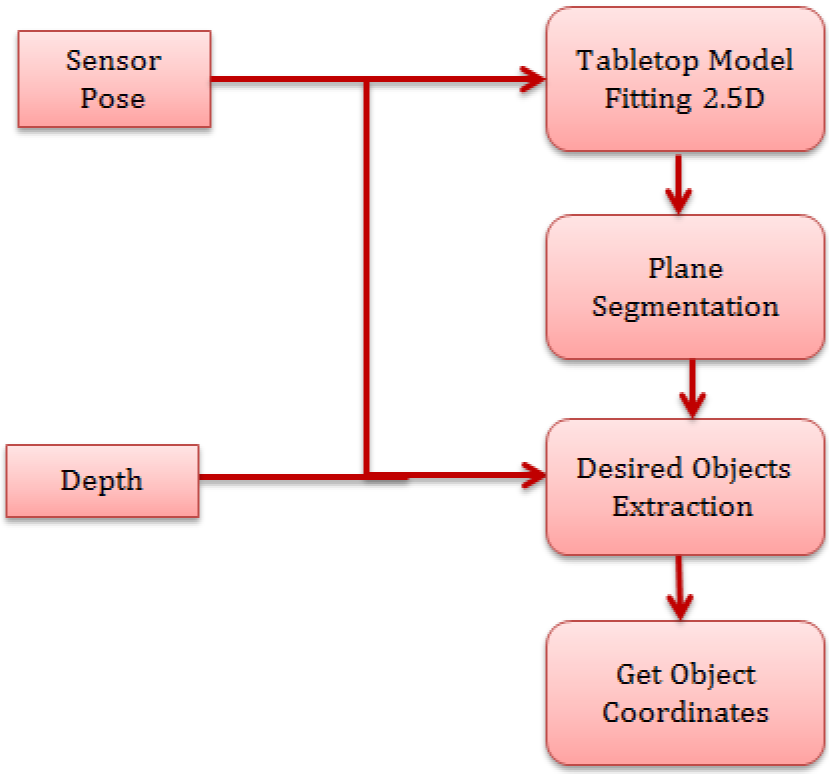

Figure 18: Object Recognition and Detection Control Loop

FRASIER knows its position in the environment as well as the cameras position relative to its base. FRASIER is able to filter out the largest surface in which the objects are placed on. A table top object segmentation for handheld objects is then performed in order to be able to determine how many objects are on the surface (or tabletop). FRASIER is then able to use a model fitting algorithm in order to determine if the object is a basic geometric shape, i.e. cylinder or sphere or cube. The positions of these objects with respect to the base are then calculated using the depth portion of the Creative Senz 3D camera. These positions can later be used to give the arm instructions with specific locations to retrieve objects.

6.2 Results

For FRASIER to be able to perform any of the computer vision tasks this year or for future years, it has to achieve alignment and integration of mechanisms for partial data views, fast segmentation into different regions based on the local surface characteristics, and reliable object detection. Computer vision determines how the robot interacts with the environment in which it operates based on the data generated by the rest of the software system. A great deal of testing was done in order to optimize the computer vision as a stand-alone system. FRASIER is able to reliably detect and recognize objects on a plane surface.

Figure 19 displays FRASIER's ability to filter out a surface, and detect different objects on a surface. FRASIER is able to remove all other objects that are not necessary for the object detection. As seen in the Figure 19, there are three objects on the table, and the output on the terminal supports that.

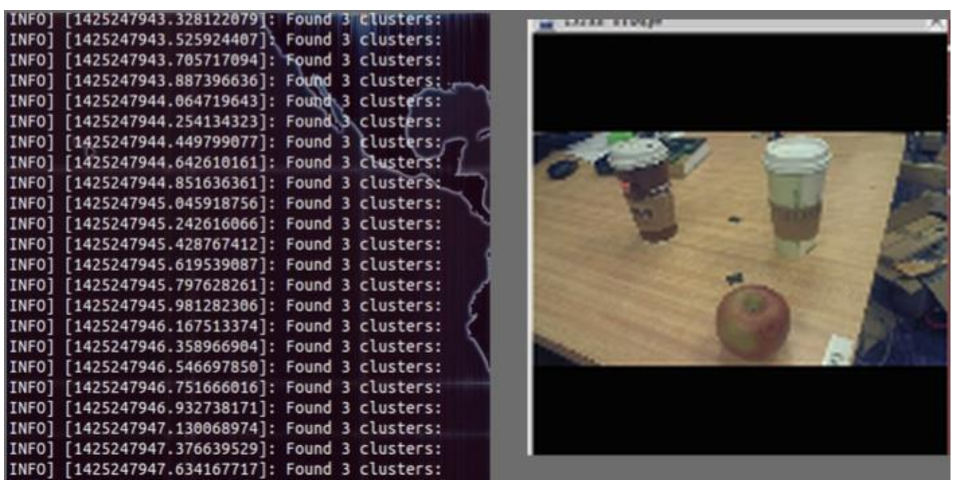

Figure 19: Results showing the number of objects found

FRASIER is also able to recognize the positions of objects with respect to its base link. Figure 20 illustrates the zone that the object recognition was tested on with the respective distance. The boxes with numbers 1 and 2 represent the different position the object was placed in. The x, y, z coordinates were obtained when the object was placed in the specific locations.

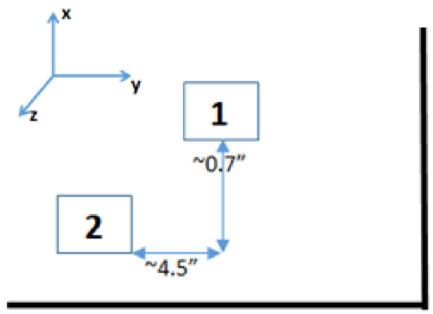

Figure 20: Segmentation zone to test object position recognition

From this setup, there are expected changes in the x direction and y direction but no expected changes in the z direction for the objects coordinates. A ~0.7" change in the x-direction and ~4.5" change in the y-direction in expected. Figure 21 to Figure 26 display the object in the two positions, as well as the Rviz view of the object in the two positions and the terminal outputs of the two positions. The terminal outputs are listed below:

Position 1 (in meters)	Position 2 (in meters)
• x: ~0.350 • y: ~-0.358 • z: ~0.745	• x: ~0.364 • y: ~-0.467 • z: ~0.728

The calculated values are listed below:

Change in the x-direction	Change in the y-direction
• 0.364 - 0.350 = 0.014m • ~0.551" (calculated) • ~0.7" (expected)	• 0.467 - 0.358 = 0.109m • ~4.29" (calculated) • ~4.5" (expected)

The calculated values are very close to the expected value. The difference of ~0.2" could be that the camera may have tilted in between captures. Following the block diagram shown in Figure 18, once the plane was segmented in out the number of objects was obtained (Figure 19), then the positions of these objects with respect to the robot's base_link was determined (Figure 23 and Figure 26).

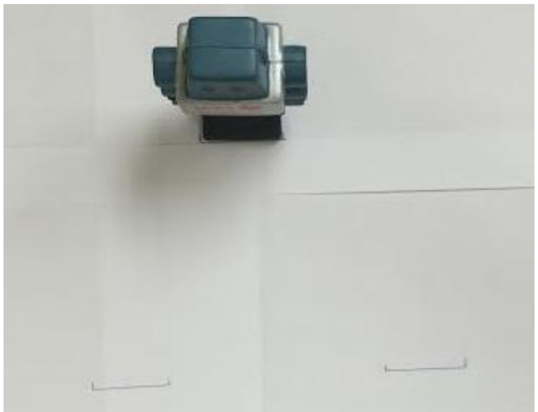

Figure 21: Object in Position 1

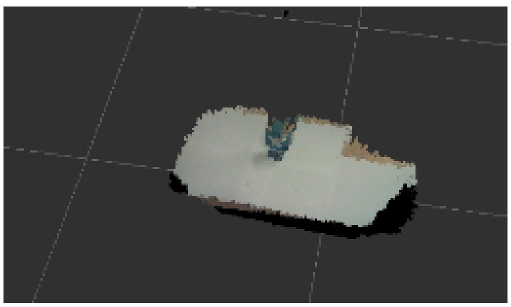

Figure 22: Object in Position 1 in Rviz

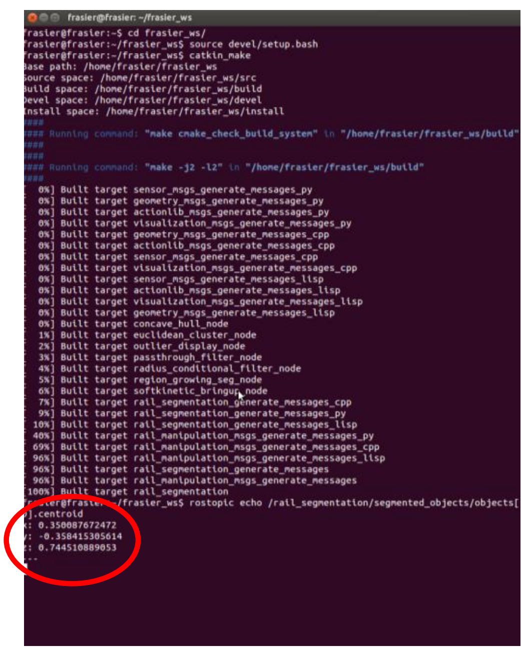

Figure 23: Terminal Output in Position 1

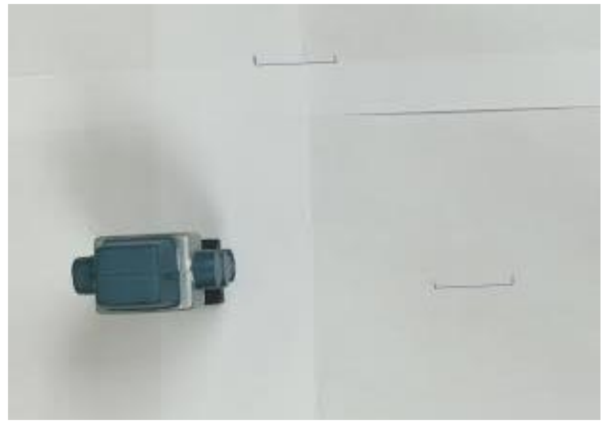

Figure 24: Object in Position 2

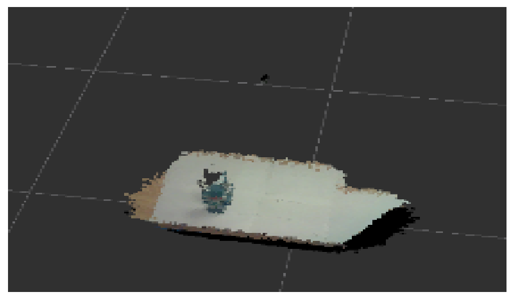

Figure 25: Object in Position 2 in Rviz

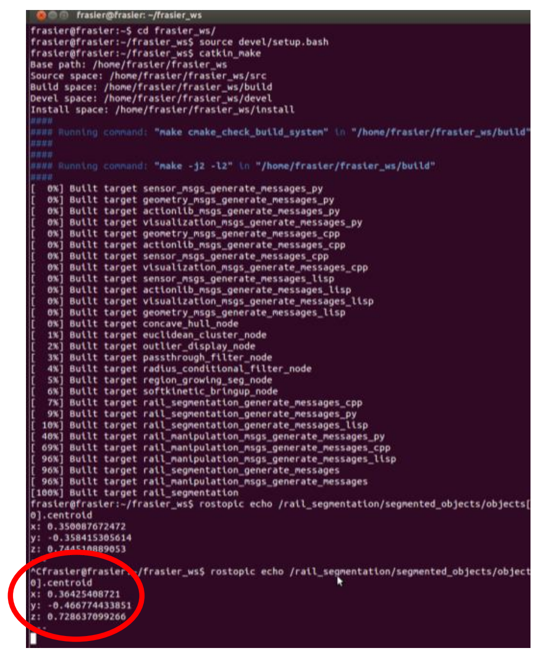

Figure 26: Terminal Output in Position 2

7 Manipulation Framework

Chapter 7 introduces the addition of a robotic manipulator to FRASIER. FRASIER's ability to interact with its environment was one of the highest ranking needs from the user studies. The following identifies the path that was taken in order to incorporate a manipulator on FRASIER.

