PAMM - A Robotic Aid to the Elderly for Mobility Assistance and Monitoring: A "Helping-Hand" for the Elderly

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Abstract

Meeting the needs of the elderly presents important technical challenges. In this research, a system concept for a robotic aid to provide mobility assistance and monitoring for the elderly and its enabling technologies are being developed. The system, called PAMM (Personal Aid for Mobility and Monitoring), is intended to assist the elderly living independently or in senior Assisted Living Facilities. It provides physical support and guidance, and it monitors the user's basic vital signs. An experimental test-bed used to evaluate the PAMM technology is described. This test-bed has a cane based configuration with a non-holonomic drive. Preliminary field trials at an eldercare facility are presented.

1 Introduction

Meeting the needs of the elderly presents important technical challenges. As an elderly individual moves toward higher levels of care (i.e., from independent living to assisted living facilities to nursing homes), costs increase while quality of life rapidly decreases. The largest change occurs during the transition into a nursing home [1]. The cost of a Skilled Nursing Facility in a major city can easily exceed $90,000 to $100,000 per year compared to less than $25,000 per year for an Assisted Living Facility. The cost-effectiveness of keeping the elderly out of nursing homes is clear. In addition, it is well known that the transition to a nursing home is a very traumatic experience for many elderly people. With an estimated 75 million “baby-boomers” reaching retirement age in the next 30 years delaying the transition from independent living or living in an Assisted Living Facility into a Skilled Nursing Facility is critical [2].

Assisted Living Facilities aid their residents with daily activities such as bathing, meal preparation and also provide intellectual stimulation. However, most cannot provide labor-intensive support, including guidance for the residents that become disoriented frequently. Approximately 30 to 40 percent of Assisted Living Facility residents suffer from some kind of senile dementia [3]. These residents often require assistance with guidance, medication regulation, health-condition monitoring, and scheduling daily activities, see Table 1.

When these disabilities progress to the point that the elderly require the constant attention of a caregiver, the transition to a Skilled Nursing Facility is traditionally the only solution. The objective of our research is to delay this transition by developing the enabling technology for robotic systems that will provide mobility assistance and monitoring for the elderly.

Table 1: Typical Assisted Living Facility Resident's Physical and Cognitive Needs.

Need	Physical Deficiency	Cause
Guidance	Failing memory, disorientation	Senile dementia, Alzheimer's.
Physical Support	Muscular- skeletal frailty, instability	Osteoporosis, Diabetes, Parkinson's, Arthritis, etc.
Health Monitoring	Poor cardiovascular potential strokes and heart attacks	Age, lack of exercise, illness (e.g. pneumonia)
Medicine and Other Scheduling	Need for a variety of medicines coupled with failing memory	Senile dementia, general frailty

A series of test-beds, called PAMMs (Personal Aids for Mobility and Monitoring), are being developed to demonstrate and evaluate this technology. The PAMMs are intended to be prototypes of future systems to assist the elderly in Assisted Living Facilities. Intelligence aids such as these have the potential to assist with cognitive tasks, such as guidance and monitoring. In addition, they could adapt to the needs of the user by adjusting their interface in response to previous user interaction.

This paper describes the first test-bed, a cane-based configuration with a skid-steer (non-holonomic) drive. A PAMM based on a walker configuration with omni-directionals drives is also being studied for individuals with more severe physical limitations.

The PAMM design has a six-axis force-torque sensor mounted under the user's handle to capture the user's intent. An admittance-based controller integrates these signals with the instruction of the schedule based planner, the facility map information, and signals from the obstacle avoidance sensor in order to control the system. On-board sensors monitor the user's basic vital signs. The system communicates via a wireless link with the facility computers to receive up-dated planning information and to provide information on the health and location of the user. Figure 1 summarizes the PAMM Concept design.

