Wheelesley, a Robotic Wheelchair System: Indoor Navigation and User Interface

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Abstract. Many people who use wheelchairs are unable to control a powered wheelchair with the standard joystick interface. A robotic wheelchair can provide users with driving assistance, taking over low level navigation to allow its user to travel efficiently and with greater ease. Our robotic wheelchair system, Wheelesley, consists of a standard powered wheelchair with an on-board computer, sensors and a graphical user interface running on a notebook computer. This paper describes the indoor navigation system and a user interface that can be easily customized for a user's abilities.

1 Introduction

Assistive robotics can improve the quality of life for disabled people. Our goal is the development of a robotic wheelchair system that provides navigational assistance in indoor and outdoor environments, which will allow its user to drive more efficiently. There are two basic requirements for any robotic wheelchair system. First and foremost, a robotic wheelchair must navigate safely. Any failures must ***

The user tells the robot where to move using high level commands such as "forward" or "right." The robot carries out each command using its sensors and control code to safely navigate. The robot provides the low level control that most of take for granted when walking or driving. For example, when walking down a busy corridor, we are not usually aware of all of the small changes we make to our course to avoid people and other obstacles in our path. However, for users in our target community, low level control requires just as much effort as high level control. For example, it may be easy for a disabled person to gesture in the direction of a doorway, but it may be difficult for that person to do the fine navigation required to direct the wheelchair through a doorway that is barely wider than the wheelchair.

Our robotic wheelchair system is intended to be a general purpose navigational assistant in environments with accessible features such as ramps and doorways of sufficient width to allow a wheelchair to pass. We do not rely on maps for navigation, which allows the wheelchair system to be used in any accessible building. A robotic wheelchair system should not be limited to one particular location, either by requiring maps or by environment modification. The focus of this paper is indoor navigation, but we are also developing navigational assistance for outdoor use.

Our target community is comprised of people who are unable to drive a powered wheelchair using a standard joystick for control. The users vary in ability and access methods. Some people have some control of a joystick, but are unable to make fine corrections to movement using the joystick. Other people are able to click one or more switches using their head or other body part. If a person has one switch site, the user selects a direction (forward, right, left or back) by using a scanning panel. For people with more than one switch site, switches are linked directly issue to a command. Some of our potential users are currently unable to control a powered wheelchair with any of the available access devices. The wide variety of user abilities in our target community requires that the system be adaptable for many types of access devices.

While members of the target community have different abilities, we assume that all users will have some common qualities. We expect that any potential user can give high level commands to the wheelchair through some access method and a customized user interface. The user of the wheelchair will be able to see, although later versions of the system may be developed for the visually impaired. We also assume that a potential user has the cognitive ability to learn to how to operate the system and to continue to successfully operate the system once out of a training environment.

2 Related work

This work is based on previous research in robot path planning and mobile robotics. The primary focus of mobile robotics research is autonomy. However, a robotic wheelchair must interact with its user, making the robotic system semi-autonomous rather than completely autonomous. A mobile robot is often only given its goal destination and a map. The wheelchair can not subscribe to this method. The user may decide to change course during traversal of the path – as he starts to go by the library on the way to the mail room, he decides to stop at the library to look for a book he needs. The wheelchair robot must be able to accept input from its user not only at the start of the trip, but throughout the journey. When the user may have restricted mobility in his arms or may be blind, the robot should have the ability to take on a greater autonomous role, but the robot will still need to work in conjunction with the user. The user interface developed for this purpose is described below in Section x.

This research differs from previous research in robotic wheelchairs and mobile robots in at least one of four ways. First, our wheelchair system will be able to navigate in indoor and outdoor environments, switching automatically between those two control modes. Second, our reactive system does not require maps or planning. The system can be used in new locations, allowing the user more freedom. Third, we investigate the interaction between the user and the wheelchair; the wheelchair system can not be an autonomous robot. The robot should provide feedback to the user as it makes navigation decisions and should ask for additional information when it is needed. Finally, we have developed an easily customizable user interface. We are developing and testing various access methods to be used with the system.

