Integrating Robotic Research: A Survey of Robotic Wheelchair Development

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Abstract

The integration of solutions to small problems is necessary to solve larger ones. However, this integration does not need the consensus of the entire robotics community. Individual research groups can integrate the necessary pieces to build solutions for larger problems. Community-wide standardization may lead to research stagnation. To address the issues of integration, five of the many research efforts towards developing a robotic wheelchair are discussed.

Introduction

The goal of this symposium[1] is to move robotics research further by merging independent efforts. Much of the work in robotics has been devoted to solving narrow problems. Once these narrow problems have been solved, the community will be served by using resources to integrate all of these pieces into a larger system that can be used to solve more complicated problems.

While integrating the solutions to many smaller problems will result in a more competent system, I do not believe that this integration needs to be done as a community. In fact, I think there are many barriers to community-wide integration, including differing hardware and differing research goals. These factors will most likely not be overcome in the near future. In order to standardize hardware or software solutions, all interested researchers must agree on the best method for solving a particular problem. This could cause stagnation of research instead of promoting further research.

To study these issues, I will present some of the current research in robotic wheelchairs. Many robotic wheelchair systems are currently being developed to aid disabled people who are unable to drive a standard powered wheelchair. While each of these systems integrates many areas of prior research, there is no integration across groups. However, I do not believe that independent research efforts prevent us from finding solutions to more complicated problems. In fact, these separate efforts will be more likely to produce different solutions, allowing us to learn more about the field.

In this paper, five robotic wheelchair systems have been selected to represent the many systems being developed. The systems are the TAO Project (Applied AI Systems, Inc.), Tin Man II (KISS Institute of Practical Robotics), Wheelesley (MIT Artificial Intelligence Laboratory), the deictically controlled wheelchair (Northeastern University), and NavChair (University of Michigan). The goals, hardware systems and accomplishments of each project are presented and used as a basis for discussing how a community integration effort can be insurmountable given these goals and hardware systems.

Each research group has a their own set of requirements for a robotic wheelchair. However, they all share two basic requirements. First and foremost, a robotic wheelchair must navigate safely. Any failures must be graceful to prevent any harm from coming to the user. Second, in order for such a system to be useful, it must interact effectively with the user. Outside of these two requirements, desirable features may include outdoor as well as indoor navigation, automatic mode selection based upon the current environment and task to reduce the cognitive overhead of the user, and easily adaptable user interfaces.

Robotic systems built for assistive technology applications are usually semi-autonomous systems. This means that a solution to Artificial Intelligence does not need to be found before we can create useful applications. The challenge at this time is to build working systems that integrate many different research areas. Robotic wheelchairs require the integration of many areas of research, including vision, indoor navigation, outdoor navigation, navigation with maps, reactive navigation, mode (or behavior) selection, sensor fusion, and user interfaces. In addition to integrating many areas of research, robotic wheelchairs, like any assistive technology device, must function reliably for long periods of time and must fail gracefully.

[1] AAAI Spring Symposium on Integrating Robotic Research, Stanford University, California, 1998

Robotic Wheelchair Systems

Since we are concerned only with the issues of integrating robotic research in projects and across projects, each system discussed below is not examined for its strengths and weaknesses. These descriptions are intended to provide a basis for the following discussion of the integration of robotic research.

Applied AI Systems: The TAO Project

Applied AI Systems, Inc. has developed two robotic wheelchair prototypes: TAO-1 and TAO-2 (Gomi & Griffith In press). The goal of the TAO Project is to create an add-on system for any standard powered wheelchair that will provide a high level of autonomy.

Hardware: TAO-1 is built on a FORTRESS Model 760V (available in Canada). TAO-2 is built on a Suzuki MC-13P (available in Japan). Both systems have two processor boxes: one for vision and one for non-vision behavior. The vision system uses two CCD color cameras. There are 12 infrared sensors and several bump sensors. Commands are given to the wheelchair using a temporary keypad. The joystick is used for overriding robotic control.

The software running on both chairs varies slightly due to different properties of each commercial wheelchair. The FORTRESS Model 760V has two differentially driven wheels and two free front casters. The Suzuki MC13-P also has two differentially driven wheels, but it also has power steering for the two front casters. The casters are turned electronically whenever the wheelchair is executing a turn. This results in wider turns than those made by the FORTRESS chair. To adjust for these differences in TAO-2, the turn behaviors were modified and two side bumpers were added to protect bystanders.

Accomplishments: The robotic wheelchair performs five functions: (1) basic collision avoidance, (2) navigation in a standard office corridor, (3) passage through narrow doorways, (4) escape from crowded or tight situations, and (5) landmark based navigation. Landmark based navigation requires a topological map that needs to be created for every new environment.

TAO-1 and TAO-2 have been tested in many indoor situations. The chairs can successfully move around office environments, following the walls in a corridor while avoiding people and obstacles. There have been occasional failures, as would be expected with prototype systems. Reported failures have occurred when the chair failed to see a glass wall and when the chair had difficultly detecting other wheelchairs in a rehabilitation facility (the tubes forming the structure of the wheelchair were not detected). In a crowded gymnasium, TAO-2 was able to wander autonomously, escaping from crowded situations caused by bystanders watching the chair.