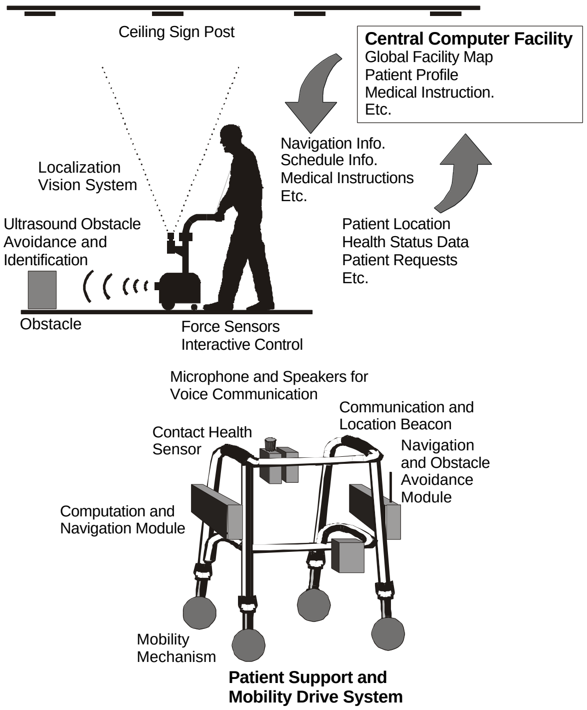

Figure 1. PAMM System Concept.

2 Background

Substantial research has been done in recent years to apply robotic technologies, particularly embeddable, miniaturized computer and electronic systems and sensors, to develop intelligent mobility aids for the disabled [5-11]. This research has focused primarily on the needs of the blind and of individuals with physical mobility problems [5-12]. Far less work has addressed the problems of the elderly.

The GuideCane [4] is one recently developed "electronic travel aid" (ETA) that assists blind people who do not require physical support. In many environments, such as their residence, the physically fit blind can function well with a simple cane. Their need is in new and highly unstructured environments such as train stations. The GuideCane detects obstacles using acoustic or vision sensing and conveys this information to the user via haptic or auditory feedback. To provide the frail blind with independent mobility, researchers have developed the PAM-AID [5]. In this work, the blind considered were not cognitively disabled. A blind individual, even one that is physically frail, has different needs than a cognitively and physically impaired elderly person, the target users of this research (see Table 1).

Some intelligent mobility aids have been designed specifically for the visually impaired elderly who, due to their frailty, find it difficult to use traditional assistance devices (i.e., a guide dog or long cane). The RoTA system is described as an effective "robotic guide dog" that provides some physical stability to the user [6]. Recently a system concept with more substantial support has been suggested [7].

A number of intelligent wheelchair-type aids are being designed for people who cannot walk and have extremely poor dexterity [8, 9, 10, 11]. The interfaces of these aids have been designed to make them easy to control despite the user's limited dexterity. Users command the aid using voice or breath-activated interfaces, or three channel joysticks. Most of these aids have intelligent interfaces that provide simple physical and cognitive assistance such as obstacle avoidance, wall-following and door passage. These devices are well suited for people who have little or no mobility, but they are not appropriate for the elderly with significant cognitive problems. In addition, Assisted Living Facilities generally do not permit residents to be confined to wheelchairs. If a resident losses the ability to walk with a cane or walker, they are transferred to Skilled Nursing Facilities. Hence, a wheelchair system will not delay the transition to Skilled Nursing Facilities.

In spite of the above research, the fundamental challenges of providing the technology to delay or eliminate the need for many individuals to move from Assisted Living Facilities, or their own homes, to Skilled Nursing Facilities remains. These challenges are the loss of cognitive competence, often combined with physical frailty. In this research, the enabling technology required to provide guidance, physical assistance, and full-time health monitoring for the elderly in Assisted Living Facilities or private homes is being developed. This research relies heavily on the advances that have been made in mobile robotics during the past decade. The work also exploits the semi-structured nature found in senior Assisted Living Facilities, or some private homes.

3 PAMM System Objectives

Working with several Assisted Living Facilities in the Boston Area, a set of performance goals for the PAMM concept were established, see Table 2.