2.1 Robotic wheelchairs

Over the years, approximately ten robotic wheelchair systems have been developed. (See [Miller, this volume] for an overview of assistive robotics.) Some systems rely on environmental modifications; these systems fail in non-modified environments. Some systems rely on maps, resulting in the failure of the system outside known environments. Some systems use only sonar sensors for navigation; the NavChair system [Simpson et al., this volume] uses a ring of sonar sensors mounted on the wheelchair tray to navigate indoor environments. The height of the sensors prevents the system from being used outdoors since it can not detect curbs. Some systems use vision; one such system uses deictic navigation [Crisman and Cleary, this volume]. The user needs to point to the desired landmark and set a series of parameters on the screen. This interface would be prohibitively difficult for many potential users.

Some of the previous wheelchair robotics research has resulted in wheelchair robots that are restricted to a particular location. In many areas of robotics, environmental assumptions can be made that simplify the navigation problem. However, a person using a wheelchair should not be limited by the device intended to assist them. While we are planning to make environmental assumptions, we will avoid the overspecialization problem by using automatic mode switching.

One example of restrictive assistive wheelchairs are systems that rely on map-based navigation. Maps may be provided to or created by the robot, but the system will perform efficiently only when a complete and accurate map is available. The system will either fail to work or work inefficiently when the robot is operating in an environment for which it has no map. If the robot can only operate efficiently in one building (as, e.g., [Perkowski and Stanton, 1991]), the user will not be able to use the technology once she leaves the doorway of the known building. Since most people need to be in several buildings during one day, this system is not general enough, although it is a step towards assistive robotics. Even more restrictive than a map-based system is that of [Wakaumi et al., 1992]. This system requires the use of a magnetic ferrite marker lane for navigation. Once the wheelchair's user leaves the magnetic path, the technology of the assistive system is useless.

Not all work in wheelchair robotics depends on modified environments or maps. In [Crisman, 1994; Crisman and Cleary, in press], a wheelchair robot navigates relative to landmarks using a vision-based system. The user of the wheelchair tells the robot where to go by clicking on a landmark in the screen image from the robot's camera and by setting parameters (such as "to the left," "to the right," in a computer window. The robot then extracts the region around the mouse click to determine to which landmark the user wishes to travel. It then uses the parameters to plan and execute the route to the landmark. The deictic navigation can be very useful for a disabled person, but a complicated menu will be difficult to control with many of the standard access methods (see section x) for people unable to use a joystick or computer mouse.

In [Simpson et al., 1995; Simpson et al., in press], the NavChair is able to navigate indoor office environments using a ring of sonar sensors placed around the front half of the wheelchair. People who are unable to drive a standard powered wheelchair have been able to drive the NavChair using sensor guidance and either the joystick or voice commands.

Gomi [Gomi and Ide, 1996; Gomi and Griffith, in press] has developed a robotic wheelchair system for indoor navigation. The system uses visual processing and is an autonomous sytem.

Another system that does not depend on environmental modifications is that of [Ojala et al., 1991]. This system is intended for wheelchair users who can not see their environment. However, the work has only been done in simulation. While simulation can provide useful design information, a simulated wheelchair can not assist anyone but a simulated user.

2.2 Mobile robotics

The navigation problem has been studied extensively in the field of mobile robotics. This project will continue to apply mobile robotics research to the particular problem of a wheelchair robot. A solution to this problem has immediate, useful real-world applications. However, the wheelchair robot has its own particular constraints that are different from the constraints of the standard robot base.

The primary focus of mobile robotics research is autonomy. However, a robotic wheelchair must interact with its user. A mobile robot is often only given its goal destination and a map. The wheelchair can not subscribe to this method. The user may decide to change course during traversal of the path – as he starts to go by the library on the way to the mail room, he decides to stop at the library to look for a book he needs. The wheelchair robot must be able to accept input from its user not only at the start of the trip, but throughout the journey. When the user may have impaired vision, the robot should have the ability to take on a greater autonomous role, but the robot will still need to work in conjunction with the user. The assisted robot should allow its user to travel more efficiently and with greater ease. To achieve these goals, the framework of mobile robotics needs to be restructured for our wheelchair domain. We need to incorporate the user into the design of the system, making the robot semi-autonomous rather than completely autonomous.

Brooks' work in mobile robotics resulted in the subsumption framework [Brooks, 1986]. In the subsumption system, many processes are running on a robot at the same time. Layers of behaviors causes the most relevant behavior to be selected at any given time while the other behaviors are suppressed. The subsumption architecture allows for robots to reactively interact with the world instead of requiring lots of planning. Since we have a human intelligence giving navigational commands to the wheelchair robot, a reactive navigation system is a good choice. The wheelchair does not need to do high level planning for navigation to be successful. The wheelchair needs to carry out the user's commands while keeping the user safe.