7.1 Methodology

One of the robot design requirements for FRASIER is the ability to handle typical objects in the home or assisted living environment. A robotic arm was designed and created to fulfill this requirement so that the robot has the ability to manipulate objects in its environment. A flexible gripper with two under-actuated fingers (Odhner, Ma, & Dollar, 2013) attached as an end-effector, is suitable for future work to be done to grasp objects found typically in a household, such as mugs and bottles. This section will explain how the team approached the design and built aspects of the robotic manipulator. To investigate more on the design and control of this manipulator, the team went through series of topics, including the hardware configuration, the hardware interface from motor drivers to connection with ROS, and software support to demonstrate the capability of the hardware.

7.1.1 Hardware Configuration

The hardware configuration includes the payload estimation and manipulator workspace estimation. First, this arm serves for small objects that usually exist in the home or assisted living environment. The most common household objects usually weigh less than one kilogram with relatively small sizes. From the statistics (Choi, Chen, Deyle, Glass, & Kemp, 2009), these objects usually weigh around 200 grams and have size within 10cm to 20cm. This added design consideration to the project to ensure that simple household objects can be lifted. Another design parameter for the arm included the arm's workspace. The workspace is defined as the volume of space in which the arm can reach and manipulate objects. To obtain the workspace design, the arm subsystem relied on camera data from the computer vision subsystem. With the robot located in front of a household table, the team was able to conclude that the robotic manipulator's workspace would need to encompass at least 12 to 18 inches in front of the robot. Using this design, the team was able to establish rudimentary linkage lengths, which then could be used to calculate the necessary torque and power requirements for the system.

Second, to reach out the objects in the surrounding environment of robot, the manipulator should have the ability reaching out in front of the robot in order to be close to the object. In other words, the outcome of manipulator kinematics should perform tasks filling the gaps between robot and target objects. Therefore, special attention was paid to the mounting of the arm on the robot's torso. The torso of FRASIER sits on the base, supports the manipulator, and provides the workspace for manipulator to perform certain tasks. The team measured the available space for the manipulator on the torso in order to reach out in the work environment, while not sacrificing the robots overall stability.

One final system design consideration was overall system power consumption. The robot in its original state came with pre-selected battery. Special attention was needed to ensure the robot could handle the load of multiple systems. To solve this problem, the team decided that it would be best to design the robot so that it wouldn't drive and move its arm at the same time. This meant that power from both systems, the arm and drivetrain, would not be able to overload the overall system. This design consideration had other advantages like better repeatability for arm manipulation and safer performance. While this design consideration helped in reducing the overall power consumption of the system, it didn't completely solve it. To hold a position, certain robot arms must be supplied constant power so they cannot be back driven. This means that the arm would still need to consume some power, even if it was not moving. Design preference was given to robotic joints that were unable to be back driven, meaning that constant power would not be needed to keep the arm in place.

The team followed the generic design pattern of serial-chain mechanical manipulator with rigid links and revolute joints between adjunct links (Craig, 2005). To demonstrate the concept of the design, the team decided to implement a manipulator prototype with three degrees of freedom (DOF). Figure 27 shows the estimation on the workspace using simulation as well as the arm configuration. This manipulator only incorporates three revolute joints. Therefore, the modularity of the hardware was considered in order to have the ability to expand up to 6-DOF. As a result of the dimensions of torso and positions of other sensors, such as Primesense, the workspace of this manipulator is limited. Also, each joint configuration follows the Denavit–Hartenberg (DH) parameters to provide the methods representing the kinematics of the manipulator (see Figure 27, Figure 28 and Table 6).

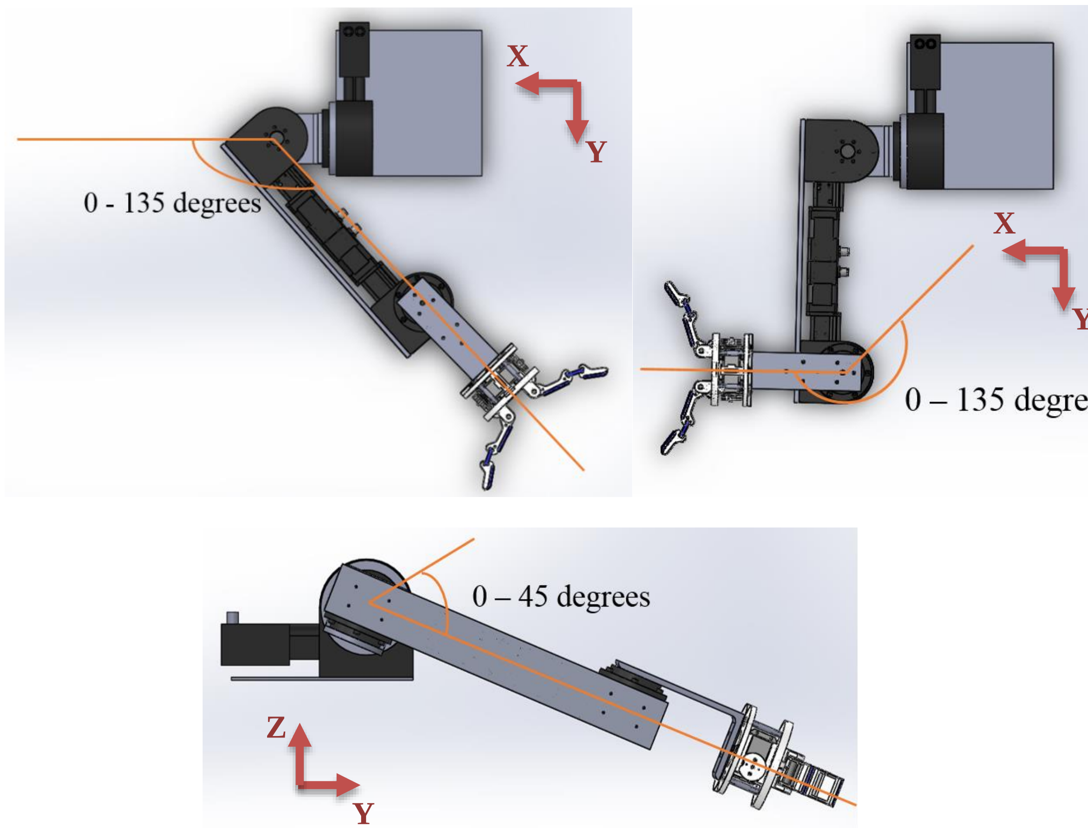

Figure 27: Manipulator with Workspace Configuration on Each Sub-Coordinate

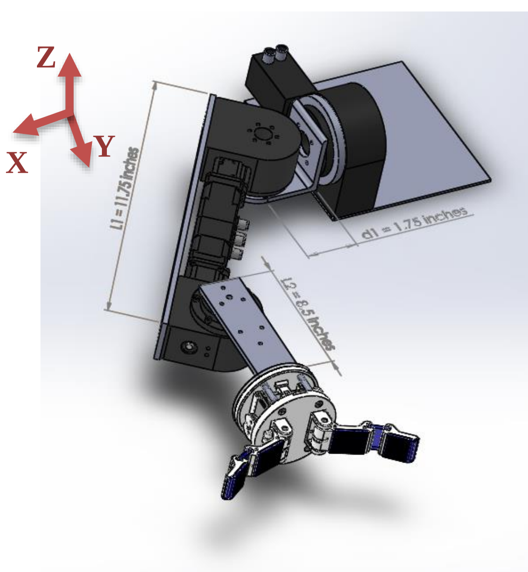

Figure 28: Entire Manipulator with Dimensions

Links \ Parameters	d [inches]	θ [degrees]	a [inches]	α [degrees]
1	1.75	Θ_1*	0	90
2	0	Θ_2*	11.75	0
3	0	Θ_3*	8.5	0

Table 6: Denavit–Hartenberg (DH) parameters (* indicates variables)

With the estimation of linkage lengths, the team performed the static forces on the manipulator and minimum torques at the shoulder joint of the robot to support the entire arm structure. Table 7 lists the physical properties of the link and the torque calculation in Table 8. For the minimum torque calculation, the team considered the extreme case where the first joint is under the maximum load and a safety factor of 1.5 was multiplied into the original load.

Name	Variable	Value	Unit
Length Linkage 1	L1	11.75	in
Length Linkage 2	L2	8.5	in
Mass Linkage 1	mL1	3.04	oz.
Mass Linkage 2	mL2	2.24	oz.
Mass Joint 1	mJ1	12.8	oz.
Mass End Effector	mJ2	23	oz.
Available Torque Shoulder Motor	Tm	1528	oz./in

Table 7: Physical Properties of Robotic Manipulator Links

			Unit	w/ SF (1.5)	
Arm Moment (Am)=	(L1/2)*mL1+L1*mJ1+(L1+L2/2)*mL2+(L1+L2)*mJ2	669.85	oz./in	1004.775	oz./in
Available Torque (Ta)=	Tm-Am	858.15	oz./in	523.225	oz./in
Stall End Mass=	Ta/(L1+L2)	42.37778	oz.	25.8382716	oz.
		2.648611	lbs.	1.61489198	lbs.

Table 8: Torque Calculation for Robotic Manipulator under Worst Case (Maximum Load for First Joint)

Another consideration on the manipulator is to avoid the back-driven movement when the joint stops moving and holds its position. When the manipulator stays at a specific position, the joint tends to move toward the direction of the gravity. Maintaining the power to each joint motor is necessary, and a designated mechanism could also keep the joint at particular angle without back driving to the gravity direction. To achieve this goal, the joint should have some internal gear mechanisms or other complex systems, such as gravity compensation that was introduced in the development of PR1 (Berger, Salisbury, Van der Loos, & Wyrobek, 2008), and explained more details in modular robotic arm developed by researchers (Eckenstein & Yim, 2013). As for FRASIER, the team decided to choose the worm gear combination to avoid the back-driven of the joint. By the implementation of worm gear, the gear system also provides a relatively large gear reduction ratio which will increase the torque of single joints compared to those without the worm gear combination. The final choice of the joint was “igus Robolink D” (igus Robolink D Data Sheet (igus).