Table 2. PAMM System Level Performance Goals.

Potential Users	Elderly with mobility difficulty due to physical frailty and/or disorientation due to aging and sickness.
Environment	Assisted Living Facilities. Known structured indoor environment with random obstacles such as furniture and people. Flat and relatively hard floor or ramps less than 5 degrees.
Physical Stability	Provide equal or better stability than that of a standard four-point cane.
Guidance and Obstacle Avoidance	Provide guidance to destinations via pre-programmed maps, schedules, user commands and sensed obstacles.
Health Monitoring	Provide continuous health monitoring.
Communication	Provide two-way communication with caretaker computer.

4 The SmartCane Prototype PAMM System

An experimental PAMM system based on a cane configuration with a skid-steer drive, called SmartCane, was built and tested, see Figure 2. The purpose of this system was to evaluate the technology being developed in this research.

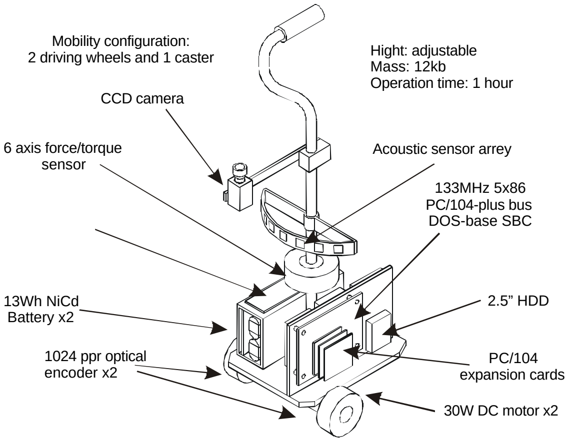

Figure 2. The SmartCane Prototype PAMM System

4.1 System Objectives

As shown in Table 3, the SmartCane is simple enough to be designed and fabricated quickly, yet functional enough as a mobility-aid to obtain practical results. The SmartCane is being used in ongoing evaluations of the technology envisioned for the final PAMM system. Currently a walker-based system with omni-directional drives, the SmartWalker, is also being developed.

Table 3. SmartCane PAMM System Design Goals.

Size	Compact and robust – Approximately 1 sq. ft. foot print
Weight	Less than 15 kg.
Speeds	0 to 0.5m/s.
Handle Loads	Maximum support force (Z) - 50 kg. Maximum forces in X and Y directions for stability and guidance 4 kg.
Battery Charging	About 8 hours between charges at duty cycle.
On-board Computing	Sufficient for planning, control, health monitoring and communication.
Sensors and Aides to Navigation.	Passive signposts acceptable for localization. Ultrasonic sensors acceptable for obstacle avoidance.
Inputs	Handle forces and voice commands
Cost	Target production cost <$5,000.

4.2 System Design

Referring to Figure 1, the SmartCane PAMM locates itself in a facility by visually reading simple sign posts strategically placed on the ceiling of the Assisted Living Facility. It uses acoustic sensors to locate obstacles, which enables it to maneuver in crowded environments. A six-axes sensor measures the forces and torques the user applies to cane handle. By monitoring these signals, PAMM estimates the user's intent.

The SmartCane communicates, via a wireless modem, with the local facility computer to obtain information such as the user’s schedule and the facility's updated maps. The PAMM concept calls for these systems, to carry sensors to monitor the health and condition of their users and transmit their status back to the facility computer. Cost constraints equired that the system be designed using commercially available components.

4.3 Experimental Design

The SmartCane employs a relatively simple skid-steering drive with two driving wheels and a rear mounted caster. Each drive motor has an incremental optical encoder for motion control and odometery. This configuration has relatively good maneuverability in congested environments as it allows an on-the-spot rotation. The mobility base is modular, so caster and motor assemblies can be rearranged to study different configurations. Figure 3 shows the mobility base with two castors.

System power of 28 Watt-hours is provided by a set of NiCd batteries. The cane uses two 30W DC drive motors.