3 Robot hardware

Fig. 1. Wheelesley, the robotic wheelchair system.

The robotic wheelchair (Figure 1) was built by the KISS Institute for Practical Robotics [Miller and Slack, 1995]. The base is a Vector Mobility powered wheelchair. The drive wheels are centered on either side of the base, allowing the chair to turn in place. There are two front casters and a rear caster with spring suspension. The robot has a 68332 processor that is used to control the robot and process sensor information. For sensing the environment, the robot has 12 SUNX proximity sensors (infrared), 6 ultrasonic range sensors, 2 shaft encoders and 2 Hall effect sensors. The infrared and sonar sensors are place around the perimeter of the wheelchair, with a higher concentration pointing towards the front half of the chair. The Hall effect sensors are mounted on the front bumper of the wheelchair. We are currently adding additional sensors for indoor and outdoor light detection.

A Macintosh Powerbook is used for the robot's graphical user interface. The focus was on creating an interface that could be easily customized for various users and their access methods (Section 5).

4 Navigational system for indoor navigation

There are two levels of control in our system: high-level directional commands and low-level computer-controlled routines. The person using the system has the highest level of control. Once given a command by the user through the access method and graphical user interface, the computer acts to keep the wheelchair out of trouble using the sensor readings. For example, if the user instructs the chair to go forward, the chair will carry out the command by taking over control until another command is issued. The chair will not allow the user to run into walls or other obstacles. If the chair is completely blocked in front, it will stop and wait for another command from the user. If it is drifting to the right, it will correct itself and move to the left. This allows the user to expend less effort when driving the chair than a person issuing all of the necessary motor commands. It can also help to mediate for people who have trouble with fine motor control but who have the ability to issue high-level commands.

Indoor navigation relies on the infrared and sonar sensors. The Hall effect sensors mounted on the bumper are a sensing method of last resort only. The user gives a high-level command ("forward," "left," "right," "backward," and "stop") through the graphical user interface. The system carries out the user's command using common sense constraints such as obstacle avoidance. Since the user must be able to successfully navigate novel environments immediately, we navigate reactively. Maps of commonly traveled environments such as the home and the office could be incorporated, but they are not currently used in the system.

5 Graphical User Interface

A robotic wheelchair system must be more than a navigation system. While it is important to develop a system that will keep its user from harm and assist in navigation, the system will be useless if it can not be adapted for its intended users. People who can not drive a traditional powered wheelchair because they are unable to use a joystick will be unable to use a robotic wheelchair system that must be driven with a joystick. The Wheelesley system solves the adaptation problem through the addition of a general user interface that can be customized for each user.

The graphical user interface is built on a Macintosh Powerbook and can be easily customized for various access methods (see Section **??** for a discussion of access methods). We have customized the interface for two access methods. The first is an eye tracking device called EagleEyes [Gips, this volume] (Section 5.2). The second is a single switch scanning device (Section 5.3).

The original uncustomized interface is shown in Figure 2. The navigational command portion of the interface consists of directional arrows and a stop button. The user controls the standard speed of the robot by clicking on the plus and minus buttons to the right of the direction buttons. The robot may move at a slower pace than the user requests when the current task requires a slower

