Field Tests on a Personal Mobility Aid for the Elderly

by

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Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of

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Abstract

The number of elderly Americans is currently rising and will continue to do so. These elderly individuals face several problems in the later years of their lives including the move into an eldercare facility. Personal mobility and monitoring aids are being developed to assist the elderly with this transition. One of these devices is the Personal Aid for Mobility and Monitoring (PAMM). PAMM is in the beginning stages of its development in the MIT Mechanical Engineering Field and Space Robotics Laboratory with an initial prototype recently constructed. This prototype was tested with many residents at an eldercare facility. Several conclusions about the control, ergonomics and overall user acceptance of the device were made. The PAMM prototype was changed accordingly and recommendations for future work are provided.

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Chapter 1

Introduction

1.1 Motivation

Current research shows that there will be a large increase in the number of elderly Americans in the future. The number of Americans aged 65 and above is projected to increase from 35 million in 2000 to 78 million in 2050 [U.S. Census, 1996]. It has also been shown that the actual numbers may be substantially higher than this projection. This large number of elderly in the United States will create important problems associated with healthcare, housing and transportation needs of the elderly. It will grow increasingly more important to fund research and development of assistive technology for the elderly.

When an elderly person begins to need more care (moving from independent living to assisted living to nursing homes), costs increase and the quality of life decreases quickly. The most noticeable change occurs during the move into a nursing home. It has been found that 20-33% of all nursing home residents could be served better by other means within the community [Dubowsky, 1999]. Many research programs have also shown the cost effectiveness of keeping the elderly out of nursing homes. Finally, most elderly prefer to stay out of nursing homes for as long as possible.

Personal mobility and monitoring aids are being developed to delay this transition into nursing homes. This will please the elderly along with being economically beneficial for society.

1.2 PAMM

A research program at the MIT Mechanical Engineering Field and Space Robotics Laboratory is currently developing the basic technology for a Personal Aid for Mobility
and Monitoring (PAMM) that aids the elderly in living independently or in assisted living facilities.

![Image of elderly person and caregiver]

**a. Traditional**

![Image of PAMM system]

**b. PAMM**

**Figure 1.1: Help for the Elderly [Dubowsky, 1999]**

**Figure 1.2: PAMM System Description [Dubowsky, 1999]**

The PAMM concept is shown in Figures 1.1 and 1.2. PAMM will locate itself within a building (home or assisted living facility) by visually reading signposts on the ceiling. It will use acoustic sensors to avoid obstacles and keep users on track in crowded situations.
It will communicate with the facility's main computer as well. Finally, PAMM will have sensors to monitor the user's health and send their vital signs back to the main computer.

A battery powered drive will aid with movement, navigation and physical support. The on-board planning and control systems will use the characteristics of each user to adapt its behavior and maximize the user's comfort and PAMM's responsiveness [Dubowsky, 1999]. A force-torque sensor will be the main interface between PAMM and the user.

A prototype of PAMM was developed by the eldercare group of the Field and Space Robotics Laboratory at MIT so that tests of basic technologies could be performed. Haoyoung Yu, Adam Skwersky, Hitsamitu Kozono, Frank Genot and Felix Auyeung comprise the eldercare group which developed the initial PAMM prototype. This prototype was made in the form of a cane so that it could be designed and fabricated quickly. However, it could be used to obtain practical results to aid in design of other configurations, such as a walker system. This initial prototype is referred to as the “smart cane”.

A main component of the smart cane and PAMM as well is the six axis force-torque sensor (FTS). Understanding the role of the FTS in the smart cane system is necessary for this research. The orientation of the FTS on the smart cane is as shown in Figure 1.3. The positive x direction is the direction of forward motion of the cane and the negative z direction is the direction of downward force on the cane handle. The y direction is the direction of side to side movement of the cane handle. Further, a more detailed explanation of the directions and specifications of the sensor can be found in Appendix B.
Figure 1.3: Orientation of FTS on Smart Cane

Ultimately the FTS will allow the motion of PAMM to vary from user to user, and will aid in the personalization of each PAMM unit.

A vision based localization system is also present on the smart cane prototype. Further explanation of this and other particular aspects of the smart cane can be found in the Home Automation and Health Care Consortium Report [see, *Personal Aid for Mobility and Monitoring: A Helping Hand for the Elderly*, Dubowsky, 1999].

For purposes of this research, the smart cane was used to test the overall man-machine interface. Testing this interface requires knowledge of the model used to control the cane. Using the FTS and admittance control the smart cane acts as a cart with virtual inertia and friction.

PAMM is the only mobility aid to use a FTS to implement control of the device. This control is very intuitive for the user because it is the type of interface found in many non-
motorized devices, such as a lawn mower or a conventional walker. The user applies a force to such a vehicle and it responds by movement. The problem with many motorized devices is that they make use of a steering wheel or joystick for the user to convey his or her intention. PAMM users, would find it difficult to use PAMM for support while at the same time using a joystick to control PAMM's movement. Thus, an FTS interface is the best choice for PAMM.

To specifically define this interface, the user applies a force and torque on the handle of the cane which is then transmitted to the FTS. These parameters then determine the desired linear and rotational velocities and accelerations by simulating two de-coupled first order mass-damper systems (one for the linear direction and one for the rotational direction).

Deciding the proper design for the adaptive parameter tuning system falls into the realm of man-machine interface research. The following section explains the problem and research in a more detailed manner.

1.3 Problem Statement and Summary of Chapters
After the development of the smart cane prototype, field tests were run on the cane to test user acceptance, the control model and the ergonomic features of the cane. Each of these issues was dealt with accordingly.

Chapter 2 covers the background research of other personal mobility aids that was necessary to understand and make advances in the development and testing of the smart cane prototype.

Chapter 3 deals with the initial field tests and the results. Preliminary findings on ergonomic features, control and user acceptance are dealt with in this chapter. These findings are then elaborated on in the following chapters.
Chapter 4 continues the discussion of the new ergonomic feature that was developed for the smart cane prototype after the initial tests. It also deals with the second set of tests at the facility which aided in the design of the new features for the smart cane.

In Chapter 5 the changes in the controls are discussed. After several experiments, the admittance model was changed greatly and the relevant issues are discussed in this chapter.

The implementation of the ergonomically modified smart cane is dealt with in Chapter 6. The results from the final experiments are presented and compared with previous results. In addition, the user acceptance of the modified and original smart cane is documented. The results from a poll of the field test participants are also presented here and they are discussed using a Likert scale (See Appendix A). Further issues which arose from this questionnaire are discussed as well.