7.1.2 Joint Control

Instead developing most software controller programs in ROS, it is more convenient to develop on a programmable hardware interface, such as Arduino. In this method, ROS will simply serve for the indirect command sending to Arduino to realize the joint control. And the Arduino will execute most low level signals generations to the stepper motor drivers. The team decided to implement on the Arduino Mega 2560 while develop features compatible with ROS using *rosserial* package in the ROS community.

Besides the selection of interface, the team went through the selection of motor drivers to fulfill the power consumption of each joint. From the data sheet of igus Robolink D, each stepper runs at a nominal voltage ranging from 24 Volts to 48 Volts with 1.8 Amps nominal current. Each stepper needs a *STEP* signal and a *DIRECTION* signal to control two different wires for joint control. Therefore, the ideal driver should have the connections for two inputs from interface (Arduino) and outputs four channels for the stepper. The search for this hardware on the major online inventory resulted into the Big Easy Driver that satisfies the requirement of the power and signal handling. To illustrate in more detailed manner, Figure 29 shows the hardware interface architecture including the manipulator and ROS side as well.

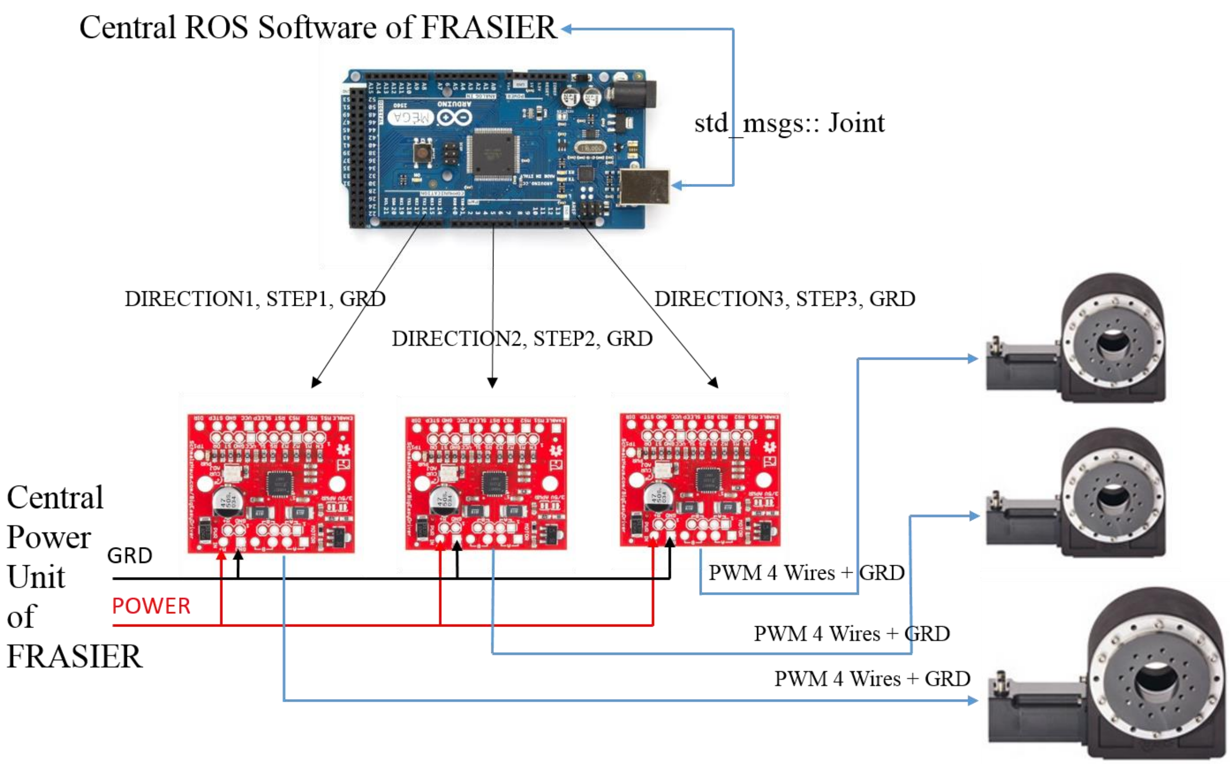

Figure 29: FRASIER Hardware Interface Architecture

7.2 Results

The design goal for the arm is to develop an affordable and modular robot arm. The team chooses “igus Robolink D” product to fulfill these requirements. Each joint has a stepper motor connected with a worm drive gearbox. The modularity of this product provides future development capability. The final fully constructed manipulator is shown in Figure 30. The team recorded several positions with regard to grasping objects and homing itself. FRASIER first searches at this place and executes the control command by ROS. To simplify scenarios during user trials, the team used predefined arm positions for positioning and other movements.

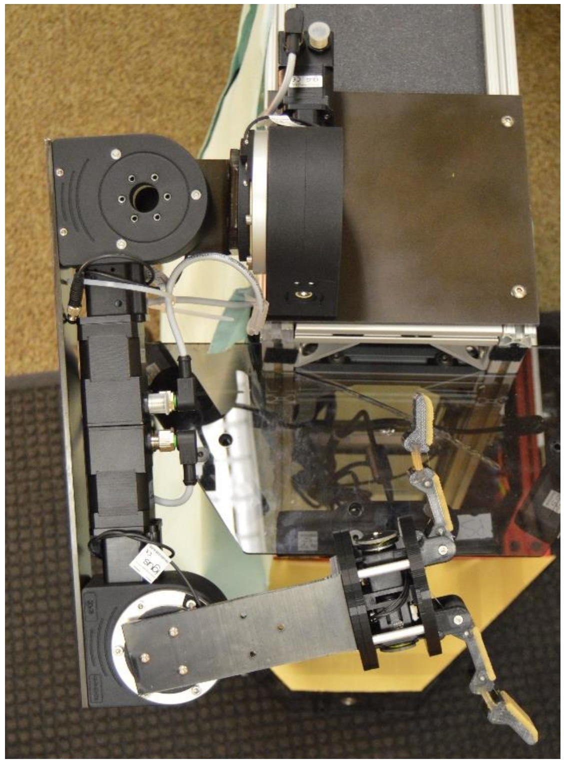

Figure 30: Fully Constructed Manipulator on FRASIER

7.3 Discussion

With the modularity of igus joint, three more DOFs can be implemented to the manipulator to provide full performance of human-like arm. Also, a modular integrated circuit will be implemented between arm joint and ROS. In the aspect of software, Ethernet communication protocols, such as EtherCAT by RoNeX, are ideal candidates to eliminate the crowded bandwidth via serial ports. This dedicated hardware interface device directly serves for the communications between ROS and hardware components by faster communications. And the majority of the software development will be concentrated on ROS to realize the more sophisticated control of the manipulator. Beyond the joint control, as six DOFs completed, inverse kinematics will enable this manipulator to perform complex motion planning algorithms with Moveit! packages from ROS. Beyond the joint control accomplished in this project, the more complex manipulator control can be accomplished by multiple ROS packages as shown in Figure 31.

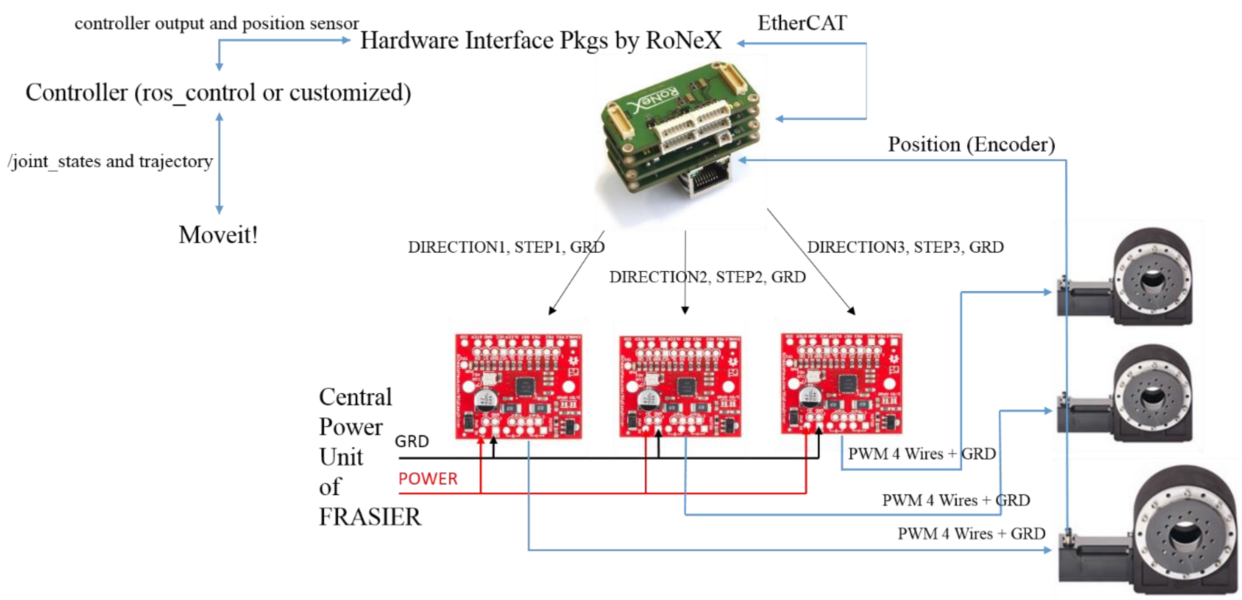

Figure 31: ROS Manipulator Control

8 User Interaction Framework

The purpose of the Graphical User Interface (GUI) is to allow users to directly interact and control different aspects of the robot. One way to achieve this capability is through the use of a touchscreen tablet that allows the user to give direct commands to the robot. This was a vital part of the companion aspect of FRASIER.

8.1 Methodology

The robot currently uses an Android Nexus 10 Tablet that allows for a streamlined integration with the Robot Operating System (ROS) due to pre-existing applications. An application for the robot was created using Android Studio. In particular, the application allows the user to create and use a calendar, instruct the robot on how to manipulate the environment, and instruct the robot to follow the user. The application is also connected with third-party applications that allow a user to monitor their blood pressure, participate in physical therapy exercises, connect to skype and play solitaire.

Depending on the operating task of the robot, the tablet could portray a companion side by representing a cartoon face. The use of a cartoon face was preferred to a humanoid appearance taken from the results of the User Studies.

For the user to directly interact and control the robot, the tablet is connected to the robot through a Bluetooth connection. With assistance from WPI's RIVeR Lab, the team was able to adapt portions of their Google Glass Driver code to work with the Nexus 10 tablet. On FRAISER a server node runs waiting for a connection message from the application. The devices pair through a RFCOMM BluetoothSocket implemented through a preexisting android library. From there the use of handler messages on the application sends a connection status messages to the robot. Once the connection status is confirmed the FRASIER server node waits for the next message from the android application using a listener. The Bluetooth connectivity was integrated with a button press in the FRASIER Application. To confirm connection between the two devices the connectedHandler was used to send a message through the connectedThread handler case WRITE_MESSAGE. This case was capable of printing a string to the FRASIER's terminal. When the button was triggered, the string set as the message was sent to the robot and printed into the terminal. Using another handler and listener format FRASIER can be set up to listen for certain messages from the table to control the robots functionalities.

8.2 Results

The final version of the graphical user interface can be seen in Figure 33 below. The large image buttons were incorporated in the application design to ease the user's interaction with the application. Having a larger button area makes it easier for a user to interact with the program and reduce any chance of error from pressing an incorrect smaller button. Each buttons icon was created specifically for this application from www.clker.com. To prevent copyright issues from other sites, this website offers free clip art images that can be used to create personal icons.

