2003

A robotically-augmented walker for older adults

Jared Glover
Carnegie Mellon University

A Robotically-Augmented Walker for Older Adults

Jared Glover, David Holstius, Michael Manojlovich, Keirsten Montgomery, Aaron Powers, Jack Wu, Sara Kiesler, Judith Matthews, and Sebastian Thrun

August 1, 2003
CMU-CS-03-170 3

School of Computer Science
Carnegie Mellon University
Pittsburgh PA 15213

Keywords: mobile robotics, elderly care, walker, assistive devices, robot navigation, guidance system

Abstract

Many older adults use walkers to improve their stability and safety while walking. We have developed a robotically augmented walker to reduce fall risk and confusion, and to increase walker convenience and enjoyment. Using a modified version of the CARMEN navigation software suite [11], the walker is capable of parking itself and returning to the user when signaled by remote control. The system also supports navigation in large indoor environments by providing simple directions to target locations such as a cafeteria. The walker received positive reviews during informal testing with residents of a Pennsylvania residence facility for older adults.

This research is sponsored by the National Science Foundation under the ITR Program, which is gratefully acknowledged. The views and concussions contained in this document are those of the authors and should not be interpreted as necessarily representing official policies of endorsements, either expressed or implied, of the United States Government of the National Science Foundation.

1. Introduction

Pedestrian mobility aids, commonly called "walkers," are a boon to older adults' mobility, but walkers may be inconvenient to use and can pose safety risks if they are used infrequently or incorrectly. For example, users have been observed to park their walkers out of easy reach, and then to walk alone, leaning against furniture and walls to regain use of their walkers. Consensus among caregivers is that this activity represents a risk for falls, a serious concern especially for frail persons.

Our solution to the out-of-reach walker is a prototype robotically-augmented walker designed to park itself unobtrusively and to return when the user signals it with a remote control device (Fig. 1). In situations where walkers are parked away from the user, as in communal dining rooms or hospitals, this system would allow users to call their walkers to them, discouraging their walking without support. Augmenting walkers in this way might reduce the need for caregiver supervision and mitigate some risks by encouraging correct walker use. The sensors and mapping software used for remote parking and retrieval also can be used to provide navigational assistance and distance feedback, increasing the walker's appeal and usability in large indoor environments. In the prototype, navigational assistance was provided to the user in the form of a continuously updated map and large arrow displayed on a screen attached to the walker, making it easy for users to discreetly re-orient themselves and arrive independently at their destination. An odometer provided positive feedback about the distance traveled.

1.1 Fall Risk in the Older Population

The population growth rate of older adults age 65 and more is double that of the general population, a trend that is expected to continue well into this century [6]. Among this growing group of older adults, falls represent a leading cause of unintentional injury and death. Approximately one-third of accidental deaths in this age group, about 10,000 per year, result from falls and the complications that arise from falls [5]. Falls also are a major cause of morbidity, or disability-related loss of function within this age group. For adults 80 years and more, marked increases in mortality and morbidity are associated with even minor slips and falls[13]. Cognitive impairments, caused by degenerative disease or polypharmacy and drug interactions, are contributing factors to falls.