Finally, plans for the future of PAMM and the initial prototype are discussed in Chapter 7.
Chapter 2

Current Mobility and Monitoring Aids

2.1 PAMAID

A Personal Adaptive Mobility Aid (PAMAID) is now being developed at Trinity College in Dublin, Ireland [MacNamara and Lacey, 1999]. PAMAID will be used by elderly people with vision problems. This project addresses the needs of a relatively large group of elderly people who are both visually and ambulatorily impaired [MacNamara and Lacey, 1999]. It has been found to be very difficult for those with visual and mobile impairment to walk using conventional methods of help. Guide dogs, long canes and standard walkers are extremely difficult for unstable blind people to use because they are in need of guidance as well as a support. PAMAID addresses this problem. It will take elderly blind people's needs away from their caretakers and at the same time greatly save caretakers' time and resources. In addition, it will increase the independence of these elderly people and lead to more active and healthier life-styles.

PAMAID is essentially a walking frame with power driven wheels. It has two modes of operation - manual and assistive. In the assistive mode, PAMAID controls the steering and travels effectively inside buildings, moving around obstacles in its path. It also gives the elderly person feedback through a speech interface. PAMAID, like PAMM, is being developed mainly for use in eldercare facilities.

Four prototypes of PAMAID have currently been built. The latest model resembles a regular walker. Its wheels are steerable and are controlled by an on-board computer. The user pushes PAMAID like a normal walker but the wheels are steered via the computer. Sonar sensors are used for navigation, which help the user avoid head high obstacles. Interestingly, a handlebar design was used in this prototype as the man-machine interface.
MacNamara and Lacey have found that this method of interfacing is the most effective of all that were attempted [MacNamara and Lacey, 1999]. A photograph of a prototype of the PAMAID system is shown in Figure 2.1.

![Photo of PAMAID prototype](image)

**Figure 2.1: PAMAID Rapid Prototype [MacNamara and Lacey, 1999]**

The current PAMAID prototype has been tested in one facility. The device was proven safe and effective with the seven subjects who tested it. A very interesting finding of MacNamara and Lacey in their field tests was that "The users found it easy to remember how to use the device (4.2 out of 5 on a Likert Scale) and were quite happy to move around with the device." [MacNamara and Lacey, 1999]. For an explanation of Likert Scaling see Appendix A. The ease of use of PAMAID is imperative for all personal mobility aids.

MacNamara, Lacey and their group plan future research and development for PAMAID. They hope to better the autonomy of the device when in use indoors. For example, a vision system will detect doors in the next PAMAID prototype. In addition, more reliable sensors are going to be used on the device.
Overall the PAMAID system is moving along quickly in research and development. Its progress is useful to consider in relation to PAMM.

2.2 HITOMI - Robotic Travel Aid (RTA)
At Yamanashi University in Takeda, Japan a travel aid for the blind is being developed [Mori, Kotani and Kiyohiro, 1994]. It will aid the blind in walking in an outdoor or indoor environment. In this study, several of the same findings as those of MacNamara and Lacey were made concerning the elderly blind population and the need for a device to help them. Based on these findings, RTA was developed by combining the technologies of the mobile robot and car navigation [Mori, Kotani and Kiyohiro, 1994].

A major difference between PAMM and RTA is that RTA's developers hoped to have it aid elderly blind people wherever they walk - be it a sidewalk, street or inside a building. In dealing with RTA's movement on the sidewalk, critical obstacles include vehicles, bicycles and pedestrians. To avoid these potential hazards, RTA - a motor wheel chair with additional components - uses a sign pattern based stereotyped motion. RTA has 5 stereotyped motions as a base and combinations of these are used to avoid obstacles [Mori, Kotani and Kiyohiro, 1994]. These combinations of stereotyped motion begin when a feature of the environment is detected. This feature is the sign pattern. Sign patterns which are always in existence (streets, shops, hotels etc.) are included in the digital map in RTA. Unusual sign patterns are dealt with by the system as they are viewed by a mounted video camera.

The way that the user interacts with RTA is also different from the way in which the user interacts with PAMM. There is a bar attached to the rear of RTA for the user to hold on to. This bar allows the user to feel the changes of the ground on which he or she is walking as well as gain support. In addition to this bar, RTA speaks to the user to inform
him or her of obstacles which move into his or her path. It then asks the user what it should do to avoid these obstacles. He or she then responds either through braille or a keyboard input.

Thus, using a motor wheel chair with a video camera, sonar system, stereotyped motion library, digital map and an audio guiding system RTA can navigate through any set city or town. Several components of the system have been tested with good results. Mori, Kotani and Kiyohiro state that there are three problems for them to solve before the system will be widely used by blind elderly people. These problems are training people to use the system, map construction and improvement of the way in which RTA moves [Mori, Kotani, and Kiyohiro, 1994].

2.3 The Guide Cane
The Guide Cane is a mobility aid for the blind which is currently being developed at the University of Michigan’s Mobile Robotics Laboratory [Borenstein and Ulrich, 1997]. The cane, though not necessarily for elderly people who require support, is interesting to look at in comparison to PAMM and particularly the smart cane prototype. The Guide Cane consists of a long handle and a head unit at the end with wheels and sensors. The wheels are mounted on a steerable but unpowered steering axle. The user pushes the cane ahead of him or herself and when the ultrasonic sensors on the head detect an obstacle, the device steers around the obstacle by giving a very distinct steering command to the user through the cane handle. The user is able to understand the cane’s path very easily and without conscious effort.

The Guide Cane uses a built in computer to control a servo motor which steers the wheel axle, and thus the wheels, relative to the cane. Ultrasonic sensors are mounted in a semicircular cluster on the cane with additional sensors facing up and to the side. A digi-
tal compass exists above the guide wheels and an incremental encoder is attached to each wheel. These encoders and the digital compass figure out the relative motion and travel speed of the user. The user interface is, quite interestingly, a joystick which the user operates using his or her thumb. With this joystick s/he can signal a specific direction of motion for the cane to follow.

A benefit of the Guide Cane is that its use is almost completely intuitive. Although it has not been developed for the elderly community, it has the key function essential to mobility aids for the elderly - ease of use. The user has only to set the desired direction of travel with the joystick and follow the cane. When the cane reaches an obstacle, the wheels move around the obstacle and keep the user moving in as close to the same direction as possible. The user brings him or herself to the nominal position behind the cane once again and follows it. Fortunately, this process is intuitive for most users. This was shown by tests on several users with a partially complete prototype. The fact that the Guide Cane can accomplish this is very interesting to consider when dealing with learning issues and the smart cane prototype.