The FRASIER Application can successfully send string messages indicating a button press from the tablet to the robot terminal through Bluetooth communication. A listener on the robot will wait for certain message to indicate a specific command.

The current version of the FRASIER Application incorporates third party android applications to give users access to a variety of different resources. The first button on the top left with the heartbeat is a heart rate monitor. When a user presses this button they are prompted one of two options. They can access Azumio Inc.'s Instant Heart Rate application that uses the camera lens and the flash of the tablet to measure the user's heart rate. The other option the user has access to is, an application that they can track their daily heartrate and blood pressure values.

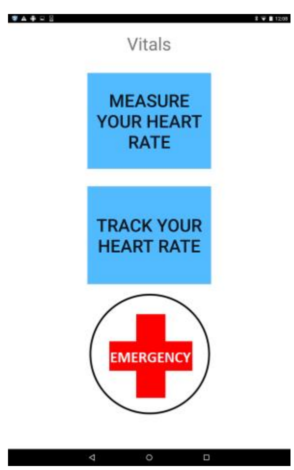

Figure 32: Representation of Vitals Sub Menu

Figure 33: Final Version of FRASIER Application

The exercise figure button on the top right links the user to a physical therapy application, Pocket Physio. The application is a guide to physiotherapy exercises for patients. The user can watch videos or read instructions on each exercise and even set reminders to continue with physical therapy each day.

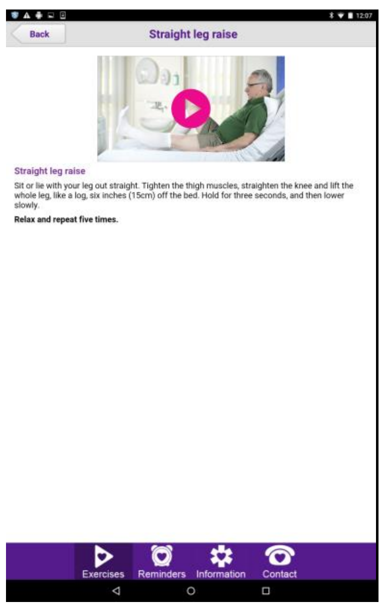

Figure 34: Picture of Pocket Physio Application

When the user selects the calendar button they have the option of viewing their calendar or creating a new event. By syncing the FRASIER application with a Google Calendar, events can easily be made and shared over several devices or with several different people. The idea behind using the Google calendar was that a doctor or a nurse can easily send calendar reminders to a patient's robot notifying them of upcoming appointments, or a family member can externally access FRASIER's calendar to be aware of a loved one's daily schedule.

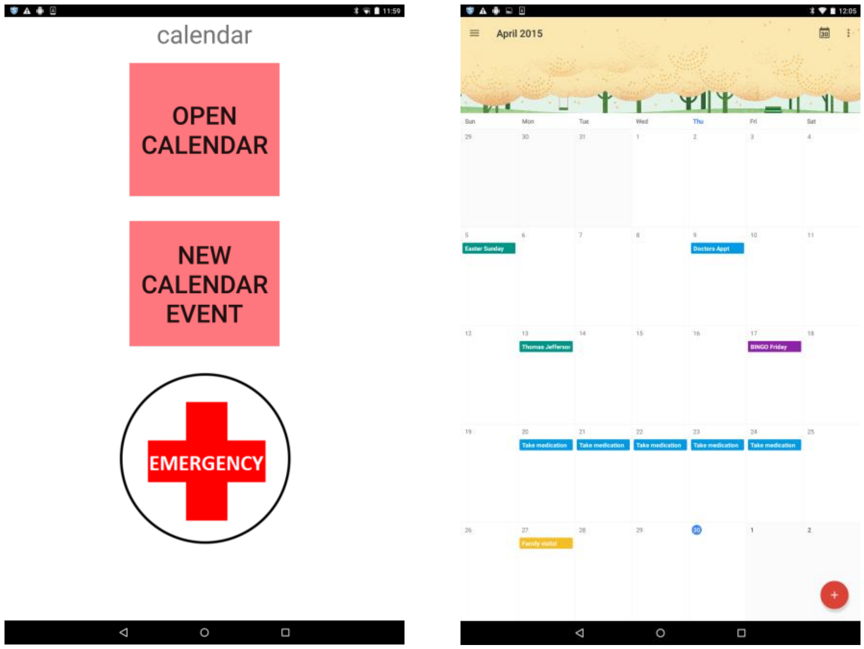

Figure 35: Calendar Option Menu along with Image of FRASIERs Google Calendar

The walking icon utilizes the Bluetooth capability to signal that the user wants the robot to follow them. When the follow button is selected a cartoon face of FRASIER appears on the screen indicating the robot is ready to follow the user. While this capability is not yet functioning, the internal framework of the application is prepared for these subsystems to be connected. From the follow screen the user can also access the control buttons for the arm. The application framework to manipulate the arm to 3 known positions has been prepared, yet the Bluetooth listener for this function has not been integrated.

Leisure Activities is linked to the button on the bottom right. This section can me modified per user giving them easy access to any games or social media sites they are interested. Currently through this sub function a user has access to play solitaire and connect to Skype. Through talking with many potential users during the User Studies they hoped that the user interface could have some entertainment for them that they otherwise might not have access to. Card games was a popular choice by these participants. Having a connection to Skype can allow users who live independently have an easy method of communicating with loved ones who live some distance away or even for a doctor to call and check up on their patient.

The last application button on the bottom right is for Emergencies. If this button is selected a sound alarm will sound notifying external individuals that help is needed. This button is also accessible on all the other pages of the application in case of emergency.

8.3 Discussion

Currently, the FRASIER application utilizes several different third party applications. Ideally for the future, some of these applications functions can be replaced with either custom user applications or application purchased through a product. For example, the Omron Blood Pressure Monitor is compatible with the Nexus Tablet and can automatically track the user's blood pressure readings. Another device that could be integrated with the FRASIER application is the iHealth Gluco-Monitoring System that can measure glucose levels and automatically update to the application on the tablet. To track movement and exercise a user can wear a fitbit bracelet that keeps track of their steps, sleep pattern, and heart rate and syncs with an application that could be integrated with the FRASIER robot.

While the application successfully communicates to the robot over Bluetooth, originally the tablet was going to pair to the robot through a ROS to Android Library. At the current time, all robot libraries run on the Hydro version of ROS, which just happens to be missing one package that interrupts the ROSjava library from successfully connecting the Nexus tablet and the robot. When converting to the Indigo version of ROS, limited documentation left little success with the library. By utilizing pre-existing Bluetooth connection code from the RIVer-Lab Google Glass Project, the code could be adapted to work on the appropriate android tablet.

9 Conclusion

The need for assistive care will continue to increase as the baby boomer generation ages. Thus, increasing the need for assistive care robots as the number of elderly will outweigh the number of available human care representatives. The robotics industry has been putting in the necessary frame work to offset the growing difference.

FRASIER was created in order to be an aid for individuals with age-related disabilities. FRASIER provides the necessary framework for future teams to continue to work and build on the current subsystems that were created and designed. With the basic functionality of the robot created other research and development groups will be able to determine the factors that continue to hinder the progress of integrating robots with humans.

The findings and developments in this project are new, because it integrates the functionality of providing care for humans with a companionship aspect. FRASIER is able to detect and recognize objects, create and use a calendar as well as navigate autonomously in a known environment. The GUI is also connected with third-party applications that allow a user to monitor their blood pressure, participate in physical therapy exercises, play solitaire and connect to Skype. The GUI also provides the interface for all the subsystems of the robot to interact with each other. FRASIER is also able to detect and recognize the position of objects. The following Table 9 shows the summary of the outcomes of this project. The outcomes compare with the design requirements stated in the Robot Design Chapter. Meanwhile, FRASIER, based on its existing functions and shapes, meets the corresponding standards stated in the ISO-13482.

Project Requirements	Project Outcomes
Basic interaction with static objects in the environment.	A 3-DOF manipulator with 2 under-actuated fingers attached and the joint control of this manipulator. FRASIER can successfully detect and recognize small tabletop objects.
A user-interactive Graphical User Interface (GUI) that allows basic realistic communications between the user and the robot.	An interactive Android Application was created that can successfully send string messages over Bluetooth to the robot. However, FRASIER is unable of translating these messages into commands for the robot to perform tasks.

Remind the user of daily activities, including scheduled medications and events.	Through the use of Google Calendar incorporated within the GUI, a user can schedule daily events and reminders.
Alert nurses or authorities in the case of an emergency. For example, by an alarm sound or flashing light.	An emergency sound alarms nurses of an emergency through the GUI if the Emergency button is pressed.
Drive autonomously when tracking and following the user.	FRASIER can detect AR tags but has not been integrated with autonomous driving.
Build a robot that is aesthetically pleasing.	A temporary outer shell was created. Feedback from the third user study showed FRASIER was found to be visually appealing. The shell is only temporary at this point due to the fact that it is not durable.

Table 9. Project Outcomes

9.1 Future Work

While FRASIER's subsystems met individual goals, there were several aspects of the systems that will need to be integrated in the future. To summarize what was discussed in previous chapters, some recommendations to consider are to:

- Incorporate the vision control system with the manipulation of the robot arm
- Integrate the GUI with FRASIER controls
- Integrate the GUI with external sensors around the home
- Protect FRASIER with a more durable shell
- Add additional degrees of freedom to the arm

To continue to develop FRASIER with users in mind, the team suggests that user study 3 be continued in order to:

- Obtain more user-robot interaction feedback
- Interview more participants living independently at home

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11 Appendices

11.1 Appendix A: Interview Questions

11.1.1 Appendix A: Study 1

<u>Personal Assistant Companion Robot Interview</u>

Name of interviewee: ____________________ Age:_____ Gender:____

1. Are there any tasks that you find challenging to accomplish on your own? (Y/N)
   a. What daily tasks do you find the most challenging for you to accomplish alone? etc. Dressing, bathing, eating, brushing your hair, etc

2. Do you ever have trouble reaching for something from a high or low shelf spot? (Y/N)
   a. Which is more challenging to do by yourself?

3. What types of objects do you have trouble grasping (mug, newspaper, books, etc)?

4. Do you already use any sort of mechanical assistance device like a grasper, walker, stool, or wheelchair, etc. to help you throughout the day? Which ones do you use?

5. What daily activities do you like to take part in (playing cards, reading books, BINGO, exercises, etc.)?

6. Is there anything that you wish you were still capable to do but no longer can do? What are they?

7. Do you already use any technology in your everyday life?

8. Do you know how to use an iPad, tablet, cellphone, etc.?

9. When you hear "Personal Assistive Companion Robot", what do you expect it to do?

   a. Would you like it if it:
      i. remind you for calendar events like medical appointments or when you need to take your medications?
      ii. have basic conversations with you?
      iii. helped you surf the web?

10. Would you like it if the robot helped you with challenging tasks? (Y/N)
    a. What type of challenging tasks? (i.e. hold things, intelligence reminders, help with certain activities, open doors, push elevator buttons)?

    b. Would you be interested in a personal assistive companion that would help you with your daily activities (exercises, games, read audiobook)?