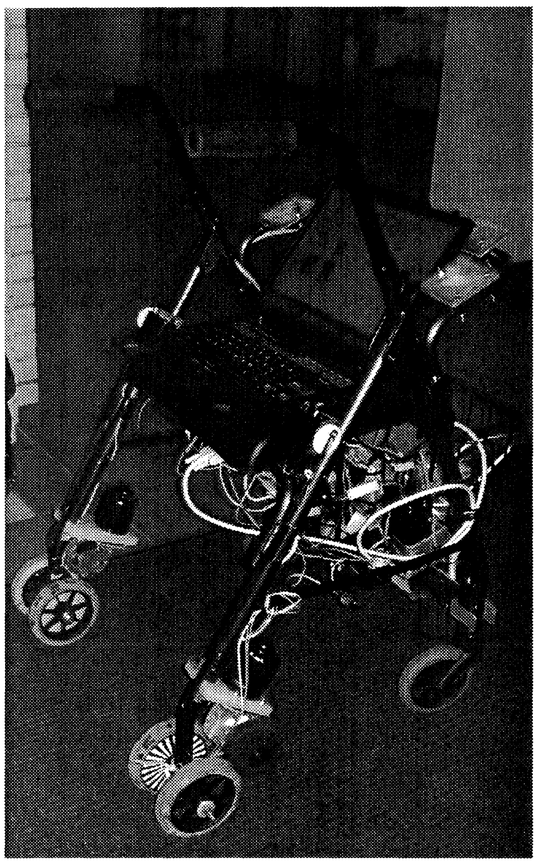


Figure 1: Prototype of the robotically augmented walker.

1.2. Fall Risk and Improper Walker Use
Falls are more likely to occur when individuals needing support do not walk consistently with the appropriate assistive device. Walkers are a simple technology but for many older adults they represent a visible prosthetic, and therefore may not be used as much as they are needed or where they are most needed (for example, in crowded public places). Walkers are sometimes inconvenient to park, navigate, and manipulate, discouraging their use. In informal interviews, caretakers and older adults told us of users who occasionally carry their walkers because they lack wheels or have insufficiently large wheels, or because their walkers are in other people's way. Users sometimes park their walkers out of the way, forcing them to rely on others to retrieve the walker or to walk unaided.

We conducted an ethnographic study of walker users in a Pennsylvania facility for independent and assisted living, and found some support for these observations. Out of 41 walkers observed during two periods of observation, 18 (44%) were parked out of reach or outside of the room where the user was located. Eight users (20%) were observed parking their own walkers out of immediate reach, and 10 staff caretakers or other residents (24%) placed walkers out of reach. We inferred from these observations that users (or staff, in a communal facility) often attempt to park their walkers unobtrusively and by doing so, put these walkers out of reach.

We also observed users engaging in the risky practice of walking back to their own walkers. Thirty users were observed re-acquiring their walkers from seated or standing positions. Out of the five cases in which the walker was parked outside of the room, 100% of users walked out of the room to retrieve it themselves. (Seven others had their walker returned to them by staff or residents, and the remainder had their walkers parked beside them and required no assistance in re-acquiring the walkers.)

Based on these observations, we concluded that a self-parking walker represents risk-reducing functionality that would be supportive of good walker-parking practice. Our solution makes use of navigational software that could be used also to provide navigation aid and feedback. Cognitive aids– such as our map-based navigation system–might mitigate fall risk further by reducing confusion or distraction while walking [13, 1].

1.3. Encouraging Walker Use
Many older adults we interviewed said they avoid walking or limit areas where they walk because they are anxious about the chance of falling, or their walker is inconvenient to use. If people reduce their frequency of walking, the consequent lack of exercise can sap their strength and coordination, which in turn exacerbates frailty and fall risk. Some technology, such as the motorized scooter, can help maintain an older person's mobility by substituting riding for walking, We argue that technology to support and encourage walking would be a useful alternative. Therefore, our parking and retrieval system was designed not only to increase safety, but also to increase the convenience, appeal, and security of walker use, to encourage walking

The navigation aid (based on the same underlying technology that enables the parking functionality) was intended not only to provide directional advice but to do so visually, using a simple large arrow that would point the way without interfering with cognitive processing and conversation by the user. An odometer was added to give positive feedback. Adding these features to a walker, we believe, could be of significant health benefit to older adults by encouraging and increasing their amount of exercise. Also, they might gain social benefits because walking in public places can increase opportunities for social interaction. A walker that can be parked and retrieved at a distance could be used in busy dining rooms where walkers can be a nuisance if they must be kept near the diner's table. Instead, the walker we designed could be parked out of the way and called back when the user is ready to leave.