In addition to obstacle avoidance, the Guide Cane can maneuver a blind person up or down stairs. This is done by strategically placed sensors which detect the difference between stairs and other obstacles. Again, the motion of the cane on stairways is very easy to follow.

There are several advanced functions which may be added to the Guide Cane as well. These functions include brakes, a global navigation system and speech input/output. Adding brakes to the system would allow slowed movement when the cane and user are travelling around an obstacle. A global navigation system would allow the blind individual to set a destination for the cane to direct them to. Finally a benefit of adding speech input or
output would be quick representation of the user’s exact location and orientation [Borenstein and Ulrich, 1997].

The Guide Cane’s obstacle avoidance system is very similar to that of PAMM. However, PAMM is not nearly as intuitive as the Guide Cane. This is an issue to examine in the next development stages of PAMM.

2.4 PAMAIMD, RTA and Guide Cane vs. PAMM

All three of the devices discussed above are somewhat similar to PAMM in some of their intended functions. However, PAMM makes use of different technologies and targets different users than these devices. These differences are how PAMM addresses issues that other personal mobility aids have not dealt with.

PAMM, unlike above devices, uses a six axis force torque sensor as the man-machine interface. This allows the user to feel in control of the device. This type of control is lacking in the Guide Cane, where a joystick interface is used. With further testing of the control model of the PAMM system this interface will make PAMM much easier to use than some of the above devices.

PAMM users will be elderly people with senile dimentia or similar disfuctions who may or may not need physical support. Since PAMM is for people who have a reduced mental function at times, use of the device will not necessarily be an intuitive act. PAMM will inherently have more difficulties with use than these other devices. In addition, PAMM must contain different system hard and software to be easy to use by such elderly people.

Although PAMAIMD, RTA and Guide Cane need to be considered in the PAMM study, PAMM deals with problems that other studies have not considered.
Chapter 3

Initial Experimentation with “Smart Cane”

3.1 Background Research

In order to test the smart-cane prototype effectively, background research was performed in this study. Extensive information about the gait patterns of the elderly and other such topics was found.

Much was discovered about average walking and falling patterns of the elderly. To begin, the average walking patterns for middle aged healthy people were found. This led to research on the gait patterns for several people. Oberg and Karsznia found that in a large sampling of people of all ages walking speed varied from 49 to 119 m/min [Oberg and Karsznia, 1993]. They also found that step length varied from 51 to 91 cm and that cadence varied from 95 to 160 steps/min [Oberg and Karsznia, 1993]. After additional research and discussions with members of the MIT Biomechanics Laboratory, it was decided that the lower numbers from this range could be taken as indicative of those for elderly people.

In addition to the parameters involved with walking, information regarding falls in the elderly was found. The most important data to come from this research was that concerning people’s reactions to falls. Usually, an elderly person reacts to a fall in anywhere between 80 and 90 ms. This reaction time is the time it takes a person to feel the fall and think about recovering from it. This data has not been significant to the research thus far.

3.2 Field Test Procedure and Initial Observations

After studying gait and falling patterns of the elderly, the first field tests with the smart cane were performed. Initially, three residents at Cadbury Commons eldercare facility in Cambridge, Massachusetts, tested the smart cane. These residents were all female and
between the ages of 75 and 95. A U-shaped walking path was made for them to follow using the cane for support. The total distance of this path was about 10 meters. Data was recorded from the force-torque sensor (FTS) to aid in testing the admittance model and ergonomics of the cane as the women walked with the cane.

Prior to the experiments with the smart cane, however, the residents were video taped walking along the path with their own canes. The three participants in these experiments lifted their cane in a cyclic pattern when they walked along the path. They all varied the amount of time between their lifting cycles but their canes were seen to leave the ground quite often during walking. This was an initial marker that using the smart cane may be difficult for them to learn because it is too large to be picked up like a regular cane. Though it is not necessary to lift the smart cane, it seems to be instinctive for users to lift their canes during use. In addition, it rolls and does not lift off of the ground like their own canes and this would possibly confuse them.

These initial observations proved to be correct as can be seen in Section 3.3.

3.3 User Acceptance
Before actually walking the path with the cane, each resident was asked how she felt about the prototype. All three of the residents voiced concerns about the cane and feeling secure with it. Most of them worried about the weight of the cane. They all seemed to feel that it was quite heavy and difficult to maneuver. In addition, each resident worried about her ability to use the prototype since she could not lift it as she did with her own cane.

These problems with acceptance of the smart cane, however, were remedied as time went on. Acceptance heightened as the residents became more familiar with the cane. More about this and other aspects of user acceptance can be seen in Chapter 6.
3.4 Ergonomic Problems
In addition to the residents stated concerns about the cane, it was evident from the video of them walking around the path that the cane design had one major ergonomic problem. The design was not suited to lending support and security to the elderly people despite the fact that this is one of the smart cane’s primary functions.

It can be seen from the video that each woman held the smart cane a good distance in front of her body while walking. With the cane in front of the user’s body it is extremely difficult for it to provide support. It is also difficult to control the device in this position. It can be seen from the data from the FTS that the women were not receiving the proper support from the cane nor were they easily controlling its motion. A plot of z forces (down/up) on the cane for one user can be seen in Figure 3.1. This shows low z forces down on the cane which is a clear indication that the user wasn’t receiving full support from the cane. In addition, the plot shows no sort of cyclic support pattern which shows their inability to control the device. This will be further explained in following chapters.

![Figure 3.1: Forces in Z Direction Over Time - First Experiments](image-url)
A reason for the women to hold the smart cane prototype so far ahead of their bodies was the fact that the handle of it extended directly from the center of the baseplate. Due to the size of the baseplate (nearly 6 inches from the center of the cane) this did not allow any of the women to keep her inside foot next to the handle of the cane as one would do with a regular cane. Thus, to keep a good distance between their inside foot and the wheels and baseplate of the smart cane the users had to walk with their arm extended with the cane out in front. This is visible in Figure 3.2 which shows a user during the initial tests with the smart cane. Additional photos of users with the smart cane with the regular handle are shown in Chapter 6 and Appendix I.

![Figure 3.2: User Walking with Smart Cane - Initial Tests](image)

An offset handle design was considered to remedy this problem. An offset handle, being even with the edge of the baseplate, would provide a way for the user to keep the handle close to her body without worrying about the baseplate interacting with her feet. More experimentation was necessary to work toward this task, however. The entire development of the offset cane handle is discussed in Chapter 4.
3.5 Control Problems
A major issue arose in the control of the smart cane during the first field tests. This issue involved the admittance model of the cane and its ability to follow the inputs from the user to the FTS. While the smart cane users were not receiving proper support from the cane, they were also not necessarily providing inputs to the sensor which were indicative of what they wished the cane to do.