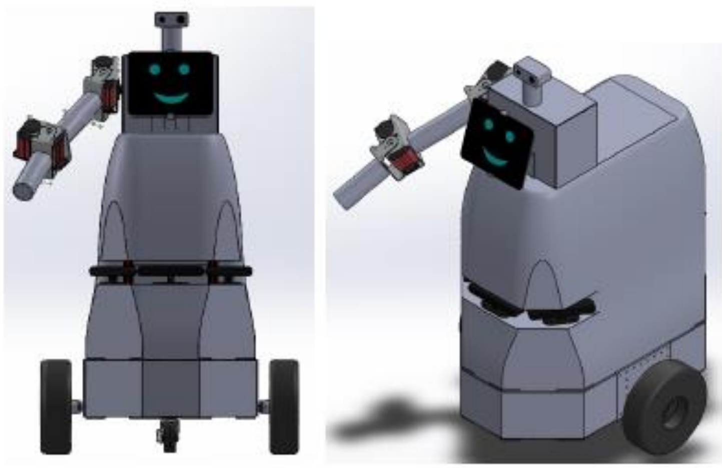
11. One of the features that we could have our robot do is have a camera to video monitor you where someone can check up on you or connect you with help. Would you feel comfortable with that?

12. What would you like for the robot to look like? (show pictures and ask what appeals to them most)

a.


b.

c. 



13. What do you think of our current robot design?

14. Do you feel that the placement of the arm is appealing? Why or why not?

    14.1. What if it had one functional arm and one dummy arm on both sides?

15. Do you want it to have a face? (Y/N)
    15.1. Would you rather it be touch screen or voice activated?
    15.2. Do you want it to look like an animal?

Other comments/ideas/concerns, etc.:

11.1.2 Appendix A: Study 2

4/17/2015 Qualtrics Survey Software

Default Question Block

Hello!

This survey is conducted for the research collaboration of psychology and robotics engineering for assistive technology at Worcester Polytechnic Institute. We are conducting this survey to determine needs of those with age-related disabilities. You are a part of a carefully selected sample and it is very important to us that you answer these questions as honestly as possible. We want to thank you so much for your time and effort to bring us one step closer to improve the quality of life of the elderly!

This survey will take you approximately 20-25 minutes to complete.

Please be assured that your responses will remain anonymous.

Please proceed to the next page.

Please rate the level of difficulty for completing the following activities of daily living independently with 1 as very difficult to 5 as very easy.

	1 Very Difficult	2 Difficult	3 Neutral	4 Easy	5 Very Easy
Eating	○	○	○	○	○
Drinking	○	○	○	○	○
Bathing/showering	○	○	○	○	○
Reaching High Shelves	○	○	○	○	○
Reaching Low Shelves	○	○	○	○	○
Climbing Stairs	○	○	○	○	○
Doing laundry	○	○	○	○	○
Cleaning	○	○	○	○	○
Speaking for long periods of time	○	○	○	○	○
Sleeping	○	○	○	○	○
Keeping Track of Appointments/Dates	○	○	○	○	○
Being on Time	○	○	○	○	○
Keeping Track of Medications	○	○	○	○	○
Taking Medications	○	○	○	○	○
Driving	○	○	○	○	○
Walking	○	○	○	○	○
Grasping objects	○	○	○	○	○
Seeing far distances	○	○	○	○	○
Seeing close distances	○	○	○	○	○
Hearing others speak	○	○	○	○	○
Taking out the trash	○	○	○	○	○
Carrying objects					

https://wpi.qualtrics.com/ControlPanel/Ajax.php?action=GetSurveyPrintPreview&T=4E1Ib2jpSaGkppwOFwE93 1/9

	○	○	○	○	○
Checking mail	○	○	○	○	○
Other (please specify):	○	○	○	○	○

Which two tasks mentioned above are most difficult for you and why?

My current home is a(n):

- ○ Dormitory
- ○ Apartment
- ○ House
- ○ 55+ Community
- ○ Assisted Living Facility
- ○ Townhouse
- ○ Condominium
- ○ Nursing Home
- ○ Group Home
- ○ Other (please specify):

I currently live:

- ○ Alone
- ○ With a roommate not related to me
- ○ With my spouse/partner
- ○ With other family members
- ○ With a live-in nurse
- ○ With a visiting nurse
- ○ With a caretaker
- ○ Other (please specify):

Do you use any of the following technological devices? (Please select all that apply)

- ☐ Grasper
- ☐ Walker
- ☐ Cane
- ☐ Stool for standing

- ☐ Stool for sitting
- ☐ Step ladder
- ☐ Hearing aid
- ☐ Glasses or contacts
- ☐ Prosthetic devices
- ☐ Leg Braces
- ☐ Crutches
- ☐ Other (please specify):

The next section involves the use of assistive technology and how it can help those with age-related disabilities. Please answer the questions below.

Do you use any technology devices? (Please select all that apply)

- ☐ Computer
- ☐ iPad
- ☐ iPod
- ☐ Smart phone
- ☐ Flip phone
- ☐ GPS
- ☐ Roomba Vacuum
- ☐ Brava Mopping Robot
- ☐ Other (please specify):
- ☐ I do not use any of these technologies

Please rate the level of comfortability of the following statements with 1 as extremely uncomfortable to 5 as extremely comfortable.

	1 Extremely Uncomfortable	2 Uncomfortable	3 Neutral	4 Comfortable	5 Extremely Comfortable
Having the option to purchase a personal assistive robot that could help with physical tasks	○	○	○	○	○
Having the option to purchase a personal assistive robot with companionship capabilities such as have basic conversations and play games with you, and help you explore the internet	○	○	○	○	○
Having the personal assistive robot assist a family member	○	○	○	○	○

Please rate the level of interest of the following statements with 1 as extremely uninterested to 5 as extremely interested.

	1 Extremely Uninterested	2 Uninterested	3 Neutral	4 Interested	5 Extremely Interested
Having a personal assistive robot that could help you with physical tasks	○	○	○	○	○
Having a personal assistive robot that had companionship capabilities such as play games with you, help you explore the internet, and have basic conversations with you	○	○	○	○	○

How likely would you get a personal assistive robot for a family member or someone you know?

- ○ Very Unlikely
- ○ Unlikely
- ○ Neutral
- ○ Likely
- ○ Very Likely

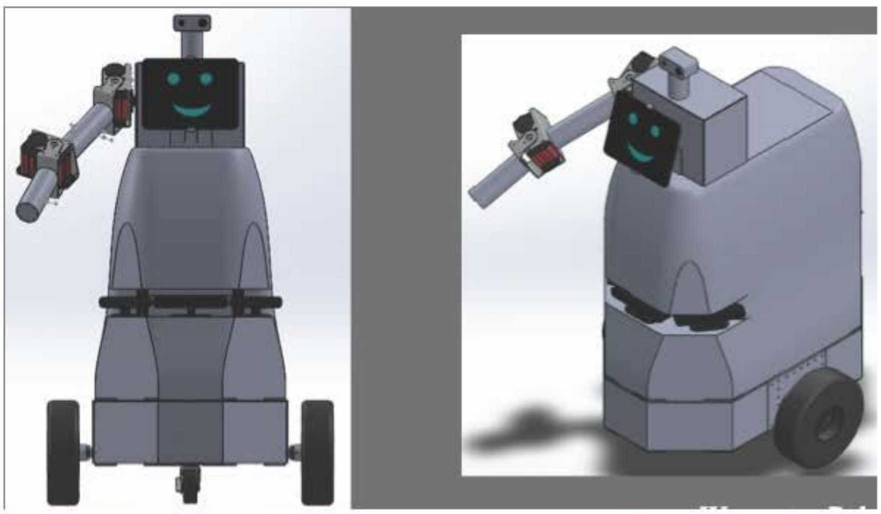
Please rate the level of importance for the following personal assistive robot capabilities with 1 as extremely unimportant to 5 as extremely important.

	1 Extremely unimportant	2 Unimportant	3 Slightly unimportant	4 Neutral	5 Slightly important	6 Important	7 Extremely important
Voice activation	○	○	○	○	○	○	○
Touch Screen	○	○	○	○	○	○	○
Ability to follow users	○	○	○	○	○	○	○
Ability to push elevator/handicap door buttons	○	○	○	○	○	○	○
Switch lights on and off	○	○	○	○	○	○	○
Ability to open/close doors	○	○	○	○	○	○	○
Ability to carry small objects	○	○	○	○	○	○	○
Ability to carry heavy objects	○	○	○	○	○	○	○
Ability to dispense medication	○	○	○	○	○	○	○
Ability to monitor vitals	○	○	○	○	○	○	○
Ability to communicate with medical staff	○	○	○	○	○	○	○
Emergency detection capabilities (e.g. detecting falls)	○	○	○	○	○	○	○
Ability to monitor user for safety	○	○	○	○	○	○	○
Intelligence reminders (for appointments, scheduled events, medication)	○	○	○	○	○	○	○
Ability to communicate with friends and family (e.g Skype, Facetime)	○	○	○	○	○	○	○
Ability to explore internet	○	○	○	○	○	○	○
Ability to display eBooks	○	○	○	○	○	○	○

Ability to read audio books	○	○	○	○	○	○	○
Ability to have physical exercise instruction	○	○	○	○	○	○	○
Ability to play games with user	○	○	○	○	○	○	○
Other (Please specify):	○	○	○	○	○	○	○

Are there any other capabilities that you believe a user might want in a personal assistive robot?

The photo you see below is a possible prototype of a personal assistive robot that we are in the process of developing. Please view this prototype and answer the questions that follow.



Please rate the following adjectives regarding your attitude about the current prototype of the robot.

	1 Extremely unappealing	2 Unappealing	3 Slightly unappealing	4 Neutral	5 Slightly appealing	6 Appealing	7 Extremely appealing
Appealing	○	○	○	○	○	○	○

Please rate the following adjectives regarding your attitude about the current prototype of the robot.

	1 Extremely unfriendly-looking	2 Unfriendly-looking	3 Slightly unfriendly-looking	4 Neutral	5 Slightly friendly-looking	6 Friendly-looking	7 Extremely friendly-looking
Friendly-looking	○	○	○	○	○	○	○

Please rate the following adjectives regarding your attitude about the current prototype of the robot.

	1 Extremely uncomforting	2 Uncomforting	3 Slightly uncomforting	4 Neutral	5 Slightly comforting	6 Comforting	7 Extremely comforting
Comfort Level	○	○	○	○	○	○	○

Please rate the following adjectives regarding your attitude about the current prototype of the robot.

	1 Extremely intimidating	2 Intimidating	3 Slightly Intimidating	4 Neutral	5 Slightly unintimidating	6 Unintimidating	7 Extremely unintimidating
Intimidating	○	○	○	○	○	○	○

How comfortable would you be with a robot like this in the following situations?

	1 Extremely Uncomfortable	2 Uncomfortable	3 Slightly Uncomfortable	4 Neutral	5 Slightly comfortable	6 Comfortable	7 Extremely Comfortable
In your living situation	○	○	○	○	○	○	○
Assisting a family member/ someone with an age-related disability	○	○	○	○	○	○	○

How likely would you use this robot?

	1 Extremely Unlikely	2 Unlikely	3 Slightly Unlkely	4 Neutral	5 Slightly Likely	6 Likely	7 Extremely Likely
Likelihood of usability	○	○	○	○	○	○	○

How appealing is the placement of the arm on the robot?