TAO-2 was also taken outdoors. The chair was tested in a snowy environment, where there were 1m walls on either side of the sidewalk. The chair navigated using its vision routines with few modifications.

KISS Institute for Practical Robotics: Tin Man II

The goal of the Tin Man project is the development of a low-cost robotic wheelchair to aid people with impaired mobility (Miller & Slack 1995). Miller and Slack point out that the focus for robotic wheelchairs, in contrast to the field of mobile robotics, is the human interface and cost issues. Two wheelchair prototypes were developed; Tin Man II is discussed here.

Hardware: The base of Tin Man II is a Vector Mobility powered wheelchair. The drive wheels are centered on either side of the base. There are two front casters and a rear caster with spring suspension. The robot has a 68332 processor on a Vesta Technologies board. There are 12 infrared sensors, 7 sonar sensors, 2 wheel encoders, and several pressure switches on a front bumper.

Accomplishments: Tin Man II has been shown to be effective in many indoor environments. There are four navigation modes for the wheelchair: (1) human guided with obstacle override, (2) turn avoiding obstacles, (3) move forward avoiding obstacles, and (4) manual mode. In the first mode, the wheelchair follows the user's joystick instructions except when an obstacle is detected. In the next two modes, the wheelchair is commanded by using two buttons. These modes also will avoid obstacles. In last mode, the joystick commands are carried out with no obstacle detection. Work is continuing on the ability to add maps to the system for commonly traveled areas.

Tin Man systems have been purchased by several research groups, including the MIT Artificial Intelligence Lab (see the next section on Wheelesley) and the University of Rochester (Bayliss *et al.* 1997), resulting in increased research in the field of robotic wheelchairs with a fairly standardized platform.

MIT AI Lab: Wheelesley

The goal of the Wheelesley project is the creation of a complete robotic wheelchair system to be used by people unable to drive standard powered wheelchairs (Yanco In press). A complete robotic wheelchair system must be able to navigate indoor and outdoor environments and should switch automatically between navigation modes for these environments. In order for the system to be useful, it must be easily customized for the access methods required for each user.

Hardware: The robotic wheelchair was built by the KISS Institute for Practical Robotics (see Tin Man II above). Wheelesley differs from Tin Man II with 4 sonar sensors instead of 7 and with Hall effect sensors on the front bumper instead of pressure switches. Additional sensors for indoor and outdoor light detection are being developed. A vision system that is being developed for outdoor navigation uses one camera and a Pentium-based notebook computer. A Macintosh Powerbook is used for the robot's graphical user interface.

Accomplishments: Wheelesley can navigate safely in indoor environments using infrared and sonar sensors. The chair can be controlled in its robotic mode by using a graphical user interface running on a Powerbook or the joystick. To demonstrate the ease of customizing the graphical user interface, Wheelesley's interface has been modified for two access methods: an eye tracking system (Yanco & Gips 1997) and single switch scanning (Yanco & Gips 1998). In both cases, the adaptation of the interface took less than one hour. Work is continuing on automatic mode selection and the vision system for outdoor navigation.

Northeastern University: Deictically Controlled Wheelchair

The goal of this project is the creation of a "gopher" robot that can be given commands easily and accurately, especially by the disabled (Crisman & Cleary In press). The robot will retrieve objects autonomously with commands from the user, either with or without the user riding in the wheelchair. The system is deictic; the user gives commands by selecting a target region on a video image of the world.

Hardware: The wheelchair base is a stripped down Invacare Arrow wheelchair – only the chair, motors and batteries were kept. The chair has a 386 PC-104 attached for control. Motion controller cards from Motion Engineering are used for the motor interface. Optical encoders measure the motion of the drive belt to detect any slipping. Ultrasonic transducers with a fan shaped beam are used on the chair. The bumper is soft foam with piezo-electric film. For vision processing, there are two cameras and a Cognex vision system.

Accomplishments: The deictic navigation system has been developed in simulation. It has been demonstrated to work in models of the real world and in randomly generated worlds. The user commands the robot by clicking on a landmark in the screen image from the robot's camera to be the target object and by setting navigation parameters in a computer window. The parameters determine the motion to be executed, the side on which the object should be located at the end of the motion, the speed that the robot should travel and the distance which should be kept between the robot and the object.

Video target tracking has been developed which has been shown to work in difficult situations (for example, when tracking a corner where both regions are the same color and material). Currently, the tracking can be accomplished at 3 frames per second.

University of Michigan: NavChair

The NavChair system developed at the University of Michigan is intended to provide mobility for people unable to efficiently drive a standard powered wheelchair (Simpson *et al.* In press). To successfully navigate indoor environments, the NavChair uses several modes and switches automatically between modes.