An important point about the walker we designed is that it was not powered when used by a person, and did not control navigation. We believe most walker users (that is, those without major visual or cognitive impairments) would benefit best from passive assistive technology that supports walking rather than controls it.

1.3 Previous Mobility-Enhancing Robotic Devices

Roboticists have developed a number of mobility-enhancing assistive technologies. Most of these are active aids, meaning that they share control over motion with the user. Most are aimed at obstacle avoidance and path navigation. There exist a number of wheelchair systems [9, 8, 10, 12], as well as several walker- and cane-based devices targeted toward blind [3] and/or elderly users.

A technology with some similarities to ours is the walker-based Guido system. Guido evolved from Lacey & MacNamara's PAM-AID, and was designed to facilitate independent exercise for the visually impaired elderly. It provides power-assisted wall or corridor following [7]. Dubowksy et al's PAMM (Personal Aid for Mobility and Monitoring, distinct from PAM-AID) project focuses on health monitoring and navigation for users in an eldercare facility, and most recently has adopted a custom-made holonomic walker frame as its physical form [4,14]. Wasson and Gunderson's walkers rely on the user's motive force to propel their devices and steer the front wheel to avoid immediate obstacles [15]. All three of these walkers are designed to exert some corrective motor-driven force, although passive modes are available.

Although these systems address the safety issues posed by visual impairments or cognitive confusion, they do not address potential falls or other mishaps while the user is coupling or uncoupling from the system.

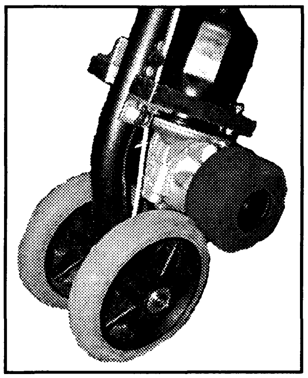
As well as being the first device designed to automate parking and retrieval, our walker also represents a design shift toward greater user autonomy and encouragement for walking itself. It reduces cognitive load through navigational feedback while allowing full control over the path of motion. The system is designed to improve convenience of use and encourage walking to public places, such as banks, beauty shops, restaurants, or communal dining rooms, where there are many opportunities for social interaction. It provides navigation and distance feedback that will increase walking enjoyment.

2. Hardware Description: Motion, Location, Navigation, and Remote Control

After reviewing a number of existing commercial walkers, we concluded that a four-wheeled walker provided sufficient stability for the additional equipment we would be installing. We then took this base design and modified it to allow for autonomous navigation as well as passive guidance. The walker base is shown in Figure 2.

Figure 2. Walker Prior to Modification

This particular four-wheeled walker was chosen due to its original braking design. To brake, the user simply has to push down on the walker, bringing the bottom of the



walker in contact with the floor.

We used this design to our advantage and implemented a drive system with a clutch that came into contact with the main wheels when the walker was lowered. Doing so allows us to maintain the ability of the walker to brake by pushing down on the wheels, while also allowing us to permit motors to drive the main wheels when needed for parking and retrieval. This assembly is shown in Fig 3. Since there are two main wheels in the rear, we added a drive assembly to each side. Doing so allows the robot to turn in any direction with a relatively small turning radius.

Figure 3. Detail of Walker Drive Assembly

With the modifications to the wheel assembly, we added two types of sensors. One sensor is used by the robotic components to gather environmental information; the other is used to gather user feedback. A SICK LMS laser range finder was mounted underneath the walker and was used to gather a 180 degree horizontal planar slice of the distances between it and any obstruction. With this sensor, as well as a pre-computed map of the environment, the walker knows where it was located at all times. As to sensors for user feedback, six buttons were built around a laptop display. Each push button's state is monitored constantly by a BasicX microcontroller, which sends information to the laptop at twenty Hertz. Also providing user feedback is an infrared remote control that is used to control the walker with the use of buttons, much like similar to that of a television remote control. The final walker design is shown in Fig 1.