	1 Extremely Unappealing	2 Unappealing	3 Slightly Unappealing	4 Neutral	5 Slightly Appealing	6 Appealing	7 Extremely Appealing
Appeal of arm placement	○	○	○	○	○	○	○

Would you prefer the robot to have one arm or two arms?

- ○ One arm
- ○ Two arms

How much would you be willing to pay for this robot?

	0	200	400	600	800	1000	1200	1400	1600	1800	2000
Cost											

Please rate the likelihood with 1 as least likely and 5 as very likely of your willingness to use the personal assistant robot If your health insurance covered some of the costs.

	1 Extremely		3 Slightly	4 I don't	5 Slightly		7 Extremely

	Unlikely	2 Unlikely	Unlikely	know	Likely	6 Likely	likely
Likelihood	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned
Reliability	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely Unconcerned
Cost	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly Unconcerned	6 Unconcerned	7 Extremely Unconcerned
Battery Life	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly Unconcerned	6 Unconcerned	7 Extremely Unconcerned
Cost	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Uconcerned	7 Extremely unconcerned
Safety of Use	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned
Navigation Ability	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned
Privacy	○	○	○	○	○	○	○

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned

Weight of Robot	◯	◯	◯	◯	◯	◯	◯

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned
Size of Robot	◯	◯	◯	◯	◯	◯	◯

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned
Adaption to Living Environment	◯	◯	◯	◯	◯	◯	◯

Please rate your level of concern for the following with 1 as extremely concerned to 7 as extremely unconcerned.

	1 Extremely concerned	2 Concerned	3 Slightly concerned	4 Neutral	5 Slightly unconcerned	6 Unconcerned	7 Extremely unconcerned
Companionship Abilities	◯	◯	◯	◯	◯	◯	◯

Thank you for taking your time to answer our survey questions regarding assistive technology. We will now ask you to answer a few demographic questions that will further aid us in interpreting our data.

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Other
- ◯ Prefer not to disclose

What is your age range (in years)?

- ◯ 17 or under
- ◯ 18-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60-69
- ◯ 70-79
- ◯ 80+

What is your employment status?

- ◯ Unemployed

- Retired
- Employed full time
- Employed part time
- Student
- Other (please specify):

Block 1

11.1.3 Appendix A: Study 3

Hello **[resident's name]**, my name is **[researcher name]** and I wanted to talk to you about your experience that you had today with our personal assistant robot! We are also looking to learn about your opinions and attitudes about this robot.

1.) What did you think of the look of the robot (was it aesthetically pleasing)? Did you like the color and size? What about the shape of it?

Color:

Size:

Shape:

a.) Do you think there should be any changes made to make it more aesthetically pleasing?

2.) Do you feel that the robot was friendly?

a.) Is there anything that would make it appear friendlier?

3.) Do you find that the robot was easy to navigate?

How easy to use was the Touch Screen?

How easy to use was the Calendar?

How easy was it to make an Appointment?

a.) Can you think if anything that would make any of these easier to use?

4.) Do you feel that the voice of the robot was aesthetically pleasing?

a.) Is there anything that you would change about it? Should there be options for the voice?

5.) Did you think that a robot arm would be useful?

a.) What did you think of the look of the arm (show picture)? Placement of the arm? Is there anything that would make it look better?

b.) What other functions do you think the arm could carry out (other than object retrieval)?

6.) Do you feel that this robot would affect your daily life? Would you use it?

7.) How safe do you feel around this robot?

8.) Is there anything else that you think the robot should do?

9.) If funds were available, how much would you be willing to pay for a robot like this?

Ask resident if they would like to add anything else such as any ideas, comments, opinions, etc.*

Additional Notes:

11.2 Appendix B: Interview Results

Assisted Living Facility	Date	N
St. Francis	10/2014	4
Vibra Healthcare	10/2014	2
Golden Pond	10/2014	3
Meeting with Jim Archer	11/2014	1
St. Mary's	11/2014	2
Salmon Beaumont	11/2014	5
Christopher Heights	12/2014	10
Holy Trinity (Ed)	12/2014	8
Salmon Health Whitney Place (Natick)	12/2014	5