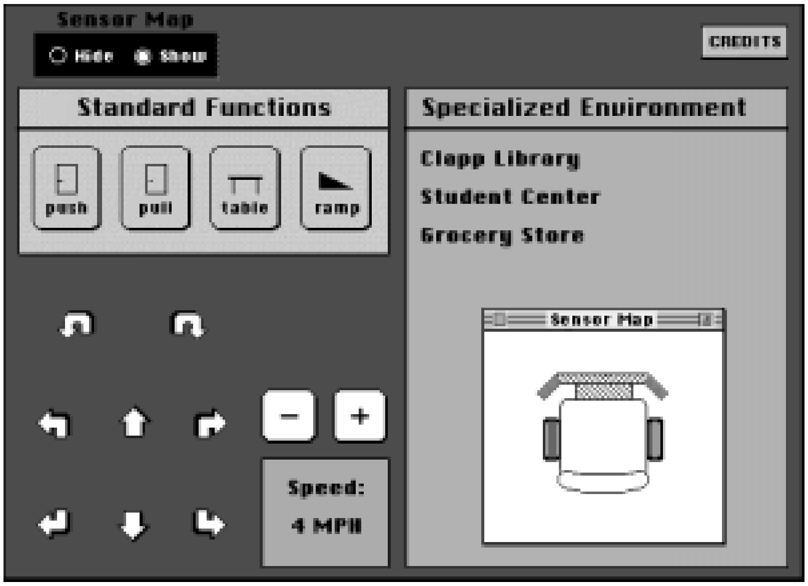


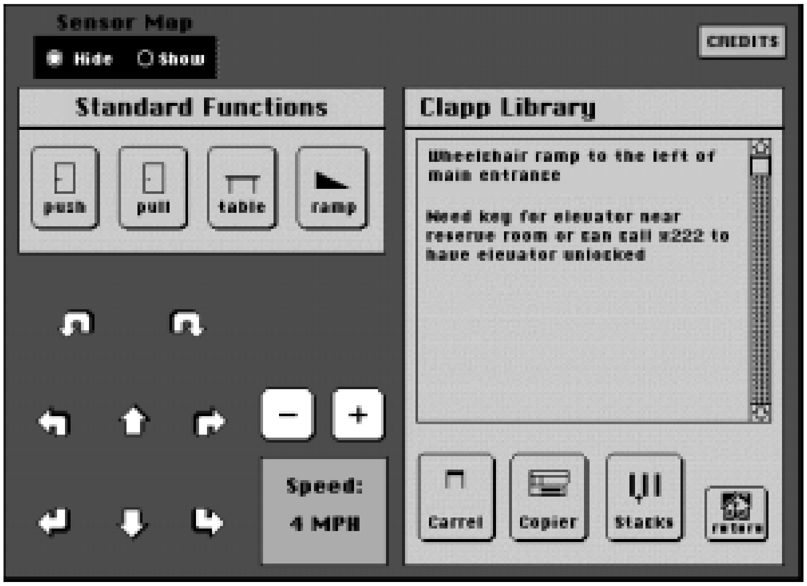
Fig. 2. The original user interface screen.

speed in order for the task to be carried out safely. The actual speed of the robot is displayed by the robot under the speed control buttons. Above the movement buttons are the "standard function" buttons. These buttons are being removed as automatic mode selection is developed.

The user can choose to hide or to show the sensor map. The sensor map shows a representation of the wheelchair. Obstacles detected by the sensors would be displayed on this sensor map. This is intended to provide a user who is unable to move his head with a picture of the obstacles in the world around him. In Figure 2, the sensor map is shown but no obstacles have been detected by the robot.

To the right of the standard functions and movement buttons is the specialized environment area. In this region, the user can tailor the system to their needs. In the system in this example, there are three specialized environments. When the user clicks on "Clapp Library", the right side of the screen changes to the specific information for Clapp Library (see Figure 3). There is a region for the user to make notes about the location of ramps, elevator locations and details about moving around the particular environment. The specialized environment area may not only be used to customize the robot to move more quickly around places the user travels frequently, but also can be used to record information such as the location of ramps in very infrequently traveled locations.

As work with access methods has progressed, features of this original interface have been determined to be too complicated for use with most access methods. Automatic mode switching instead of mode buttons is an example of a change that has been made. We include the orignial interface here to show what types



Wheelchair ramp to the left of main entrance

Need key for elevator near reserve room or can call x222 to have elevator unlocked

Fig. 3. The original user interface screen in a specialized environment.

information can be included.

5.1 Access methods

In the rehabilitation community, access methods are devices used to enable people to drive wheelcahirs or control computers. Many access methods for powered wheelchairs are currently used. The default access method is a joystick. If a user has sufficient control with a joystick, no additional assistance is necessary. These users would not be candidates for a robotic wheelchair since they are able to drive without the system. If a person has some control of a joystick, but not very fine control, joystick movement can be limited through the addition of a plate which restricts the joystick to primary directions. Users in this group might be aided by a robotic system. If they push the joystick forward, the fine control could be taken over by the robotic system.

If a user is unable to use a joystick, there are other access devices which can be employed. A switch or group of switches can be used to control the wheelchair. If a user has the ability to use multiple switches, different switches can be linked to each navigation command. The multiple switches can be placed on the wheelchair tray, mounted around the user's head or place anywhere that the user will be able to reliably hit them.