3. Software Description: Mapping and Motion

The basic software components of our walker are similar to those of many autonomous robots, and provide for navigation, localization, map building and editing, motor control, and sensory interface. As a base for our software development we use CARMEN [11], which provides a robust framework where all the above components were already handled in some way.

Of the walker's two main features —parking and returning and navigational guidance — CARMEN provides the basic functionality needed for the former, leaving the navigational guidance system and a fairly substantial amount of sensor component integration programming to be done by our research team.

3.1 Navigational Guidance

Although the navigational abilities provided by CARMEN are extremely useful for autonomous navigation needed for the walker's valet service, the path-planning information displayed by CARMEN is much different from the information a person would use to obtain navigational assistance. For most people navigating through indoor environments, the most relevant information about a path pertains to the intersections they traverse, whereas CARMEN displays waypoints and vectors between them that usually have little or nothing to do with the topological structure of the environment. Furthermore, goal-points in the default CARMEN planner are actual points in Euclidean space, whereas goal-points to persons in indoor environments are usually rooms or corridors. Rather than take the existing planner and augment it so that it would allow for more robust goal-points and possibly provide more meaningful information about paths to the user, we chose o develop an entirely new, room-based planner.

3.2 A Room-Based Planner

To take advantage of the topological structure of a room-based environment, the first step is to discern the topology of the environment. One way to represent this topology is in a graph with weighted edges, where the nodes represent doors or borders, the edges represent rooms or areas, and the weights on the edges represent distances between borders. Although more complicated techniques may be employed to approximate path cost between doors (including the algorithm used by the CARMEN planner), Euclidean distance was deemed adequate enough for the walker, provided that the areas were sufficiently uncluttered and convex.

Once such a graph is created, the user's location is added to the graph as a new node, with edges connecting it to the doors in the room the user is currently in. A* planning (with a Euclidean distance heuristic) is then used on the graph to find a sequence of doors representing a path for the user to take to the goal room.

When developing this planner, some thought was given to building these graphs completely autonomously, but with only the 2-dimensional occupancy grids that CARMEN provided, differentiating between rooms or areas in a way that would be meaningful to people would be a difficult problem. For example, a border between two rooms in many houses may be marked only by a change in the color of carpeting, or by the fact that there is a dining table in one room and a sofa and television in the other. Thus, with no visual data to go by, fully autonomous room discovery was deemed impractical, if not impossible. However, once we allow border locations and room names to be added manually, a straightforward space-filling algorithm on the occupancy grid of the map suffices to quickly build a complete topological graph for any environment [Fig 4, Fig 5].

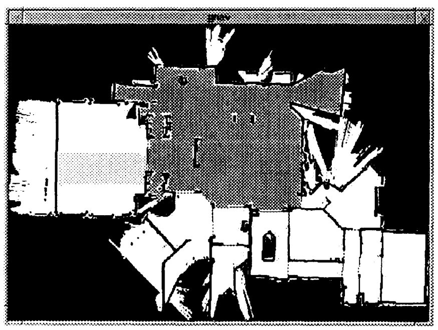


Figure 4. Graphical display of the space-filling algorithm used to build topological graphs of room-based environments. Borders between rooms are shown in red, filled rooms in green,

and rooms in the process of being filled in yellow.

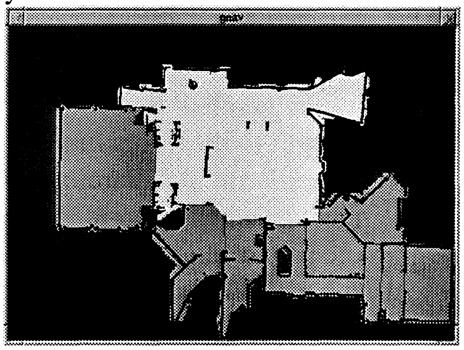


Figure 5: Graphical display of the map after its topological graph has been built. The room the user is currently in is shown in yellow.