Table 10: Assisted Living Facilities visited

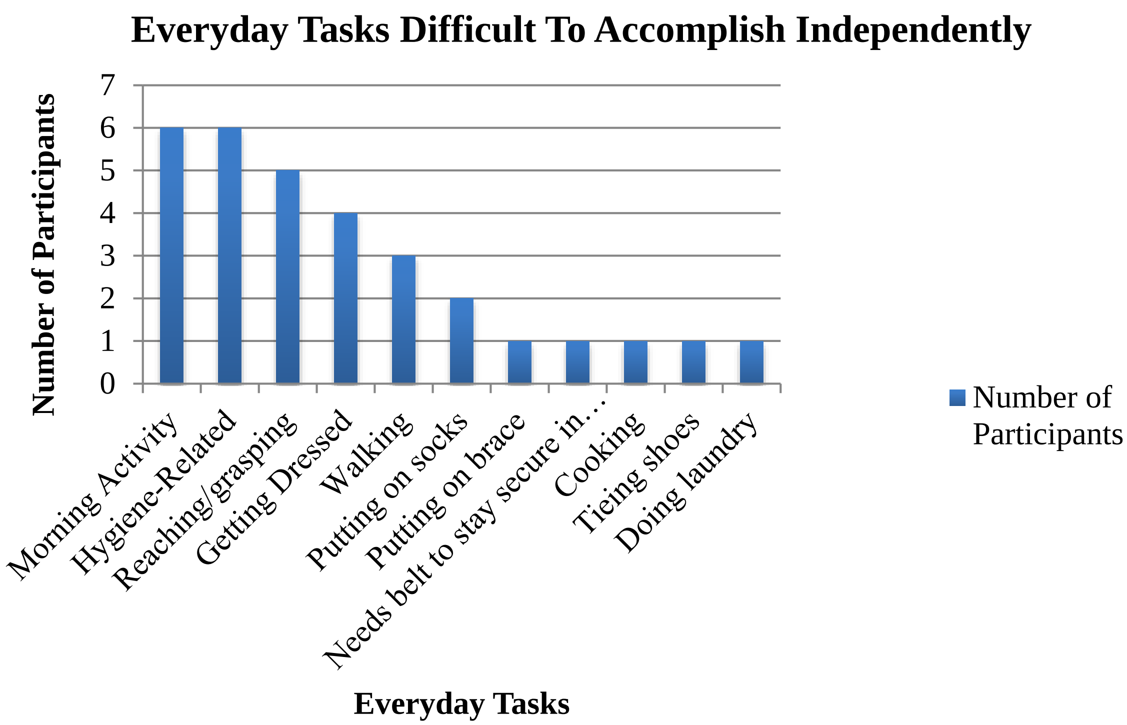


Figure 36: Common everyday tasks difficult to accomplish independently

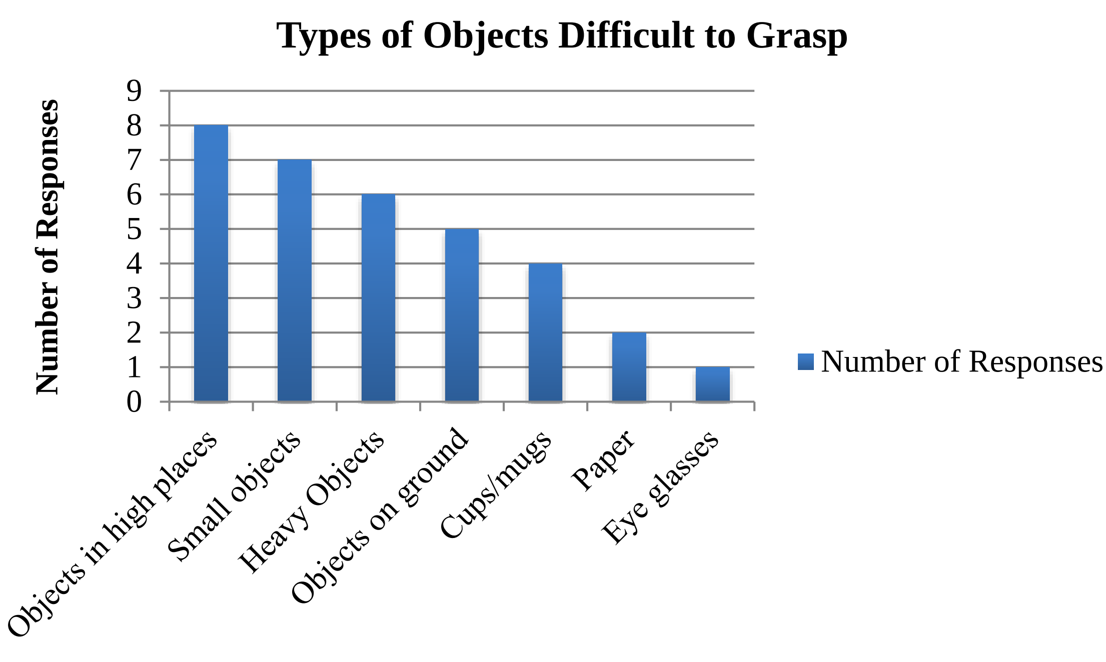


Figure 37: Common types of objects difficult to grasp

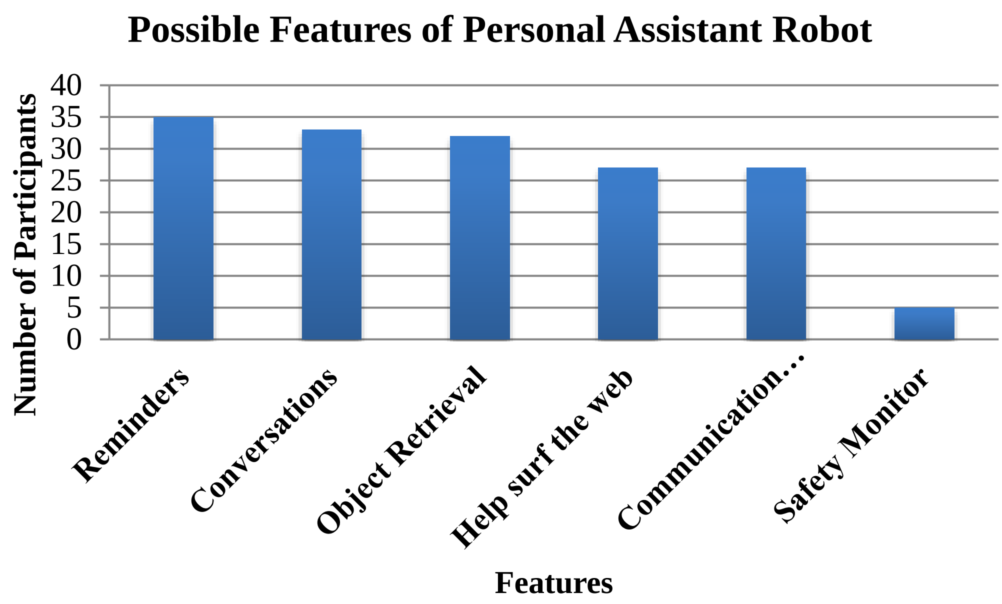


Figure 38: Rated features of the personal assistant robot

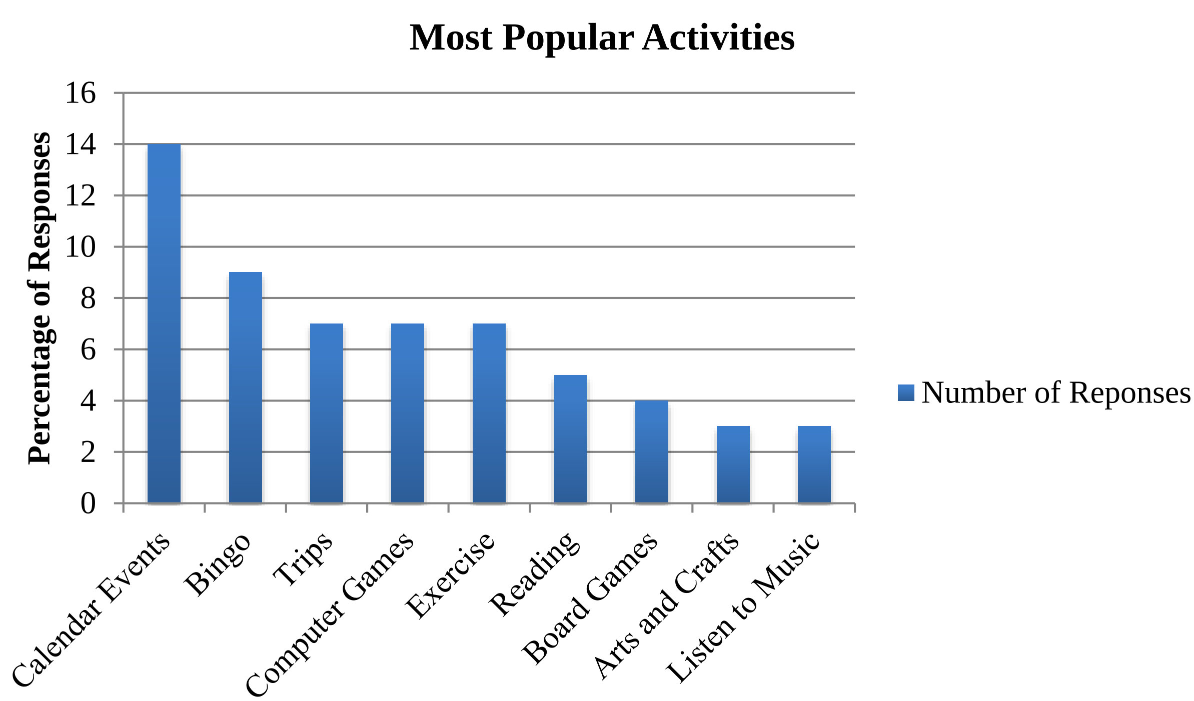


Figure 39: Most popular activities

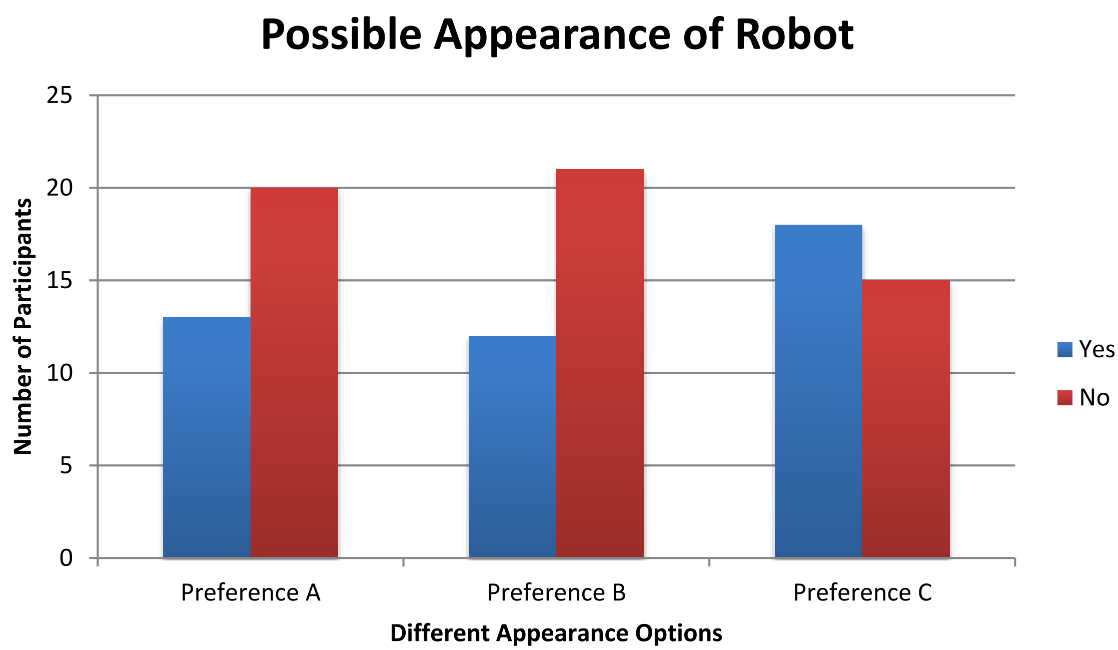


Figure 40: Ratings of possible robot appearances

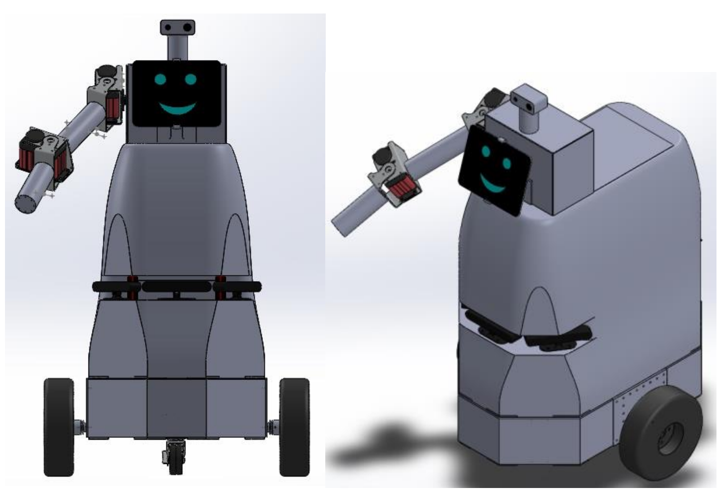


Figure 41: Prototype of current personal assistant robot

11.3 Appendix C: Survey Results

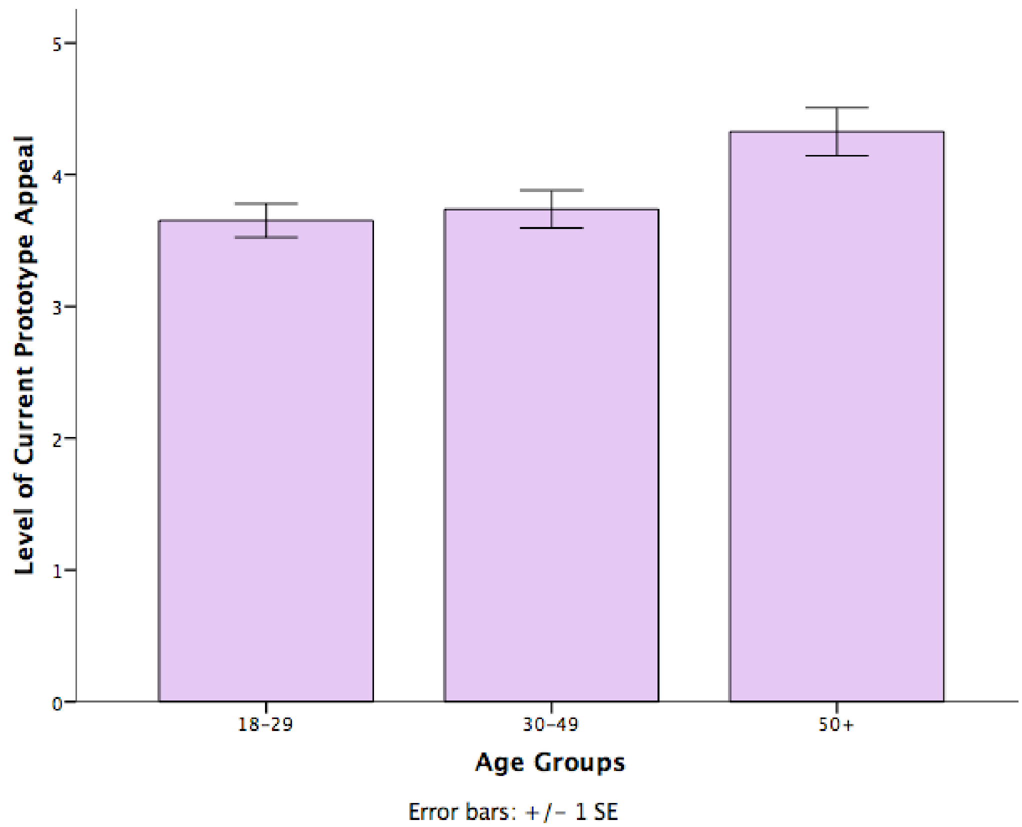


Figure 42: Age groups on Level of Appeal of Robot Prototype

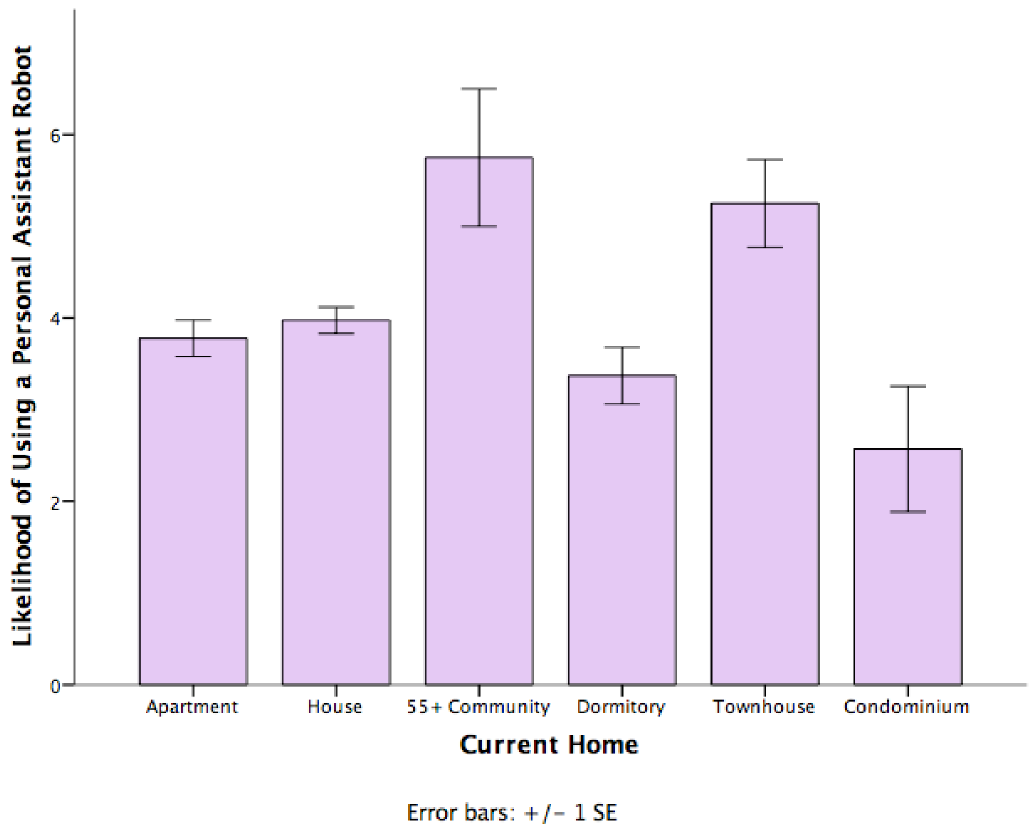


Figure 43: Main effect of current home and likelihood of usability

11.4 Appendix D: Stakeholders

ID	Title	Description	Role	Priority	Communication
SH.01	Co-Advisor	Capstone project advisor, RBE	Grades, report editing, major advising role,	1	Weekly meetings, email
SH.02	Co-Advisor	Capstone project advisor, Psychology	Grades, report editing, major advising role, site visiting, usability studies	1	Weekly meeting, email
SH.03	User	Individuals who use PARbot	Define needs, provide feedback	1	Interviews, email
SH.04	Unaffiliated Individual	Anyone near, impacted by, or interacting by PARbot	Impact only, no direct role	2	

