abstract

Mobility and independence are essential components of a high quality of life. Although they lack the strength to operate manual wheelchairs, most physically disabled older adults with cognitive impairment are also not permitted to use powered wheelchairs due to concerns about their safety. The resulting restriction of mobility often leads to frustration and depression. To address this need, the authors are developing an intelligent powered wheelchair to enable safe navigation and encourage interaction between the driver and his/her environment. The assistive technology described in this article is intended to increase independent mobility, thereby improving the quality of life of older adults with cognitive impairments.

Key words: *mobility, artificial intelligence, assistive technology, wheelchairs, cognitive impairment*

The Future of Wheelchairs: Intelligent Collision Avoidance and Navigation Assistance

Pooja Viswanathan, BMath, MSc Candidate, *Department of Computer Science, University of British Columbia, Vancouver, BC.*

Jennifer Boger, MASc, *Research Manager, Intelligent Assistive Technology and Systems Lab, Department of Occupational Science and Occupational Therapy, University of Toronto; Toronto Rehabilitation Institute, Toronto, ON.*

Jesse Hoey, PhD, *Lecturer, School of Computing, University of Dundee, Dundee, Scotland; Toronto Rehabilitation Institute, Toronto, ON.*

Pantelis Elinas, MSc, PhD Candidate, *Department of Computer Science, University of British Columbia, Vancouver, BC.*

Alex Mihailidis, PhD, PEng, *Assistant Professor and Head of Intelligent Assistive Technology and Systems Lab, Department of Occupational Science and Occupational Therapy, University of Toronto; Toronto Rehabilitation Institute, Toronto, ON.*

Introduction

As the older adult population in Canada continues to grow, there is an increased need for improved health care and new assistive technologies to ensure continued independence and a high quality of life.[1] Mobility has been identified as a key component of physical well-being and happiness, enabling people to interact with their surroundings. Unfortunately, the mobility and independence of many older adults is often reduced due to physical disabilities. Wheelchairs have been found to positively enhance the mobility of several long-term care (LTC) residents.[2] Since most older adults lack the strength to use manual wheelchairs, they require powered wheelchairs for effective mobility. However, safe operation of powered wheelchairs requires a significant level of cognitive capacity. It is estimated that 63% of LTC residents have dementia or Alzheimer's disease.[3] Physically disabled older adults with such cognitive impairments lack the skills needed to safely manoeuvre powered wheelchairs and are therefore not allowed to operate them. Exclusion from the use of powered wheelchairs and the lack of strength required for manual wheelchair use result in greatly impaired or nonexistent mobility for a large number of LTC residents.

Reduced mobility often results in decreased opportunities to explore and socialize, leading to social isolation and depression.[4] For example, one study has reported that among noninstitutionalized U.S. adults, 31% of people with major mobility difficulties were frequently depressed or anxious, versus only 4% of those without mobility difficulties.[5] Loss of mobility also results in increased dependence on caregivers in order to fulfill daily tasks. The authors believe that intelligent technologies can be applied to powered wheelchairs to enable safe and independent mobility. This will significantly improve the quality of life of wheelchair users while simultaneously reducing the burden on caregivers.

This article discusses the design of a new intelligent wheelchair that will eventually perform three main tasks: one, promote safe wheelchair operation by preventing collisions; two, map the environment to provide navigation assistance;

and three, prompt and encourage the user's (i.e., the wheelchair driver's) mobility and exploration.

Intelligent Wheelchair Design

The safety of the wheelchair user and those sharing the environment is of utmost importance. It has been reported that 73–80% of older adults experience a trip or fall after being hit by a wheelchair.[6] Even a minor collision can lead to a fall, and 5–10% of these falls result in a fracture, particularly a hip fracture, in the older adult population.[7] Hip fractures have serious consequences for this population, usually leading to a severe reduction in mobility and up to a 40% mortality rate within 6 months as a result of complications.[8] Thus, a noncontact method of collision avoidance is needed to ensure the safety of residents in LTC facilities. This article discusses current research involving the use of a stereovision video camera as the primary sensor to aid in safe navigation.

Previously developed intelligent wheelchairs that help with planning and navigation tasks include MAid,[9] Navchair,[10] and PLAYBOT.[11] These wheelchairs are designed for autonomous navigation with little or no supervision by the user. However, a powered wheelchair that moves on its own can lead to confusion and frustration among the targeted user population (i.e., individuals with dementia), particularly if users do not understand that the wheelchair is autonomously guiding them or if the wheelchair's actions do not support the user's intent. On the other hand, wheelchairs that leave the majority of the planning and navigation to the user and assist solely in collision avoidance are also not ideal for users with cognitive impairment, as their planning capabilities are often quite limited.[1] The authors are implementing a mixed-initiative control strategy, where the wheelchair relies both on its own intelligence as well as user preferences and abilities. This strategy provides the user with supportive, passive assistance in navigating the environment without taking the control away from the user.