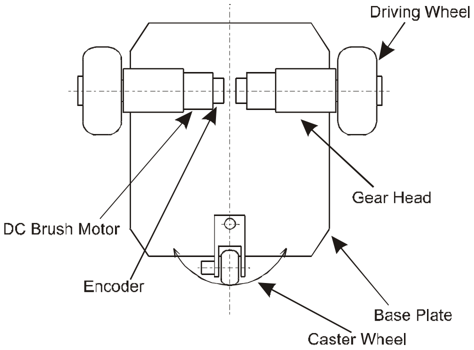

Figure 3. Mobility base Design.

The heart of the system is its computer, a PC/104plus system running an MS-DOS operating system, see Figure 4. The PC/104plus is an inexpensive, compact, energy-efficient and physically robust family of components [12]. The details of the PAMM computer system electronic design can be found in Reference [13].

A CCD camera reads the ceiling localization signposts [14]. A half-ring of five acoustic ranging sensors provides the information for obstacle detection. Each ranging sensor consists of a commercially available electrostatic transducer and ranging module [15]. A 6-channel JR3 force-torque sensor, mounted on the cane's shaft, measures the user's interaction with the cane [16].

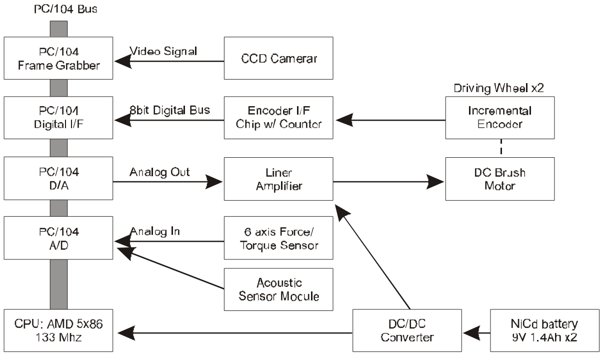

Figure 4. SmartCane Electronics Configuration.

4.4 Mobility Control

Modes of Operation

The Smartcane's mobility control system is a significant challenge. The control has four modes. The first mode is user-driven non-holonoic admittance control [17, 18]. In this mode, the user controls the path and speed, while PAMM provides physical support. The speed and direction of PAMM is determined from the forces and torques the user applies to the cane's handle. These forces and torques are measured by a sensor located in the cane's handle (see Figure 2).

In the second mode, using a facility map PAMM leads the user along a planned path at a pre-determined speed. The path is modified in real-time to avoid obstacles detected by the on-board acoustic sensors shown in Figure 2

In the third mode, PAMM also leads the user along a path, as seen in the second mode. However, in this mode the user can control the cane's speed with an admittance controller that varies the speed along the path based on the forces applied to the handle.

In the design concept for the fourth mode, the user would also control the speed with an admittance controller. However, he would be able to modify the path using methods such as the Coordinated Jacobian Transpose Control [19] or the method of Elastic Bands [20]. The input for the path modifications would again be forces and moments to the handle. While this would permit the user to direct PAMM from the path, it would react by gently guiding the user back to the path.

In the admittance-based control, the cane moves in response to the forces and torques applied to a force/torque sensor as if the cane had the characteristics of the selected dynamic model [21]. The model is chosen to create a desired feel for the user. The parameters of the admittance model can be varied for different users. The current design uses a two DOF (linear and rotary) mass damper. The motion given by the admittance controller is converted to command wheel velocities of the skid-steering system using the system's inverse kinematics. Figure 5 shows a diagram of the admittance controller.

The successful implementation of the above control concepts is made complex by two factors. First, forces applied to the handle by the user to provide support in walking must be distinguished from forces applied by the user to indicate his directional intent. Second, the non-holonomic mobility drive, while mechanically simple, makes the control of the SmartCane cane complex.