SH.05	Caregiver	Individuals working with PARbot or being displaced by PARbot	Define needs, provide feedback	3	Interviews, email
SH.06	Insurance/Medicare	Organizations that help provide/pay for assistive care	Define needs, purchasing	2	
SH.07	OSHA	Occupational Safety and Health Organization	Defines safety requirements	1	regulations (indirect)
SH.08	Maintainer	Individual responsible for mechanical and software maintenance	Impacts mechanical and software constraints	2	
SH.09	Marketing	Organization responsible for marketing completed project	Impacts aesthetics, provides feedback	2	email
SH.10	National Science Foundation	Government agency that promotes scientific research	Funding	1	email, through SH.01
SH.11	Jim Archer	WPI alumni, Parkinson's patient	Define needs, provide feedback	2	Interviews, case studies
SH.12	Golden Pond, etc.	Assisted living facilities	Define needs, provide feedback, customer	3	visits

Table 11: Stakeholder Analysis

11.5 Appendix E: Needs Analysis

ID	Title	Description	Category	Stakeholder	Priority
ND.01	Size	Should be able to fit through a standard door and navigate around average home and living facility	Physical Design	SH.01,SH.03,SH.05	1
ND.02	Reminder	Should be able to remind user of scheduled events	User Interface	SH.02, SH.03, SH.05	3

ND.03	Cost	Should not be overly expensive for consumers	Marketing	SH.03, SH.06	4
ND.04	Companionship	Should act as a friendly, non-threatening, companion to user	User Interface	SH.02, SH.03, SH.05	3
ND.05	Following	Should be able to follow a user	Robotic Design	SH.01	1
ND.06	Injuries	Should not injure someone if robot collides with person	Safety	SH.02, SH.03, SH.04, SH.07	1
ND.07	Assistance	Should be able to push an elevator button or flip a light switch	Robotic Design	SH.01, SH.03	2
ND.08	Navigation	Should be able to navigate an area autonomously	Robotic Design	SH.01, SH.10	1
ND.09	Storage	Should be able to be stored in a small area	Physical Design	SH.01	2
ND.10	Life	Should be able to operate for 8 hours between full charges	Physical Design	SH.01, SH.03	2
ND.11	Carrying	Should be able to carry larger objects (shopping bags, food trays, etc)	Physical Design	SH.01, SH.03	1

ND.12	Alert	Should alert other people when user is in distress	User Interface	SH.02, SH.03, SH.05	2
ND.13	Ease of Use	Should be usable by elderly users, especially with physical disabilities	User Interface	SH.03	1
ND.14	Interaction	Should be able to interact with environment (i.e. sensors)	Robotic Design	SH.01, SH.02, SH.07	3
ND.15	Production Cost	Should not be overly expensive to produce	Robotic Design	SH.01	2
ND.16	Maneuvering	Should be able to drive through a typical house (fit through doors)	Robotic Design	SH.03, SH.11	1
ND.17	Medication Delivery	Should be able to dispense medication when needed	Robotic Design	SH.01, Sh.02, SH.03	3

Table 12: Needs Analysis

11.6 Appendix F: Technical Measures

Using technical measurements, the team can display further insight into the analysis and thought process of classifying project needs and requirements. Through having a better understanding of these goals, the project team can deliver a successful technical solution and testing method for each. By further interpreting the technical measures, the team can maintain the life cycle of the project and ensure that the appropriate assessment of solutions to meet the project objectives occurs. The measurements listed below can each be directly related back to the original project needs and requirements set forward by the stakeholders. The technical measures include measures of effectiveness (MOEs), measures of performance (MOPs), technical performance measures (TPMs) and key performance parameters (KPPs) and are further explained below.

11.6.1 Measures of Effectiveness

Table 13 shows the top five Measures of Effectiveness for the FRASIER project. Measures of Effectiveness are "operational" measures of success that are closely related to the project objectives.

MOE	Title	Description	Method of Testing
E.1	Battery Life	Robot runs for minimum of 8 hours without charging.	Run battery at normal operation parameters for 8 hours
E.2	Following	Robot will follow a person as they walk.	Have a person walk in front of robot when robot is in tracking mode
E.3	Carrying	Robot will be able to carry firm objects for user.	Place objects in/on holding mechanism (i.e. claw, arm, shelf, etc.) and have robot move towards person
E.4	Voice Commands	Robot will respond to voice commands from user.	Use pre-programmed commands and evaluate how robot responds
E.5	Pill Dispensing	Robot will dispense pills for user according to pre-programmed instructions.	Set robot to dispense pills and evaluate response based on commands input

Table 13: Measures of Effectiveness

Table 13 suggests solutions that will directly meet the user needs. The method of testing is listed to ensure the objective is reachable and can be determined when met. It is important to note that MOEs are tasks that the project must be able to accomplish that are not system specific. This means that an MOE such as E.3 (Carrying) may be accomplished in any number of ways; however the way in which it is accomplished will not be evaluated at this level. Similarly, MOE E.4 is not specific to how the robot will respond. Some possible options include turning to face the user, following the user, carrying out simple actions, or powering up from low-power mode. As long as the robot responds in some way, specified elsewhere, the MOE is considered to be achieved.

11.6.2 Measures of Performance

Table 14 lists the Measures of Performance (MOPs), focusing on the technical definitions to how the project goals will be met. MOPs are the measures that characterize physical or functional attributes.

MOP	Title	Description	Method of Testing
P.1	Low Power Mode	Robot will enter low-power mode when not in use for 30 minutes	Let robot sit with no active tasks for 30 minutes.
P.2	PrimeSense	Robot will use PrimeSense cameras to track and follow user.	Enable only PrimeSense cameras; have a person walk in front of robot when robot is in tracking mode
P.3	Carrying	Robot will have a tray with rollers to carry and move objects weighing up to 15 pounds	Place objects on shelf and have robot move towards person. Ensure rollers don't move until robot has stopped.
P.4	Turn To Voice	Robot will use voice recognition software to recognize user voice and turn towards them.	Have person use commands from different static location in the room. Have them move and talk.
P.5	Pill Dispensing	Robot will use a rotating pill-dispenser base to dispense the correct number of pills to user.	Run multiple programs through with different values and evaluate effectiveness.

Table 14: Measures of Performance

Specific methods of testing have been listed with each measure to prove quantifiable success of the MOEs. For example, MOE E.5 simply says that the robot will dispense pills but MOP P.5 defines how the robot will do it: using a rotating pill dispenser base. Measures of performance are not necessarily defined in terms of specific technology, but give a more definitive standard for the system as a whole.

11.6.3 Typical Performance Measures

Table 15 shows some of the Technical Performance Measures associated with FRASIER. Technical Performance Measures are measurable standards that work together to make up different MOPs. The table of Technical Performance Measures (TPMs) helps determine how well the system elements are satisfying the requirements.

TPM	Title	Description	Method of Testing
T.1	Weight	Robot will weigh less than 40 lbs without external objects	Remove external objects and weight on a scale
T.2	Low-Power	Robot will be able to reboot from low power mode in less than 30 seconds	Allow robot to go into low power mode and wake it up. Time how long it takes to fully wake up
T.3	Turn to Voice	Robot will be able to turn to face user within +/- 10 degrees	Activate turn to voice algorithm, stand in different positions and use voice commands to initiate robot turning
T.4	Stopping with User	Robot will stop within three feet of user when following	Activate following algorithm and have a user stop in front of robot while following. Measure distance between stopping position and robot.
T.5	Color Tracking	Robot will track colors with the Pixie camera at angles +/- 30 degrees from the plane perpendicular to the camera	Run color tracking algorithm and watch to see when robot loses tracking on object/user. Record angles.

Table 15: Technical Performance Measures

Taken from the MOPs, the TPMs can directly determine the effectiveness of determining differences between actual and planned performance parameters. They can help determine the opportunities to make design trades to reduce overall risk. Each TPM is designed like a requirement, to pass or fail within a certain allowance. For example, the Low-Power TPM, T.1, is a part of P.1, Battery Life; however, T.1 specifically looks at one aspect of battery life: the ability for the robot to go into low-power mode, to save battery, and still be restarted in a set period of time should the user require it.

11.6.4 Key Performance Parameters

Table 16 shows the Key Performance Parameters for the FRASIER project. Key Performance Parameters are a critical subset of TPMs that must be met or the project will not succeed or be able to move forward.

KPP	Title	Description	Method of Testing
K.1	Following with Sensors	Robot should be able to safely follow a person using PrimeSensors.	Have robot follow a person, have the person stop to ensure the robot stops at a safe distance.
K.2	Battery Life	Battery should last for the length of a user day, approx. 8 hours	Run robot for length of 8 hours to ensure it is capable to last a whole user day.
K.3	Functionality	Robot must be able to assist user with daily activities, such as carry objects for user.	Place practical object on robot tray or in arm and have robot move to user.
K.4	Size	Robot should be less than 36"x36"x48" in a normal, operating orientation in order to comply with OSHA and ADA standards, as well as to fit through doorways and hallways. (29 CFR 1910)	Compliance with OSHA and ADA Regulations and check robot size with door frames and hallways.
K.5	Pill Dispensing	Pill dispenser should be able to hold and dispense one weeks' worth of pills without error.	Load pills in correct holding chambers and dispense different combinations of amounts of pills.

Table 16: Key Performance Parameters

Failure to meet these measures could result in redesign or termination of the project. For example, K.4 discusses the maximum dimensions the robot can be in order to fit through doorways per ADA regulations. Should the robot not meet this KPP, it may not be able to fit through standard commercial building hallways and doorways, making it not useful. Given each technical measure and requirement, FRASIER will have to interact differently with certain parts of the environment. These interactions can either be with the physical world around us of with the user. These interactions and how they affect the environment were considered when determining the basis for each functionality.

11.7 Appendix G: Robot Design Options

Figure 44: Robot Option Preference A

Figure 45: Robot Option Preference B

Figure 46: Robot Option Preference C