4. Software description of UI

The prototype walker's user interface had six goals:

- To enable the user to park and retrieve the walker;
- To allow the user to select a destination from a list;
- To keep the user informed of his or her current location;
- To dynamically guide the user to his or her chosen destination; and
- To provide feedback on distance traveled.
- To minimize distraction.

For parking, a user needs to control the walker while out of reach. A screen-based or voice-command interface for parking and retrieval was determined to be impractical. Instead, our walker features a handheld remote control device for parking and retrieving it. The device has two separate buttons on the remote – one to signal the walker to park, and the other to request its return. Possible changes in this design are discussed in Section 5.1.

The prototype's navigational interface is primarily graphical. The walker's location is displayed on the screen of a laptop computer attached to the walker's seat/platform [Fig. 6]. To accommodate older adults with reduced eyesight, the screen-based display shows only four possible destinations at a time in a large, high-contrast font. Users can scroll through additional destinations or select a destination by pressing a button mounted on the walker frame.

In addition to the destination-selection components, the onscreen interface displays a map of the residence generated during the site-mapping phase of the project. As the user moves aroung aided by the walker, this map dynamically rotates and translates the walker's position to keep the walker's present location and heading centered and facing upward. A large arrow is continuously updated to point the user toward his or her currently selected destination. [Fig. 7] The arrow cues the user to the next sequential room on the shortest path to the destination. Hence, users are able to discern the visual cueing even when going to an unfamiliar location.

Figure 6. Using the Location System. Note the buttons located along frame above laptop screen

To increase the walker's appeal to users, a distance-traveled indicator was added as a screen-based component. This display provides positive feedback to the user about their current level of mobility. Just as the map's similarity to an in-car GPS system is intended to evoke themes of independence and mobility, the odometer display is intended to reinforce users' self-perceptions of activity and energy. Data on how often and how far users move also could be useful to caregivers or health professionals.

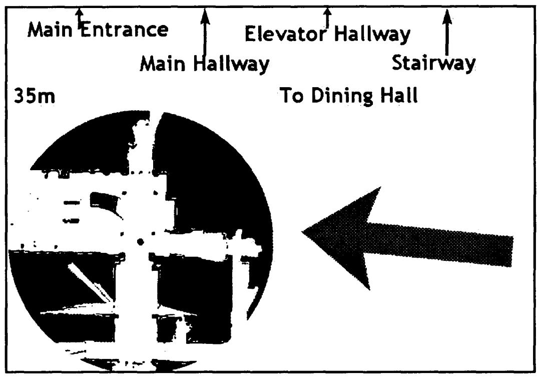


Figure 7: The user display as tested. The arrows above text pointed to numbered buttons above the edge of the LCD panel

5. User Feedback

To evaluate the viability of this work, we presented the prototype walker to staff and to an advisory panel of six older adults, some of whom used walkers, at the Longwood multi-level care facility for feedback and suggestions. We had discussions with these groups early in the design phase, in the middle of development, and after the end of development. The staff and panelists were offered the chance to try out the walker prototype and to offer suggestions.

All panel members recalled problems parking their walker out of reach or walkers getting in the way of people sitting at tables. They were enthusiastic about the walker's ability to park itself. Several panelists said that they knew people who would benefit from the navigation functionality of the walker because of their forgetfulness, but we did not test any such persons using our prototype.

While testing the walker, we observed that users required some instruction to use the walker at first. The remote control had been adapted from a universal device and had many unlabelled buttons that offered no functionality. Also, when looking at the interface (figure 6), some users did not recall which location they had selected – perhaps because "To Dining Hall" was confused with text at the top of the screen. The map and directional arrow were understood and followed clearly. Our observations suggest that the interface requires some redesign to make locations and choices more understandable.

Another problem users exhibited with the prototype involved the push-down-to-brake system. Several walker users kept leaning on the walker, which engaged the brake and made it difficult to move forward. Because many walker users will want to lean on their walkers, in a future version of the walker, we will use a walker that uses hand brakes instead of weight-activated brakes.