Trying to use the cane for support caused the residents to supply forces and torques to the cane that were not consistent with their intentions for the cane movement. This caused the cane to diverge from the path that the user wished to follow. It made it necessary for them to physically bring the smart cane back to the desired direction. Often times they were unable to do this, causing the cane to travel further in the incorrect direction.

These problems brought about the major issues in using a FTS sensor as the primary interface for the system. This interface is very intuitive if thought of in terms of non-motorized vehicles. (See explanation of FTS interface in Chapter 1, Section 1.2.) However, when used with a motorized system such as PAMM, it becomes more difficult to implement. Both the user’s intentions and the user’s support effect the signals from the FTS. The sum of these signals alters the direction and velocity of the device. Users do not find this very intuitive, they are unable to separate their forces and torques to control PAMM’s motion.

After some time, the residents did learn how to keep the cane on track but at that point, very few of them were seeking support from the cane. Thus, in order to allow the user to obtain the necessary support, the control of PAMM was modified. The development of the modified control and a more in depth explanation of the model is given in Chapter 5.
Chapter 4

Experimentation and Offset Handle Design

4.1 Initial Tests
In order to begin designing a way to offset the current smart cane handle so that it would be flush with the edge of the baseplate of the cane, ergonomic feasibility needed to be determined. Due to unbalanced forces, an offset handle could cause the cane to tip over under the force of the user. To determine the cane’s stability, forces and torques put on regular canes were measured.

A mount for the FTS was designed and fabricated so that it could be secured on a regular four point cane. (See Figure 4.1) For additional part drawings refer to Appendix B.

![Diagram of Mount for Force Torque Sensor]

**Figure 4.1: Mount for Force Torque Sensor**

The four point cane was then used to perform tests with the residents. Residents again varied in age from 75 to 95. Six residents, both male and female, used the conventional
cane with the FTS mounted to it. (Other information about these residents can be found in Table 4.1.) The residents were asked to walk along a straight path of 6 meters while using the cane the way they would use their regular cane. They were asked to stop at the end of 6 meters and take their hand off of the cane to produce a zero force condition in the data for calibration. Then they walked the 6 meters again. Data was recorded at all times while the residents were using the cane. A photo of one of the residents using the cane with the mounted FTS can be seen in Figure 4.2.

![Image](image.png)

**Figure 4.2: Resident Using the Cane with Mounted FTS**

It should be noted that in this photo, the resident has the cane placed near her body and not in front of her body. This shows the natural tendency to hold a cane close to one’s body to obtain support. In Chapter 6, it will be shown that the offset handle allows this type of hold with the smart cane. However, prior to designing the handle the proper offset length needed to be determined to prevent tipping of the cane and injury of the user.
4.2 Results of the FTS Experiments
The data from the FTS experiments was analyzed using MATLAB. It aided in determining the amount that the handle could be offset.

First, the forces on the cane in the z direction (up/down) were analyzed. See Figure 1.3 for orientation of x, y and z axis in relation to the cane. A typical data set from the experiments is shown in Figure 4.3

![Figure 4.3: Typical Data Set- Force in Z Direction Over Time](image)

This data set follows one user from the start of her walk to the time when she stopped to turn around and walk back along the path. It can be seen from this data that the user picked up the cane with nearly the same force every time she did so. In addition, though her downward force on the cane fluctuated, on average it was higher toward the middle and end of her walk as she needed more support from the cane. As each user reached the middle and end of his or her walk, s/he became tired and needed more support. This constant lifting force and higher downward force toward the end of the walk was shown to be
true for nearly all of the six residents. In addition, the average lifting forces of all of the residents were very close. Averaging these forces gives an average lifting force for all residents of 22.9 N or 5.14 lbs. Table 4.1 shows the maximum downward forces on the cane in the x direction for each resident.

A cyclic pattern of each user with the cane can be seen in the data as well. Each user walked with a fairly constant pattern of picking up the cane and putting it down to use it for support. This can be seen in Figure 4.4 which is a smaller section of the plot from Figure 4.3.

![Figure 4.4: Small Section of Z Force Plot](image)

Next, the forces on the cane in the y direction (left/right) were analyzed using MATLAB. A typical graph showing the y forces over time can be seen in Figure 4.5
Figure 4.5: Typical Data Set - Force in Y Direction Over Time

Figure 4.5 shows data from the beginning of a user's walk. As can be seen from the plot, the y forces are not nearly as cyclical as the Z forces. However, they do effect the stability of the PAMM cane system with an offset handle. Table 4.2 shows the maximum forces in the y direction for all users.

Next, the torques on the cane around the x axis were analyzed again using MATLAB. A typical graph showing the x torques over time can be seen in Figure 4.6.
Figure 4.6: Typical Data Set - Torque Around X Axis Over Time

Figure 4.6 shows data for part of a user's walk with the cane. As can be seen from the graph, the amount of torque in the x direction varies throughout the walk. Unlike the z force, it fluctuates from high to low throughout the entire walk from beginning to end. It appears that a fluctuation from positive to negative torques occurs every time the user lifts and returns the cane to the ground. Table 4.2 contains the maximum torques on the cane in the x direction.

As can be seen from Table 4.1, the highest force put on the cane in the negative z direction from all of the users was 147.66 N (33.20 lbs). This number was neglected for future calculations. The fifth user clearly exaggerated his downward force on the cane. He explained this fact after the experiments. In general, he was not cooperative during the
experiments. Thus, for purposes of calculation the maximum force put on the cane by these six users was 87.24 N (19.61 lbs).