The intelligent wheelchair system being developed by the authors is comprised of a powered wheelchair (Nimble™ Rocket), a three-dimensional (3D) stereovision camera (Point Grey Research's Bumblebee® camera), and a laptop computer (Fujitsu P7120 Lifebook). For the preliminary trials, the Bumblebee camera is mounted on the front of the wheelchair, as seen in Figure 1. The laptop is housed under the wheelchair seat and is responsible for the wheelchair's computing (e.g., image processing and navigation).

Safe Navigation and Collision Avoidance

Using stereovision techniques, the Bumblebee camera acquires a pair of images simultaneously and uses these images to compute the distance to objects in front of the chair. Distance information is stored in maps that are continually updated as the wheelchair moves through its environment (see Figure 2).[12] When an obstacle is detected within a predefined distance threshold, the wheelchair is stopped. Subsequently, the direction of greatest freedom (the area beside the obstacle with the most amount of free space) is computed after scanning the entire region in front of the wheelchair. This direction is suggested to the user through an audio prompt (e.g., "try turning left" or "try turning right"). Prompts are continually issued until the user successfully avoids and passes the obstacle.

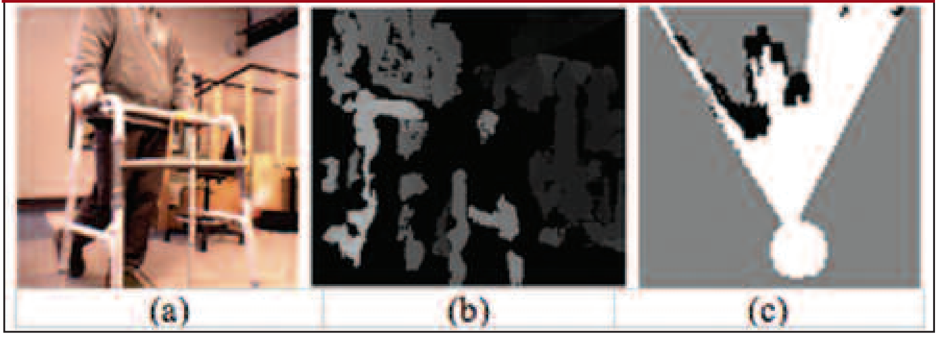
Figure 1: Intelligent Nimble Rocket Wheelchair

As a fail-safe mechanism, the mechanical bumper skirt described by Wang *et al.*[13] will also be installed on the wheelchair. The skirt stops the wheelchair upon contact with an object at less than 100 g of force.

Global Mapping of the Environment

In addition to ensuring collision avoidance, the wheelchair can provide further navigational assistance by learning a global map of its environment. The mapping task is accomplished using a technique called ΣSLAM,[14] in which 3D landmarks are identified in the images from the stereovision video camera and used to construct dense global maps, as shown in Figure 3. Fixed obstacles in the

Figure 2: The Creation of Navigational Maps with the Bumblebee Camera



Images of a person standing in front of the wheelchair with a walker. Navigation maps are generated representing (a) camera view, (b) distance (depth) map and (c) 2D bird's-eye view of obstacles in the environment. In (b), the closer an object is, the brighter it appears. In (c), black represents known obstacles, white represents free space, and grey represents unknown regions.

environment are represented as dark regions in the map. After constructing the global maps, labels can be assigned to different regions in the map (e.g., bathroom, lounge, etc.) for use in navigation assistance. Future work involves determining the current location of the wheelchair with respect to the global map, identifying locations of interest, and planning the best route from the current location to the desired location.