The added weight of the robotic equipment to the walker did not appear to make it harder for users to push it around. The wheels made the walker fairly easy to push and no users commented negatively on that weight. However, the panel commented that they would not be able to take the device with them if the walker were heavy; they many of them must be able to lift their walker to put it into a car. Thus, the current prototype walker is suitable only for one indoor environment and must be redesigned for greater portability.

6. Conclusions and Future Research

We have developed a prototype robotic walker that is capable of self-parking and returning to the user when signaled by remote control. Based on our observations, we believe this functionality represents a risk-reducing and appealing technology that could contribute to fall reduction among elders. Feedback from elders was positive: during informal testing, users successfully navigated to a chosen destination by using the screen-based interface, and also expressed enthusiasm for the device.

The mechanical and software aspects of remote parking are currently being improved, and we expect further revisions to the interface before we conduct formal user studies. Possible interface enhancements include voice recognition, spoken directions, dynamic user localization (rather than returning to the same spot), and/or a touch-screen interface. Although the current functionality is a significant improvement over standard walker models, as robotic technology improves, even more effective fall prevention will surely become possible through advanced sensing and actuation techniques. As with any project, we see several possible improvements that would provide avenues for extending the functionality of the walker.

6.1 UI Extensions/Improvements

The external buttons for location selection are functional but proved fragile in actual use. The use of a touch screen instead would permit an immediate mapping of location and screen prompt rather than requiring direction arrows to reference the buttons. It would also allow elimination of hardware and wiring associated with the buttons. Touch screens are also easier to clean than buttons or dials that protrude from a device.

Visual and hearing acuity are known to decrease with age. This decline presents a problem for any visual or auditory interface on devices for older adults. The feasibility of optional or additional visual and audio directions and cues should be considered. Voice command recognition would require extensive development to overcome problems associated with ambient noise and changing voice characteristics and is therefore less likely to be included in near future versions.

Another dimension of the walker interface to consider is a redesign that minimizes the stigma associated with using a walker. To the extent that a walker can be used in exercise regimes and to carry objects and park itself with these objects, it could be adapted by younger people, who would not otherwise use a walker.

6.2 Hardware / Sensors and Motor Extensions/Improvements

Though the additional weight of the hardware components was not excessive, research will continue to improve the drive mechanisms with the goal of increasing reliability and reducing weight.

An additional sensor that faces rearward on the walker is possible. This sensor would allow the walker to stop automatically if users appear to be moving the walker while they are not facing the device square to the handles or if they are placing themselves too far behind the walker for safe operation.

At present, the remote control device is infrared, which requires line-of-sight to activate. Providing some form of radio/wireless control would allow the walker to park out of view.

The current remote control was also large, unwieldy, and had a number of buttons that were not in use. A better design might consist of a single switch to both park and retrieve the walker.

6.3 Mapping and Location Finding Software Extensions/Improvements

For any robotics application, there is a goal to improve autonomy of the device. Improved autonomy would permit autonomous discovery of topological structure maps but in a way that is immediately meaningful to humans.

An issue we did not address involves the integration of this device into a community environment. Doing so would require central monitoring and scheduling as well as handling of multi-agent scenarios (e.g., where several walkers may be vying for the same parking area).

User-sensing and localization is also an area where we can improve autonomy. Future versions of the system might monitor the user's behavior more closely and potentially provide better alignment and stability.

Ultimately, the walker could move from passive to active guidance. This could be done in stages, with the first being obstacle avoidance during use, and then moving into active navigational assistance and directed walking. In conclusion, fall-reducing technology with increased effectiveness and appeal has the potential to make a large difference in quality of life for the elderly, and the potential is increasing every year.

7. Acknowledgements

Support for this research was provided by the National Science Foundation (IIS-0085796). We thank the Nursebot team for help in developing the prototype walker, especially Jamie Schulte; the UPMC Living-At-Home staff, and the UPMC Rehabilitation clinicians who familiarized us with walkers. Special thanks to the adults from Longwood at Oakmont who served on our advisory panel, gave feedback, and participated in our user studies; and to the staff at Longwood at Oakmont, and to Jayne Greene. We also thank members of the Project on People and Robots for their participation and advice (NSF IIS-0121426).