**Table 4.1: Reduced Z Force Data**

<table>
<thead>
<tr>
<th>User</th>
<th>Weight (lbs)</th>
<th>Time of Reading (s)</th>
<th>Maximum Z Force (N)</th>
<th>Maximum Z Force (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>53</td>
<td>52.03</td>
<td>11.70</td>
</tr>
<tr>
<td>2</td>
<td>124</td>
<td>13</td>
<td>43.12</td>
<td>9.70</td>
</tr>
<tr>
<td>3</td>
<td>115</td>
<td>11</td>
<td>48.51</td>
<td>10.91</td>
</tr>
<tr>
<td>4</td>
<td>115</td>
<td>45</td>
<td>51.3</td>
<td>11.53</td>
</tr>
<tr>
<td>5</td>
<td>142</td>
<td>34</td>
<td>147.66</td>
<td>33.20</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>84</td>
<td>87.24</td>
<td>19.61</td>
</tr>
</tbody>
</table>

**Table 4.2: Reduced Y Force Data**

<table>
<thead>
<tr>
<th>User</th>
<th>Time of Reading (s)</th>
<th>Maximum Y Force (N)</th>
<th>Maximum Y Force (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.65</td>
<td>15.45</td>
<td>3.47</td>
</tr>
<tr>
<td>2</td>
<td>37.47</td>
<td>16.67</td>
<td>3.74</td>
</tr>
<tr>
<td>3</td>
<td>4.81</td>
<td>8.12</td>
<td>1.83</td>
</tr>
<tr>
<td>4</td>
<td>49.6</td>
<td>10.42</td>
<td>2.34</td>
</tr>
<tr>
<td>5</td>
<td>9.90</td>
<td>16.22</td>
<td>3.64</td>
</tr>
<tr>
<td>6</td>
<td>45.47</td>
<td>8.43</td>
<td>1.89</td>
</tr>
</tbody>
</table>

As can be seen by Table 4.2, the maximum force in the y direction applied by a resident was 16.67 N (3.74 lbs). This force is very low in comparison to the maximum Z force. However, when coupled with other forces and torques it must be taken into account when analyzing the stability of the the offset handle design.
Table 4.3: Reduced X Torque Data

<table>
<thead>
<tr>
<th>User</th>
<th>Time of Reading (s)</th>
<th>Maximum X Torque (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>3.05</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>2.72</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>5.06</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>2.57</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>5.45</td>
</tr>
<tr>
<td>6</td>
<td>154</td>
<td>2.915</td>
</tr>
</tbody>
</table>

As can be seen from Table 4.3, the maximum torque in the x direction applied by a resident was 5.45 Nm. This again, however, was produced by the same user who exaggerated forces on the cane. Thus, again for the purposes of calculation, the maximum x torque applied was considered to be 5.06 Nm.

Using the maximum forces (y and z directions) and torque (x direction) in physical calculations (See Appendix E), it was determined that if the handle were offset such that the edge of the mount was just beyond the edge of the baseplate, the smart cane would not tip over under the grip of any one of the six residents who were tested with the four point cane. This positioned the cane handle at a distance of 5.8 inches from the center of the baseplate. This would be the maximum offset that would be permitted, smaller offsets were also considered. The calculations which provided this answer are shown in Appendix E.

4.3 New Handle Design
The handle of the smart cane prototype was then offset. In order to study different offsets the design is adjustable. Also it will permit the side to which the cane handle is offset can to be changed. This allows the prototype to accommodate both right and left handed
users. A sketch of the smart cane with the offset handle attached is shown in Figure 4.7.

The offset handle configuration consists of 2 additional mounts and a shaft connecting these mounts. The center mount takes the place of the FTS which is offset with the rest of the handle at the edge of the baseplate. The FTS is attached to the second mount in the offset handle configuration (left mount in Figure 4.7). A steel shaft connects these two mounts. The length of the steel shaft can be varied to give different values of the offset. By having several steel shafts available in varying sizes, it is possible to quickly change the offset. If the difference in length required is minimal, the amount that the shaft is screwed into the mount can be varied. To change the side of the cane that the handle is mounted to requires screwing the steel shaft into the opposite side of the mount.

A detailed drawing of the offset handle design can be found in Appendix F. This drawing includes the two new mounts and the threaded shaft.

This design was selected because it could be implemented with minor changes to the current system. Clearly other design ideas would be considered for the future of PAMM.

The offset handle was fabricated and attached to the smart cane for added experiments. The results of these experiments are shown and compared with the results of the non-offset handle experiments in Chapter 6.
Figure 4.7: Smart Cane with Offset Handle
Chapter 5

Changes in the Control of the Smart Cane

5.1 Background
As stated previously, the admittance control of the system treats the cane as a cart with virtual inertia and damping. As shown in Chapter 3, it was found that the elderly users of the cane apply forces and torques which differ from what they intend to apply on the cane for control purposes. This causes a motion of the cane away from its expected path. Several of the users were unable to compensate for this unwanted motion.

This problem was seen in the initial experiments at Cadbury Commons. Users complained about the smart cane trying to “get away from” them. They felt that it was very difficult to control, mainly because of the unintentional forces and torques that they applied to the cane. It was determined that these problems had to be altered prior to attempting more experiments at the facility.

5.2 The Modified Smart Cane Control
To solve the problem caused by unintentional user forces on the cane, the admittance model was changed to account for the support forces of the user.

The model worked in the following manner. If there was a positive force in the z direction (up on the handle) the cane would begin to move forward. Similarly, if there was a negative z force on the cane handle (downward) but the force in the x direction was greater than that force, there was motion of the cane in the x direction. Finally, if there was a negative z force on the cane and this force was greater than the force in the x direction, the cane would not move. This would supposedly compensate for the user’s added forces while asking for support. Basically, if the user was to lean heavily on the cane at any point, its motion would be stopped.
This admittance model was tested at Cadbury Commons using the same experimental procedure as explained in Chapter 3. It was found that the users still had difficulty controlling the motion of the cane. Although they did not complain as much as they had been with the original admittance model, they found several problems with the new control. It was seen that the downward unintentional forces were compensated for by this model but the unintentional torques on the handle were still disturbing the cane’s motion.

The users applied very high torques to the cane handle around the z axis. This can be seen in Figure 5.1, which is a typical data set from a straight line walk with the cane during the second tests at the facility. The maximum torque in the z direction on the cane handle for this user was 4.23 Nm. These very high torques were common to all of the users at the facility who tested the cane, even though they only wished to move straight ahead.

![Graph showing torque over time](image)

**Figure 5.1: Torque around Z Axis over Time**

The user whose data is shown in Figure 5.1, similar to the others, was completely unaware that she was applying such high torques to the handle of the cane. She simply
twisted her hand while using the cane for support. When asked if they could prevent this motion, all of the residents did not believe they had made any such motion.

As with the first tests, users began to understand how to control the cane more easily as the tests went on. Again, however, while they were controlling the cane they were clearly not using it for support. This can be seen in any of the data that was taken later in the experimental session. Figure 5.2 shows very low downward forces on the cane handle by a typical user and this proves that they were not using the cane for support.

![Graph showing downward forces over time](image)

**Figure 5.2: Downward (Z) Force over Time (End of Experimental Session)**

Hence this admittance model was not preventing the uncontrollable motion of the cane due to the involuntary torques. It was decided that another admittance model was required.