Another access method for wheelchairs is a sip and puff system. With this method, the user controls the wheelchair with blowing or sucking on a tube. If the user can control the air well enough, soft and hard sips or puffs can be linked to control commands.

If the user has only one switch site, the wheelchair must be controlled using single switch scanning. In this mode, a panel of lights scans through four directional commands (forward, left, right and backward). The user clicks the switch when the desired command is lit, then hits the switch again to stop the chair after the command has been executed for the user's desired duration. If the user is traveling forward and drifts left, he must stop, turn the chair to the right and then select forward again. This mode of driving is very slow and difficult; it is the method of last resort. Obviously, a robotic wheelchair system could help this group of users.

Most research on robotic wheelchairs has not focused on the issue of access methods. Most of the current systems are driven using a joystick (for example, [**?**], [**?**], and [**?**]). A few researchers have used voice control for driving a robotic wheelchair [**?**]. Voice control can be problematic because a failure to recognize a voice command could cause the user to be unable to travel safely. Additionally, some members of our target community are non-verbal.

5.2 Customizing the user interface for EagleEyes

EagleEyes [Gips et al., this volume] is a technology that allows a person to control a computer through five electrodes placed on the head. Electrodes are placed above and below an eye and to the left and right of the eyes. A fifth electrode is placed on the user's forehead or ear to serve as a ground. The electrodes measure the EOG (electro-oculographic potential), which corresponds to the angle of the eyes in the head. The leads from these electrodes are connected to two differential electrophysiological amplifiers. The amplifier outputs are connected to a signal acquisition system for the Macintosh.

Custom software interprets the two signals and translates them into cursor (mouse pointer) coordinates on the computer screen. The difference between the voltages of the electrodes above and below the eye is used to control the vertical position of the cursor. The voltage difference of the electrodes to the left and right of the eyes controls the horizontal position of the cursor. If the user holds the cursor in a small region for a short period of time the software issues a mouse click.

It took less than one hour to customize the user interface for use with EagleEyes [Yanco and Gips, 1996]. The user interface screen (Figure 4) has been designed to accommodate the needs of the EagleEyes system. Large buttons are easier to use with an electrode system than small ones. We have four large direction arrows and four large stop buttons. We provide four stop buttons so that the user will be near a stop button regardless of where the cursor is placed on the screen. See Figure 5 for a photo of the two systems being used together.

5.3 Customizing the user interface for single switch scanning

Single switch scanning is the access method of last resort for traditional powered wheelchairs. The control panel scans through forward, left, right and backward.

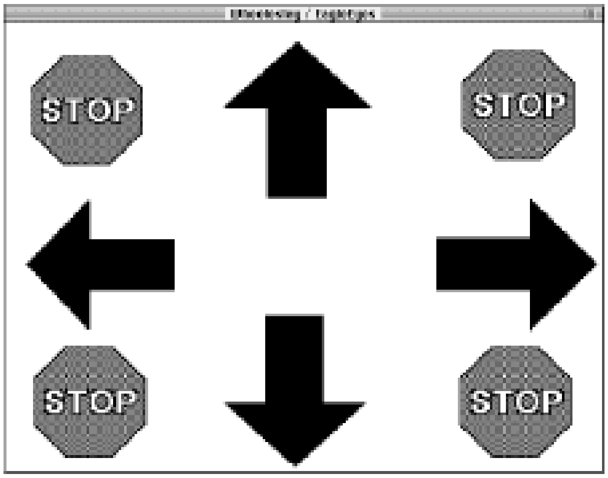


Fig. 4. The customized interface for use with EagleEyes.

The user clicks the single switch when the control panel shows the desired direction. Usually, these systems are not "latched" for forward. This means that person must keep pressing the switch as long as he wishes to go forward. Latching the system would mean the wheelchair would start going forward when the switch was pressed and would continue going forward until the switch is pressed again. This is considered too dangerous for a standard powered wheelchair configuration since the wheelchair would continue to drive if the user was unable to press the switch to stop it.

Driving under this method is very tedious. However, the addition of the robotic system makes driving much easier. The user does not need to make adjustments to avoid obstacles or to compensate for drifting towards walls while traveling down a hallway. Additionally, the system can be latched due to the safety provided by robotic control.

Customization for this access method took less than 1 hour. We are currently running user tests with able-bodied subjects to determine the amount of improvement in speed and ease of use gained through the use robotic control versus no navigational assistance.