Preliminary Results

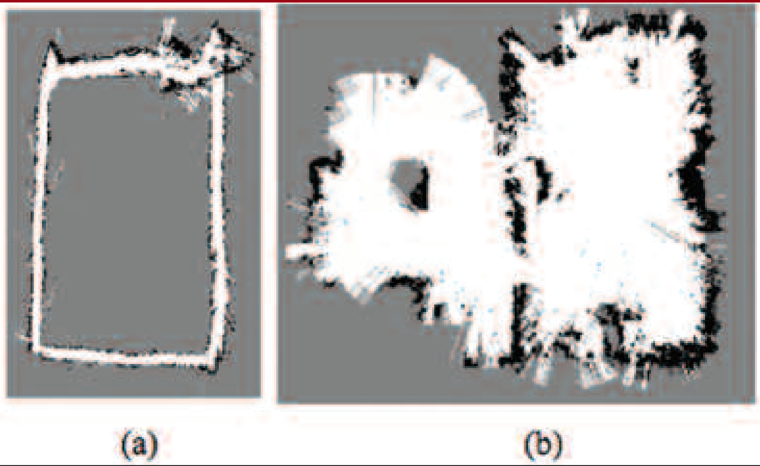
Preliminary experiments have been conducted to test the efficacy of the collision avoidance subsystem in a prototype intelligent wheelchair. Experiments were conducted within a controlled laboratory environment (with no natural light). Objects commonly found in a long-term care facility were used to test the anticollision and prompting modules, namely, a wall, a four-legged walker, a cane, a stationary person, and a moving person. The wheelchair was driven towards each object at a constant velocity by an experienced driver. When an object was present, the anticollision system stopped the wheelchair in 96 of 100 trials (96%). The correct directional prompt was given in 50 of 50 trials (100%). When no object was present, the wheelchair did not stop or issue prompts (i.e., no false alarms were raised).

Although the above results are promising, the frailty of the population in a LTC setting demands that the system performs with as close to 100% accuracy as possible, regardless of the object in front of it. The authors are currently working on improving the performance of the system in the controlled environment, as well as testing the system in more naturalistic conditions. Subsequently, the system will be tested in LTC facilities with older adults with cognitive impairments, the intended users of this new assistive technology.

Future Work

The next stage of research in the intelligent wheelchair system described above is to enable the system to identify its current location and automatically learn locations of interest to the user. The wheelchair can recognize where it is by identifying features in incoming images from the camera and matching them to corresponding features in the preconstructed global map. Desired locations can be learned by using the driver's daily schedule (provided to the system as input from a caregiver), observing his/her patterns of daily behaviour, and using any other available information, such as a schedule of special events held at the LTC facility (e.g., a barbeque). The wheelchair system will then use a decision-theoretic model (a type of artificial intelligence) to determine the optimal route based on the wheelchair's current and desired locations (in the global map), obstacles in the wheelchair's path (for anticollision), and other contexts such as user preferences. For example, if it is almost

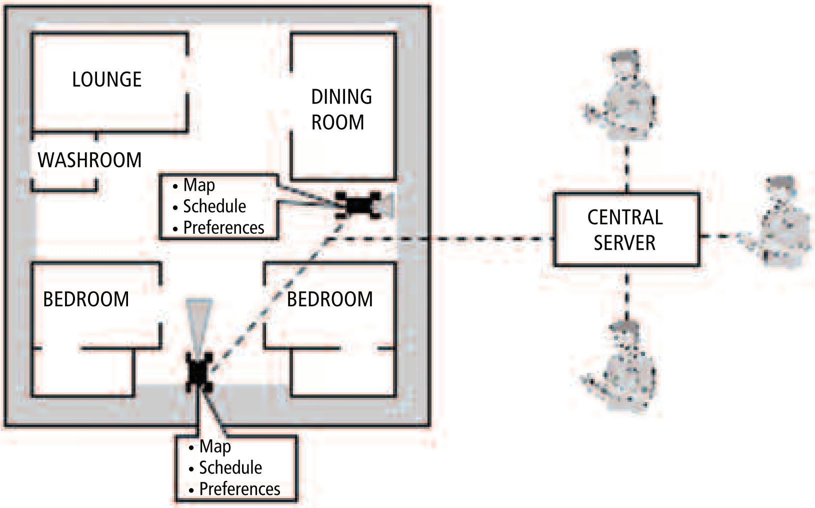
Figure 3: Global Mapping of the Environment



Global maps of (a) a corridor and (b) two rooms with two connecting doorways.

Source: Elinas et al., 2006.[14] © 2006 IEEE

Figure 4: Communication and Coordination among Intelligent Systems



The intelligent wheelchair will eventually be able to plan and make decisions based on available information such as map/location, user preferences, and schedule. As indicated by the dashed lines, each wheelchair will also be able to communicate with other chairs or assistive technologies (e.g., an intelligent walker) in the environment, and share data with a central server, which can transmit information to the user's care provider(s).

Adapted from: Mihailidis et al. In press.[1]

Key Points

Among older adults, mobility and independence are often reduced due to physical and/or cognitive disabilities.

Physically disabled older adults with cognitive impairments are incapable of safely manoeuvring powered wheelchairs and lack the strength to operate manual wheelchairs.

A new intelligent wheelchair is being developed that ensures safe navigation, maps the environment to provide navigation assistance, and offers prompts to encourage user mobility and exploration.

A mixed-initiative control strategy is implemented to provide supportive, passive assistance to the user without taking his/her control away.