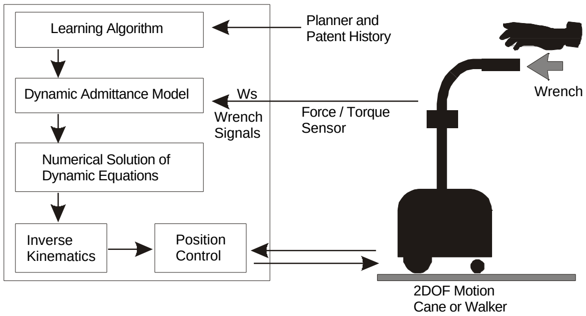

Figure 5. Admittance Controller.

The problem of separating the user's support forces on the handle from his intent control forces is currently being addressed in the research. Learning algorithms that can identify the support forces for an individual user from training data are being studied.

To control the SmartCane, a trajectory-tracking algorithm using non-holonomic feedback control has been implemented and tested. It is based on the nonlinear feedback posture-tracking algorithm developed by Samson [22]. The controller follows the trajectory by tracking the desired velocities. Using this controller, PAMM converges to the trajectory asymptotically**.** An advantage of this algorithm over many other non-holonomic control methods is that it has no control action when the desired speed is zero, even when position errors exist. It is most suitable for this application since it allows the user to stop and will not force the user to the intended trajectory.

4.5 System Motion Planning

Motion planning requirements for the SmartCane need to determine where the system is located in the Assisted Living Facility at all times (the localization task), and where it needs to guide the user (such as bringing the user to the cafeteria). It then needs to plan the best path based on a facility map while avoiding obstacles and accepting user-inputs (see Figure 6).

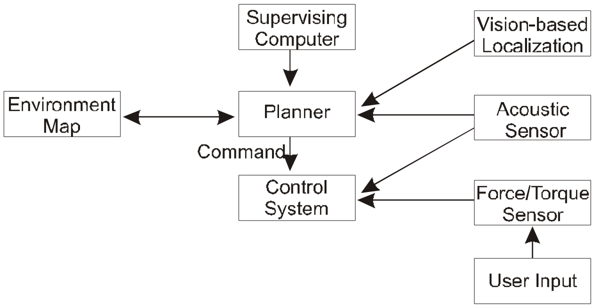

Figure 6. System Planner.

Localization.

A typical Assisted Living Facility has 1 to 5 floors with 7,500 sq. ft. (710 sq. meters) per floor. The large size and the similarity of the rooms and halls in an Assisted Living Facility would make recognition by vision and acoustic systems difficult and computationally complex. The SmartCane avoids these problems by using signposts (see Figure 7). The signposts are placed periodically on the ceiling of the facility where an upward-facing camera reads them.

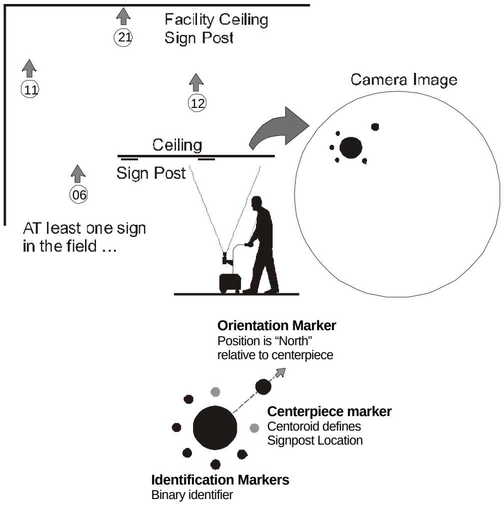

Figure 7. Localization Signpost Method.

The signpost has three elements. The first two, "Orientation Marker" and "Centerpiece Marker" are self-explanatory. Each signpost also has a unique pattern of Identification Markers. The presence or absence of individual markers represents a binary number. A design with **N** placeholders for identification markers allows 2^{N+1}-1 separate signposts.