6 Future work

– vision system – outdoor navigation – more access devices

7 Summary

This research project is aimed towards developed a usable, low-cost assistive robotic wheelchair system for disabled people. In our initial work towards this

Fig. 5. The robotic wheelchair system being driven using an eye tracking system.

goal, we have developed a graphical user interface which allows the user to communicate with the wheelchair's on-board computer. The robotic wheelchair must work with the user to accomplish the user's goals, accepting input as the task progresses, while preventing damage to the user and the robot.

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Bibliography

[Brooks, 1986] Rodney A. Brooks. "A robust layered control system for a mobile robot." *IEEE Journal of Robotics and Automation*, Vol. 2, No. 1, March 1986, pp. 14-23.

[Crisman, 1994] Jill Crisman. "Deictic primitives for general purpose navigation." *AIAA Conference on Intelligent Robots in Factory, Field, Space and Service (CIRFFSS)*, 1994.

[Crisman and Cleary, this volume] Jill D. Crisman and Michael E. Cleary. "Progress on the deictically controlled wheelchair." To appear in *Lecture Notes in Artifi-*

cial Intelligence: Assistive Technology and Artificial Intelligence, Vibhu Mittal, Holly A. Yanco and John Aronis (eds.), Springer-Verlag, 1998.

[Gips et al., 1996] James Gips, Philip DiMattia, Francis X. Curran, and Peter Olivieri. "Using EagleEyes – an electrodes based device for controlling the computer with your eyes – to help people with special needs." *Interdisciplinary Aspects on Computers Helping People with Special Needs*, Joachim Klaus, Eduard Auff, Willibald Kremser, Wolfgang Zagler (eds.), R. Oldenbourg, Vienna, 1996, pp. 77-83.

[Gips, this issue]

[Gomi and Ide, 1996] T. Gomi and K. Ide. "The Development of an Intelligent Wheelchair." In *Proceedings of Intelligent Vehicles Symposium*, Tokyo, 1996.

[Gomi and Griffith, this volume] Takashi Gomi and Ann Griffith. "Developing intelligent wheelchairs for the handicapped." *Lecture Notes in Artificial Intelligence: Assistive Technology and Artificial Intelligence*, Vibhu Mittal, Holly A. Yanco and John Aronis (eds.), Springer-Verlag, 1998.

[Miller, this volume] David P. Miller. "Assistive robotics: semi-autonomous movement towards independence." *Lecture Notes in Artificial Intelligence: Assistive Technology and Artificial Intelligence*, Vibhu Mittal, Holly A. Yanco and John Aronis (eds.), Springer-Verlag, 1998.

[Miller and Slack, 1995] David P. Miller and Marc G. Slack. "Design and testing of a low-cost robotic wheelchair prototype." *Autonomous Robots*, Vol. 2, 1995, pp. 77-88.

[Ojala et al., 1991] Jari Ojala, Kenji Inoue, Ken Sasaki and Masaharu Takano. "Development of an intelligent wheelchair using computer graphics animation and simulation." Computer Graphics Forum, Vol. 10, 1991, pp. 285-295.

[Perkowski and Stanton, 1991] Marek A. Perkowski and Kevin Stanton. "Robotics for the handicapped." *Northcon Conference Record*, 1991, pp. 278-284.

[Simpson et al., 1995] Richard Simpson, Simon P. Levine, David A. Bell, Yoram Koren, Johann Borenstein and Lincoln A. Jaros. "The NavChair assistive navigation system." *IJCAI-95 Workshop on Developing AI Applications for People with Disabilities*, Montreal, Canada, 1995, pp. 167-178.

[Simpson et al., this volume] Richard C. Simpson, Simon P. Levine, David A. Bell, Lincoln A. Jaros, Yoram Koren, and Johann Borenstein. "NavChair: an assistive wheelchair navigation system with automatic adaptation." *Lecture Notes in Artificial Intelligence: Assistive Technology and Artificial Intelligence*, Vibhu Mittal, Holly A. Yanco and John Aronis (eds.), Springer-Verlag, 1998.

[Wakaumi et al., 1992] Hiroo Wakaumi, Koichi Nakamura, and Takayoshi Matsumura. "Development of an automated wheelchair guided by a magnetic ferrite marker lane." *Journal of Rehabilitation Research and Development*, Vol. 29, No.

1, Winter 1992, pp. 27-34.