### 5.3 Final Admittance Model and Experiments

A second altered admittance model was developed to solve the controllability problem. This model allows the smart cane to follow a straight-line for most of its motion. It is a
mass model without any damping, it allows the user to travel only forward while the cane is moving. When the user is standing still, but leaning on the cane handle, there is no movement from the cane. To begin movement, the user need only to lift up slightly and push in his or her intended direction. When the user is walking with the cane at his or her side, s/he doesn’t put any forward or backward force on the handle. The cane velocity remains nearly constant. An emergency break also exists in the model so that when the user removes his or her hand from the cane handle the cane automatically stops.

In order to turn, one must stop the cane’s motion completely and then turn it. To do this, the user applies a torque around the z axis. The model ignores unintentional forces and torques by using a ratio of the forward force and z torque to decide the intended direction. This allows the user to only go in his or her intended direction. Inputs from the support forces and torques are not taken into consideration while the cane is moving. Torques around the z axis are only taken into account while the cane is at a standstill so that the user can turn.

This model was tested at Cadbury Commons in the same manner as explained in Chapter 3. Residents who had and had not walked with the cane were used. The cane was found to be much more controllable for the residents who had used the cane before. With the cane only obeying forward commands while in motion, users did not have to compensate for unintentional forces and torques. They needed only initiate force in their desired direction, use the cane for support and stop in order to change direction. The users were much more pleased with this control of the device.

With the new control model and prolonged exposure to the cane, residents appeared much more comfortable. Each user spoke of how happy they were with its motion compared to previous controllers. The model prevented the cane from doing anything other than what the user intended. Clearly the cane now had much greater user acceptance.
The smart cane with its final control model was also tested with residents at the facility who had never used the cane before. These tests showed very promising results. The new users learned to use the cane much more quickly than those who had learned on previous control models. They were able to control the cane after a few meters of walking, as opposed to after several 10 meter walks with it.

Although this control model currently appears to be the best model based on user acceptance and ease of use, there is still much work to be done. The residents still had some trouble turning the cane. It was difficult for them to understand to turn when the cane was not moving. Spinning the cane around its handle was not an intuitive motion for the users. This will have to be remedied in future control models.

It is too soon to select the final control law that should be implemented for the PAMM cane system. The final model tried was used for experiments with the new cane handle and it will continue to be used for more tests with the smart cane prototype.
Chapter 6

Smart Cane with and without the Offset Handle

6.1 Comparison of Configurations
When residents used the smart cane with the original handle mounted to the center of the baseplate they held the cane in front of their body and did not receive enough support from the PAMM. This can be seen in the data from the field experiments with the new admittance model and the centrally located cane handle. (See Figure 6.1) The data shows that the maximum Z forces (supporting forces) on the smart cane during these tests are lower than the maximum forces on the smart cane during the tests with the offset handle. A lower Z force on the cane by the user means that he or she is not getting enough support from the cane. When the user feels more comfortable leaning on the cane he or she puts more force on the handle. With the non-offset handle, however, users were not comfortable and did not use the cane for full support. The maximum forces during tests with that cane were about 25 to 30 N.

In contrast, when using the regular four point cane, maximum forces were much higher. Depending upon the need for a cane, maximum forces ranged from 40 to 90 N. (See Chapter 4) This shows that the users were obtaining substantial support from the four point cane.

Finally, the smart cane with the offset handle showed greater support forces on the cane by users than those on the cane with the regular handle. The tests using the offset handle were conducted in the same way as those described in Chapter 3. A few residents were tested. Some had used the cane before and some had not. On average, the maximum forces in the z direction from the residents were higher than those from when the handle
was not offset. This shows that the residents were more comfortable using the cane with the offset handle and were more apt to use the smart cane for support in this configuration.

A typical data set from both the tests with the non-offset handle and the experiments with the offset handle are shown in Figure 6.1. The higher forces in the z direction during offset handle smart cane use are very clear from this figure. The data shown with the thinner line is the data from the offset handle use. As can be seen, there are forces on the order of 80 N down on the handle with use of the offset cane and downward forces of only about 25 N with use of the regular cane handle.

**Figure 6.1: Forces in Z direction over Time (offset and non-offset handles)**

Additional data showing forces in the Z direction for the non-offset and offset handles is shown in Appendices G and H.
Figure 6.2: User Walking with Non-offset Handle Configuration

Figure 6.3: Another User Walking with Non-offset Handle Configuration
Another point for comparison of the two handle configurations is the position of the user with respect to the smart cane. As stated earlier, when using the non offset handle the user walked behind the cane and held her arm in an awkward position. The outstretched and awkward arm position of the user can be seen in Figures 6.2 and 6.3.

Clearly the user in Figure 6.2 has the cane in a very uncomfortable position. She has her front arm extended in such a way that she cannot receive support from the cane. Similarly, in Figure 6.3 the user has the smart cane a distance in front and out to the side of his body. As seen in Figure 4.2, it is necessary to hold a regular four point cane close to one’s body to receive proper support. The user in Figure 6.3 is not receiving proper support from the smart cane.

Conversely, a change in position of the user was noted when she walked with the offset handle configuration. She brought the cane directly next to her body instead of keeping it in front of her. This can be seen in Figure 6.4.

In Figure 6.4 the user has the cane close to her body and her arm bent in the proper position to receive support from the cane. This figure distinctly shows the offset handle and how it allows the user to walk properly.

Figure 6.5 shows a side by side comparison of the different cane handles in use. The user with the offset handle configuration is holding the cane in the proper position and the other user is not. The difference in position of the users is very evident from this figure.
Figure 6.4: User Walking with Offset Handle Configuration

Figure 6.5: Regular Handle Configuration vs. Offset Handle Configuration

It was deduced then that the offset handle is a better configuration for use on the smart cane. Overall, this configuration provides better support and easier walking and cane con-
trol for the user. For additional pictures of users walking with the two handle designs see Appendix I.

6.2 User Acceptance
User acceptance was qualitatively evaluated during all of the experiments, however, to obtain a more quantitative idea of the residents' feelings about the cane, a questionnaire was administered to the residents after using the non-offset handle cane and again after using the offset handle cane. Several important facts were discovered. The full questionnaires and responses with averages and standard deviations are shown in Appendix J.

First, after using the cane with the non-offset handle and the final iteration of the admittance model, users were pleased with the cane and how its control had changed. Unfortunately, they still had some reservations about using the cane. They worried about it being bulky and getting in the way of their feet. In addition, they felt that they did not receive enough support from the cane.