At least one signpost must be visible to the camera onboard the SmartCane. This allows the cane to continually determine its absolute position and orientation within the facility. If the camera's field-of-view on the ceiling is 12 sq. meters, then a 37,500-sq. ft. (3500 sq. meters) facility would need approximately 300 signposts. A design with **N**=8 would suffice.

Obstacle Avoidance.

For obstacle avoidance, the admittance controller uses a shared control system similar to the one used by Aigner and McCarragher [23]. It combines user input and obstacle detection to prevent collisions, yet allows the user to exert control over which obstacle free path is taken. Control sharing can also be thought of as "input filtering." Results have shown that this discrete shared control was suitable for preventing collisions, but it made the cane difficult to control in cluttered environments. A Vector Field Histogram (VFH) method is being considered to make the shared control smoother [24].

Mapping.

The PAMM will have a fairly accurate map of the facility including walls, doors and stationary furniture. Methods have been developed, such as the Dempster-Shafer technique, to fuse acoustic readings from new objects into evidential gridmaps [25]. Such evidential maps can be used for VFH obstacle avoidance. Sometimes it is important to not only identify an object as an obstacle, but also to recognize it and detemine its location and orientation. For example, PAMM might be asked to guide a user to a chair. In order to accomplish this task, it will be necessary to idenfiy the chair's location. One way to accomplish this would be to mark the chair so that a vision system can easily distinguish it from other objects. This solution, however, would increase the facility's costs to accomodate the PAMM's.

Some of our recent experiments suggest that the acoustic sensors might be able to recognize objects from a limited set. While such an approach would have significant limitations in a general unstructured environment, it may be effective in an elderly residence where the number of different types of objects is limited and the basic map of the environment is well known. The concept for this system is shown in Figure 8. An ultrasonic echo detected by the transducer is amplified and converted into a signal representing the amplitude of the echo as a function of time. This signal represents multiple echoes of varying intensity returning from a target. If the echoes returning from a chair and those returning from a person are distinctly different, then artificial neural networks can be trained to distinguish them.

Initial results are promising. In an uncluttered environment, the acoustic system was able to distinguish between a chair and a person with 90% accuracy using neural-nets. Studies are being done to determine the limits of this approach to object recognition.

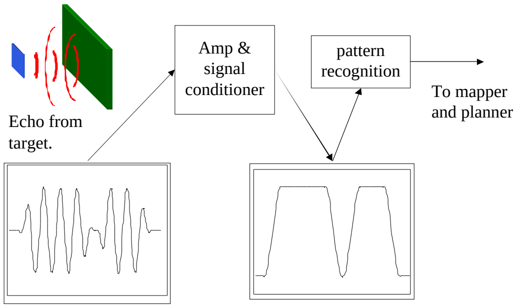

Figure 8: Acoustic Object Recognition.

5 Laboratory Experimental Results

The technology of the SmartCane has been tested extensively in simulation studies and laboratory evaluations. In these tests, the basic features and effectiveness of the localization, map building, obstacle avoidance, and control have been evaluated. For example Figures 9 and 10 shows the laboratory performance of the SmartCane with and without the signpost localization control. In each case PAMM asked to follow an elliptical-like path approximately 15 meters long. There are signposts on the ceiling in the neighborhood of the path. Figure 9 shows the system that depends upon odometery using the wheel encoders for location. The errors grow during the motion and by the second turn the cane is essentially “lost.” The small circles in the figure show where on the path the cane’s actual position is measured by the CCD camera. However these values are not used by the system to correct its location. In Figure 10 the localization information from the camera and signposts is used by the non-holonomic controller to correct the path of the cane. The figure shows that the cane is able to complete the route successfully.

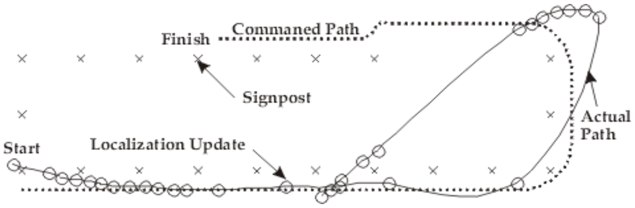

Figure 9. Experimental Tracking Performance without Localization Control.