References

[1]American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. "Guideline for the prevention of falls in older persons, "*The Journal of the American Geriatrics Society*, vol. 49, pp. 664 – 672, 2001.

[2] Blair, S.N., H. W. Kohl, R. S. Paffenbarger, D. G. Clark, K. H. Cooper, and L. W. Gibbons, "Physical fitness and all-cause mortality," *Journal of the American Medical Association*, vol. 262, pp. 2395-2401, 1989.

[3] Borenstein, J. and I. Ulrich, "The GuideCane – A computerized travel aid for the active guidance of blind pedestrians," In *IEEE Int. Conf. On Robotics and Automation*, Albuquerque, 1997, pp. 1283-1288.

[4] Dubowsky S, F. Genot S. Godding, H. Kozono, A. Skwersky, H. Yu H, L S. Yu, "PAMM - A Robotic Aid to the Elderly for Mobility Assistance and Monitoring," In *IEEE International Conf. on Robotics and Automation*, San Francisco, 2000, PP. 570 – 576.

[5] Eakman, A, M. Haven, S. Ager, R. Buchanan, N. Fee, S. Gollick, M. Michels, L. Olson, K. Satterfield, and K. Stevenson, "Fall prevention in long-term care: An in-house interdisciplinary team approach," *Topics in Geriatric Rehabilitation*, vol. 17, pp. 29 – 39, 1998.

[6] Kinsella, K. and V. Velkoff, "An aging world: 2001," Report of the United States Census Bureau, 2001. Available: http://www.census.gov/Press-Release/www/2001/cb01-198.html (URL).

[7] Lacey G, S. MacNamara, and K. Dawson-Howe, "Personal adaptive mobility aid for the frail and elderly blind," In *Lecture Notes in Artificial Intelligence 1458: Assistive Technology and Artificial Intelligence*, V. Mittal, H. Yanco, J. Aronis, and R. Simpson, Eds, New York: Springer, 1998, pp. 211-220.

[8] Lankenau A and T. Röfer, "A Versatile and Safe Mobility Assistant. *IEEE Robotics and Automation Magazine*, " vol. 8, pp. 29-37, 2001.

[9] Levine, S. P., D. Bell, L. Jaros, R. Simpson, Y. Koren, and J. Borenstein. The navchair assistive wheelchair navigation system. *IEEE Transactions on Rehabilitation Engineering*, vol. 7, no. 4, 1999.

[10] Mazo M., "An integral system for assisted mobility," *IEEE Robotics and Automation Magazine*, vol. 46-56, 2001.

[11] Montemerlo, M., N. Roy, N., and S. Thrun, Perspectives on standardization in mobile robot programming: The Carnegie Mellon Navigation (CARMEN) Toolkit," Carnegie Mellon University, Pittsburgh, PA, March 2003. Available: http://www.cs.cmu.edu/~carmen.

[12] Prassler E, J. Scholz and P. Fiorini, "A robotic wheelchair for crowded public environments, " *IEEE Robotics & Automation Magazine*, vol. 8, pp. 38-45, 2001.

[13] Rubenstein, L., C. Powers, and C. MacLean, C. "Quality indicators for the management and prevention of falls and mobility problems in vulnerable elders, " *Annals of Internal Medicine,* vol. 135, no. 8, pp. 686 – 693, 2001.

[14] Spenko, M., "Design and analysis of the SmartWalker, a mobility aid for the elderly," Master's. thesis, Department of Mechanical Engineering, MIT, Cambridge, MA, 2001..

[15] Wasson G, J. Gunderson, S. Graves, and R. Felder, "An assistive robotic agent for pedestrian mobility," In *Inter. Conf. on Autonomous Agents*, pp.169-173, 2001.