The fact that users were not receiving enough support from the cane with the non-offset handle shows clearly in the response to the first questionnaire. In responding to the statement, "The cane gave me enough support" the residents did not agree. The average ranking on a Likert scale was 2.8 out of 5. Users were clearly not receiving the support that they do from their own canes and this was probably a function of the handle position.

The preliminary questionnaire also shows that users were very insecure and confused about the cane. When asked to respond to the statement "The cane confuses me" the users mostly agreed. The average response was a 3.6 out of 5 on a Likert Scale. Similarly, residents agreed with the statement, "I feel uneasy when I'm using the cane". The average response to this question was a 4 out of 5. Thus, after some exposure to the cane and a bit of learning, users still felt a bit worried about using the cane.
These problems of confusion and uneasiness did not disappear after implementing the offset handle design. They were slightly lessened but there were continuing problems in this area. It should be noted, however, that a user suggested a “training course” for PAMM usage when it actually comes to market. This course would serve not only to teach the users how to walk with PAMM but also as an orientation to the device. The users want to know what they are using to support themselves and a course such as this could provide this help.

Also, as is clearly seen from the second questionnaire, there is a learning period with the cane. After prolonged exposure, the users will become much more amenable to using the device. The users did not feel that the cane was easy to use, even after the offset handle was implemented. However, they did note that it was easier to use after having walked with it for some time. Administering additional questionnaires after more use of the smart cane would aid in proving this point.

The major difference in user acceptance of the smart cane with the offset handle was the fact that the users realized that they were receiving more support from it. As stated earlier, when using the cane with the non-offset handle users noted not receiving enough support from it. When asked to respond to the statement, “The cane with the new handle gave me enough support” most of the residents agreed. The average rating was a 4.2 out of 5. This is a much better rating than what was recorded with the non-offset cane handle.

The heightened user support from the cane shows how important the offset handle is to the smart cane design. The user will not receive proper support if the handle is too far away from her body. Even the user him or herself feels more comfortable with the support from the offset handle.

The second questionnaire also uncovered a few more pieces of information about the offset handle design. First, the users felt more safe using the offset variation of the cane.
They rated the following statement a 3.8 out of 5: “I feel safe using the cane with the new handle”. In addition, they noted that the cane with the offset handle did not get in their way as much as the original smart cane.

Thus, several important aspects of user acceptance of the smart cane prototype were discovered through surveys of the users of the cane. These surveys show that the new handle for the smart cane provides better support and comfort for the user. In addition, elderly users will need a training period with PAMM to quell their curiosity about the device along with teaching them how to use it.
Chapter 7

Future Work

7.1 Ergonomics
The ergonomics and the human interface with the smart cane were greatly changed as a result of this research. The handle was offset so that users could keep the cane close to their bodies. This increased the stability and support that they received from the cane.

More work can be done on the ergonomics of the smart cane, however. For example, during this research, altering the type of cane handle was considered. This was never developed fully but it is necessary to look into. There may be a way to better support an elderly person during walking such as by supporting their arm from the elbow to the hand. The handle could be configured to perform such a task. It is too premature to say what type of handle would be best but more research will be done on this subject.

7.2 Admittance Model
The admittance model of the smart cane has been varied to the point of acceptability for this prototype. However, much work is necessary in the future. Users continue to have trouble turning the smart cane while it is stationary. The model could be altered to avoid these problems. An altered linear motion admittance model is perfectly acceptable for the smart cane at the moment but if any changes are made to the system the model will most likely need to be changed again. In addition, this model will need to be modified for use on the second prototype.

7.3 User Acceptance
Several important aspects of the user acceptance of the smart cane device were developed and considered. These ideas aided in the implementation of certain aspects of the smart
cane prototype. In the future, more surveys will be administered to track the changes in user acceptance as exposure to the prototype is prolonged. In addition, user acceptance of the smart cane prototype will be taken into consideration when developing the second prototype.

7.4 Second Prototype
Currently a second prototype of the PAMM device is being considered. This prototype will again aid in determining several factors concerning the device. The second prototype will be referred to as MOD II.

The MOD II device will be a walker configuration so that the user can receive more substantial physical support from the device. Developing MOD II as a walker presents new problems with the design and implementation of the device. Several lessons were learned from the field tests of the smart cane prototype and these lessons will be used in the development of the MOD II system.
Appendix A

Likert Scale Explanation
Likert Scaling is an undimensional scaling method like Thurstone or Guttman Scaling.

The steps involved in administering a Likert Scale are as follows:

1. Defining the focus
2. Generating the items
3. Selecting the items
4. Administering the scale

After the focus for the scale has been chosen, the items for question are generated and the best are chosen. These are referred to as items because they are comments that the people taking the questionnaire will respond to. For example, an item could be “The cane was difficult to use”.

Next, in administering the scale, the participants are asked to rate each comment on a scale of 1 to 5 where each number represents the following:

1 = strongly disagree
2 = disagree
3 = undecided
4 = agree
5 = strongly agree

Average responses and standard deviations are found for each comment and this is used to assess the focus of the scale.
Appendix B

Force Torque Sensor Specifications
The force torque sensor that was used on the smart cane is a JR3 force torque sensor. It is able to determine forces in the x, y and z directions as well as torques in the x, y and z directions. The FTS specifications are shown in Table B.1.

<table>
<thead>
<tr>
<th>JR3 Model</th>
<th>Dimensions</th>
<th>Available Load Ratings (lbs)</th>
<th>Available Torque Ratings (in-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30E15A</td>
<td>3.0 in. diameter</td>
<td>75, 100</td>
<td>225, 300</td>
</tr>
<tr>
<td></td>
<td>1.5 in. thick</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The sensor load rating is the full scale rating for the X or Y axis. The Z axis full scale rating is twice the sensor rating. The full scale moment rating for all axes is the sensor rating times the sensor diameter. [http://www.jr3.com]

A detailed figure representing the orientation of the FTS can be seen in Figure B.1. The orientation of the device on the cane was shown in Chapter 1. This figure shows the orientation of the device itself.
Figure B.1: FTS and its Orientation (http://www.jr3.com)
Appendix C

Part Drawing for the FTS Mount
The part drawing for the FTS mount that was fabricated for tests with the four point cane can be seen in Figure C.1 on the following page.
Figure C.1: Dimensioned Part Drawing for the FTS Mount
Appendix D

Additional Data from FTS Experiments
Although, the maximum forces in the z and y directions and the moments about the x axis are shown in Tables 4.1, 4.2, and 4.3 the plots of these forces and torques over time for more of the tested users are shown in the following figures.