Intelligent wheelchairs will help to reduce the burden on health care personnel and resources, and increase the quality of life of older adults with cognitive impairments by restoring mobility and independence.

lunchtime according to the user's schedule, the wheelchair can guide the user to his/her meal by computing the best route from the wheelchair's current location to the region of the map labelled as the dining room. In addition to verbal prompts, visual feedback will also be provided to the users via an LCD screen mounted on the wheelchair. It is anticipated that this rich data set will allow the wheelchair to assist its driver in getting to places of interest in a timely fashion, as well as encourage the driver to explore and interact with his/her environment in a safe manner.

In addition, future work will allow each wheelchair to exchange information with other wheelchairs in the environment as well as share its data with a central server that can communicate with the user's care provider(s), such as LTC staff (see Figure 4).[1] Through communication and coordination with intelligent systems installed in other residents' rooms or wheelchairs, the intelligent wheelchair can bring a group of residents together for some daily activity at a scheduled time, thus encouraging social interaction. The new intelligent wheelchair system is thus designed to fit seamlessly into the existing health care system and help LTC residents, both with and without mobility aids, and LTC personnel. As the chair operates in the same manner as conventional powered chairs, it is anticipated that there will be minimal interaction between the chair and the caregiver. Support provided by the caregiver will include charging the chair nightly and, if the global mapping/navigation feature is used, updating the owner/driver's schedule as appropriate. There will be an option for the caregiver to turn the anti-collision/guidance system on and off. Future testing with the targeted user groups, including a representative sample of professional caregivers, will have to be conducted to ensure the operation of the chair is appropriate for everyone in the environment.

Conclusions

The navigational and planning features of the intelligent powered wheelchair described in this article show promise as a tool that will enable safe wheelchair use, while taking into account user preferences, health needs, health care provider needs and goals. It has been found that many older adults in LTC facilities who do have a powered wheelchair do not use them effectively to explore their environments unless prompted to do so by a nurse or caregiver.[1] The proposed intelligent wheelchair will encourage these users to explore their surroundings though the use of automated planning and prompting. It is hoped that the features of this system will encourage safe exploration and social interaction, activities that are essential in lowering boredom and depression to maintain social well-being and a higher quality of life.

References

1. Mihailidis A, Elinas P, Boger J, et al. An Intelligent Powered Wheelchair to Enable Mobility of Cognitively Impaired Older Adults: An Anti-Collision System. IEEE Transactions on Neural Systems & Rehabilitation Engineering (in press).
2. Pawlson LG, Goodwin M, Keith K. Wheelchair use by ambulatory nursing home residents. J Am Geriatr Soc, 1986;34:860–4.
3. Kane RA, Caplan AL, editors. Everyday Ethics: Resolving dilemmas in nursing home life. New York: Springer, 1990.
4. Simpson R. Smart wheelchairs: a literature review. J Rehab Res Dev 2005;42:423–36.
5. Iezzoni LI, McCarthy EP, Davis RB et al. Mobility difficulties are not only a problem of old age. J Gen Intern Med 2001;16:235–43.
6. Corfman TA, Cooper RA, Dvorznack MJ, et al. A video-based analysis of "trips and falls" during electric powered wheelchair driving. Presented at RESNA Annual Conference, Reno, NV, 2001.
7. Nevitt MC, Cummings SR, Kidd S, et al. Risk factors for recurrent nonsyncopal falls. J Am Med Assoc 1989;261:2663–8.
8. Jaglal S, Sherry PG, Schatzker J. The impact and consequences of hip fracture in Ontario. Can J Surg 1996;39:105–11.
9. Prassler E, Scholz J, Friorini P. A robotic wheelchair for crowded public environments. IEEE Robotics and Automation Magazine 2001;8:38–45.
10. Levine SP, Bell DA, Jaros LA, et al. The navchair assistive wheelchair navigation system. IEEE Transactions on Rehabilitation Engineering 1999;7.
11. Tsotos JK, Verghese G, Dickinson S, et al. PLAYBOT: A visually-guided robot for physically disabled children. Image and Vision Computing 1998;16:275–92.
12. Hoey J, Mihailidis A, Gunn D, et al. Obstacle Avoidance Wheelchair System. Presented at Proceedings of the International Conference on Robotics and Automation, Orlando, FL, 2006.
13. Wang RH, Holliday PJ, Fernie GR. "Enabling safe powered wheelchair mobility with long term care residents with cognitive limitations," accepted at Twenty-third International Seating Symposium, Orlando, Florida, 2007.
14. Elinas P, Sim R, Little JJ. ΣSLAM: Stereo vision slam using the Rao-Blackwellised particle filter and a novel mixture proposal distribution. Presented at Proceedings of the International Conference on Robotics and Automation, Orlando, FL, 2006.