Hardware: The NavChair's base is an Everest & Jennings Lancer power wheelchair. There are 12 ultrasonic sensors mounted around the front and sides of a standard wheelchair tray. Robotic control is accomplished using an IBM compatible 33Hz 80486 based computer. The system can be driven using a joystick or with voice control. For voice control, a Verbex Voice System SpeechCommander is used.

Accomplishments: The system navigates indoor environments using three modes: general obstacle avoidance, door passage, and automatic wall following. In general obstacle avoidance mode, the chair maintains a safe distance from obstacles while executing the user's commands. In door passage mode, the minimum safe distance is decreased to allow the wheelchair to pass through the narrow opening. In automatic wall following mode, the system will follow a wall indicated by the user's joystick movements while avoiding obstacles in front of the chair and on the side without the wall that is being followed.

Although some users could select the proper mode quite effectively, requiring mode selection of other users is not feasible. To avoid the user-based mode selection problem, the three modes are selected automatically using a combination of knowledge of the current location on a topological map and of information about the immediate surroundings from the sonar data.

Discussion

Even with the common goal of creating a robotic wheelchair, there are many different approaches. All of the systems above are providing some form of navigational assistance, but each research group is solving different problems. The different goals are not just an artifact of the projects selected for discussion in this paper; any other set of robotic wheelchairs systems selected for discussion would have the same type of differing research goals. These differences can be caused by many factors, including different hardware and varying approaches.

The systems presented above have widely varying hardware, except for Tin Man II and Wheelesley. Putting aside the different commercial wheelchair bases that are being used, each system has different types of sensors for detecting the world. The NavChair uses only sonar sensors. The TAO Project uses a stereo vision system, infrared sensors and bump sensors. The deictic chair uses a stereo vision system, sonar sensors with a fan shaped beam, and a bumper with piezo-electric film. Tin Man II uses sonar, infrared and bump sensors. In much of the work on Wheelesley to date, the hardware configuration was similar to Tin Man II. However, even in the case of similar hardware, different approaches have been taken towards solving the problem. Using a standardized base will not lead to community-wide integration. Researchers will still take different approaches to solving the problems at hand.

As with any research area, there are many ways to approach the problem. While attempting to reach the ultimate goal, the subproblems that are solved can introduce new research ideas into the community. The systems described above take different approaches, as is reflected by the goals that each system is trying to accomplish and by the differences in navigation methods.

The TAO Project and NavChair use topological maps, but the other systems do not. (Tin Man II mentions adding the capability of using maps as future work.) Vision systems have used on the TAO wheelchairs and the deictic wheelchair. Both of their systems use two cameras for stereo vision. A one camera vision system is being developed for Wheelesley. The other two systems have no vision capabilities. Wheelchairs with no vision systems are unlikely to work in outdoor environments, which is confirmed by the indoor only operation of Tin Man, NavChair and Wheelesley (without the vision system). Standardized integration in this research area would stop lines of research that can produce interesting solutions.

Despite these independent approaches, each group has moved towards creating a working system. Differing goals can lead to expanded research in an area. If every group were solving the exact same problem in exactly the same way, there would be a reduced likelihood of the development of interesting solutions.

Sharing of results through publications is preferable to forcing the community to select a common base and to use shared code libraries. Published results may be implemented on different bases, allowing our community to create a larger research base rather than restricting it.

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References

Bayliss, J.; Brown, C.; Carceroni, R.; Eveland, C.; Harman, C.; Singhal, A.; and Van Wie, M. 1997. Mobile robotics 1997. Technical Report 661, The University of Rochester Computer Science Department.

Crisman, J. D., and Cleary, M. E. In press. Progress on the deictically controlled wheelchair. In Mittal et al. (In press).

Gomi, T., and Griffith, A. In press. Developing intelligent wheelchairs for the handicapped. In Mittal et al. (In press).

Miller, D. P., and Slack, M. G. 1995. Design and testing of a low-cost robotic wheelchair prototype. *Autonomous Robots* 2:77–88.

Mittal, V.; Yanco, H. A.; and Aronis, J., eds. In press. *Lecture Notes in Artificial Intelligence: Assistive Technology and Artificial Intelligence*. Springer-Verlag.

Simpson, R. C.; Levine, S. P.; Bell, D. A.; Jaros, L. A.; Koren, Y.; and Borenstein, J. In press. Navchair: an assistive wheelchair navigation system with automatic adaptation. In Mittal et al. (In press).

Yanco, H. A., and Gips, J. 1997. Preliminary investigation of a semi-autonomous robotic wheelchair directed through electrodes. In Sprigle, S., ed., *Proceedings of the Rehabilitation Engineering Society of North America 1997 Annual Conference*, 414–416. RESNA Press.

Yanco, H. A., and Gips, J. 1998. Driver performance using single switch scanning with a powered wheelchair: robotic assisted control versus traditional control. Submitted to *RESNA-98*.

Yanco, H. A. In press. Wheelesley, a robotic wheelchair system: indoor navigation and user interface. In Mittal et al. (In press).