![Graph of Z force over time](image_url)

**Figure D.1: Force in Z Direction Over Time**
Figure D.2: Force in Z Direction Over Time
Figure D.3: Force in Y Direction Over Time
Figure D.4: Force in Y Direction Over Time
Figure D.5: Torque Around X Axis Over Time
Figure D.6: Torque Around X Axis Over Time
Appendix E

Physical Calculations for Length to Offset Cane Handle
In order to figure out how far the cane handle could be offset without allowing the cane to tip over during use, the data from tests with a regular four point cane was analyzed. The maximum force in the z and y directions and the maximum torque around the x axis were used to calculate the amount with which to offset the cane handle.

Figure E.1 shows the free body diagram used in calculations.

![Free Body Diagram](image)

**Figure E.1: Free Body Diagram**

$F_z$ is the downward force by the user on the offset handle. $F_y$ is the sideward force on the handle by the user. $M_x$, though not shown in the free body diagram, is the moment about the x axis on the cane handle. $L$ is the length from the center of the smart cane to the
edge of the wheels. This length is 15.24 cm. \( H \) is the height of the cane handle from the wheels. This height varies depending upon the user’s height but for most of the participants in the experiments it was 80.1 cm. \( l \) is the amount that the handle can be offset without a user tipping over the cane. The weight of the cane is 12 kg.

Next, to find the amount that the handle could be offset by, the moments about the \( x \) axis were balanced giving the following equation

\[
M_x + F_y H = mgl
\]

(E.1)

where all of the variables have been defined.

The force downward on the cane handle was also balanced with the weight of the cane to aid in deciding the offset giving the following equation

\[
F_x l = mgL
\]

(E.2)

where all of the variables have been defined.

Analyzation of the above equations showed that the handle could be offset to the edge of the baseplate (5.8 inches from the center of the baseplate) without the user tipping the cane during use. These equations can be used to decide optimal lengths for varying forces and torques on the handle by different users.
Appendix F

Detailed Representations of Offset Handle

F.1 Three Dimensional Model

The offset handle configuration that was shown on the two dimensional model of the cane is shown in more detail in Figure F.1.

Figure F.1: 3-D Model of Handle - Viewed as if on Smart Cane (back view)

A different view of the offset handle configuration is shown in Figure F.2. This view shows other features of the configuration.

Figure F.2: 3-D Model of Handle - Varied View
As can be seen from the previous two figures, the offset handle configuration was made to conform with the current smart cane device. It offsets the handle in such a way that it can be used with the parts that already exist on the smart cane prototype.

**F.2 Part Drawings**
Detailed part drawings are included for each of the two mounts and the steel shaft in Figures F.1, F.2 and F.3 of this section.
Figure E.1: Part Drawing for Mount 1
Figure E.2: Part Drawing for Mount 2
Figure F.3: Part Drawing for Steel Shaft

It should be noted concerning Figure F.3 that the length of the shaft will vary depending upon the user. Eventually several shafts will be machined so that they may be easily replaced. As of now, however, only a small number of shafts have been fabricated.
Appendix G

Additional Data from Non-Offset Handle Tests
A representative plot of non-offset handle forces in the z direction is shown in Chapter 6.

Additional data from the non-offset handle tests is shown in the following figures.

Figure G.1: Force in Z Direction Over Time - Non-Offset Handle
Figure G.2: Force in Z Direction Over Time - Non-Offset Handle
Appendix H

Additional Data from Offset Handle Tests
A representative plot of the forces on the cane handle in the z direction from the offset handle tests is shown in Chapter 6. Additional data from the offset handle tests is shown in the following figures.

Figure H.1: Force in Z Direction Over Time - Offset Handle
Figure H.2: Force in Z Direction Over Time - Offset Handle
Figure H.3: Force in Z Direction Over Time - Offset Handle
Appendix I

More Photos of the Smart Cane in Use
The following figures show another side by side comparison of the two different handles on the smart cane prototype and how they affect the user’s position.

Figure I.1: Comparison of Smart Cane Handles
Appendix J

Full Questionnaire and Responses
The preliminary questionnaire and responses for all participants are shown in Table J.1. The users were asked to rank each item from 1 to 5 with 1 meaning he or she strongly disagreed and 5 meaning he or she strongly agreed. (See Appendix A) The average response for each comment is shown after all user responses. The standard deviation is also shown.

Table J.1: First Questionnaire and Responses

<table>
<thead>
<tr>
<th>Item</th>
<th>User Response</th>
<th>User Response</th>
<th>User Response</th>
<th>User Response</th>
<th>Average Response</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The cane gave me enough support</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td>I felt that the cane kept me from falling</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>The cane was too big</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>The cane got in my way while I was walking</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>I would use the cane in this facility</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2.4</td>
</tr>
<tr>
<td>I would use the cane instead of my regular</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>The cane was too heavy</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td>I liked the cane as much as my own cane</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>I used the cane to help me walk</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>The cane went too fast for me to use it</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3.2</td>
</tr>
<tr>
<td>The cane confuses me</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>It’s difficult to learn to use the cane</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3.4</td>
</tr>
<tr>
<td>I feel uneasy when I’m using the cane</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>The cane goes where I intend it to go</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.6</td>
</tr>
<tr>
<td>I don’t need to look at the cane to use it</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2.6</td>
</tr>
</tbody>
</table>
The second questionnaire and responses for all participants are shown in Table J.2. Again the users were asked to rank each item from 1 to 5. The average response and the standard deviation for each item is shown after all user responses.

**Table J.2: Second Questionnaire and Responses**

<table>
<thead>
<tr>
<th>Item</th>
<th>User Response</th>
<th>User Response</th>
<th>User Response</th>
<th>User Response</th>
<th>Average Response</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The cane I used today gave me enough support</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4.2</td>
<td>0.4</td>
</tr>
<tr>
<td>I feel safe using my own cane</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4.8</td>
<td>0.4</td>
</tr>
<tr>
<td>I feel safe using the cane I used today</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3.8</td>
<td>0.748</td>
</tr>
<tr>
<td>I feel safe using the cane with the handle in the middle</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3.2</td>
<td>0.748</td>
</tr>
<tr>
<td>It is easy to use my own cane</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4.6</td>
<td>0.48</td>
</tr>
<tr>
<td>It is easy to use the cane I used today</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3.6</td>
<td>1.02</td>
</tr>
<tr>
<td>It is easy to use the cane with the handle in the middle</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2.8</td>
<td>0.4</td>
</tr>
<tr>
<td>The cane I used today got in my way</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2.8</td>
<td>0.748</td>
</tr>
</tbody>
</table>
References