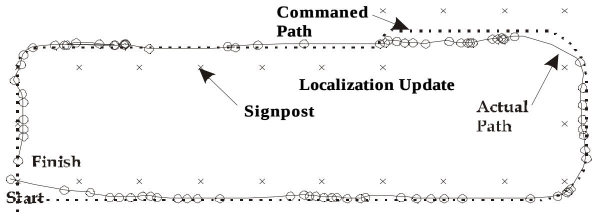

Figure 10. Experimental Tracking Performance with Active Localization.

6 Preliminary SmartCane Field Trials

Field trials of the SmartCane system have been made at the Cadbury Commons Assisted Living Facility in Cambridge, Massachusetts, see Figure 11. The system was used by men and women ranging in age from 75 to 95 years old. The admittance model, ergonomics, and overall user acceptance of PAMM were evaluated.

These tests have produced a number of very simple yet important results. It was observed that while walking, users held the cane too far in front of them to provide adequate physical support. They had difficulties keeping the cane close because of their fear of tripping over the base. An offset handle, shown in Figure 11, was added to the cane to solve this problem [26]. It might seem that the offset handle would not provide adequate support to the user, however, measurements showed that the cane base, with its motors, electronics and batteries, provides sufficient ballast for the offset handle design [26].

The field trials also showed a high degree of user acceptance of the system as measured by survey and by informal interview [26]. While some users had initial difficulty controlling the cane, most were able to adapt to it after a few hours of training. The elderly generally require some training with a physical therapist for common mobility aids, like canes and walkers.

Figure 11. Field trials of SmartCane System.

Mode I of the SmartCane, the preplanned trajectory, was relatively easy for most users. Mastering the admittance control modes, however, was more difficult. In these modes, the user "drives" the cane to some degree. The degree of difficulty was clearly a function of the selected admittance model. For example, the users found it difficult guiding the cane accurately when the admittance models had large damping. In this case, the user needs to apply a substantial forward force to keep the cane in motion, however some users had a tendency to apply a torque to the handle at the same time. This resulted in rotational oscillations of the cane. Current studies are investigating methods to have the cane "learn" the best admittance model for a given user based on measured behaviors during training.

The results of the field trials demonstrate that the basic technical concepts of the SmartCane are sound. The trials are continuing with an emphasis on developing user interface software to make the system more effective.

7 The SmartWalker Prototype PAMM

A walker based PAMM with near omni-directional drives is currently under development. It has many of the features of the SmartCane, however it will provide greater mobility and physical stability. The use of omni-directional drive units will make the mobility control for this system simpler, eliminating the need for non-holonomic control. However, it does present some challenges in developing omni-directional drives that are power efficient, robust, lightweight and can operate on a range of floor surfaces. In addition, the SmartWalker will be a test-bed for more advanced concepts, such as on-board control and planning systems that will "learn" the characteristics of the user and adapt their behavior to maximize user comfort and PAMM’s responsiveness. It is expected that much of this methodology will also be useful for the SmartCane configuration.

8 Summary and Conclusions

This paper describes an experimental test-bed, SmartCane, which is being used to develop enabling technologies for a Personal Aid for Mobility and Monitoring. Even though many of the systems on the

SmartCane are still being developed, it is already yielding important results. The SmartCane is able to assist individuals with only minor mobility impairments. During the second half of this year, a SmartWalker will be developed to address the needs of users with more severe impairments. It is expected that some users will be best suited to use the walker configuration of the PAMM concept and others the SmartCane. The systems and technology being developed for the SmartCane will also be used for the SmartWalker. Currently, work on the SmartCane includes the implementation of user voice command elements, wireless facility communication, and health monitoring sensors. These elements will then be evaluated in Assisted Living Facility trials.

Acknowledgements

This project is being funded by the MIT Home Automation and Health Care Consortium.

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