The Network-Enabled Powered Wheelchair Adaptor Kit - First Prototype

Alexander Ferworn, Ankit Arora, Devin Ostrom, Wing Shiu
Network-Centric Applied Research Team
Ryerson University
350 Victoria St.
Toronto, Ontario, Canada
M5B 2K3

***Abstract*- The Network-Centric Applied Research Team (N-CART) is continuing work on a project known as the Network-Enabled Powered Wheelchair Adaptor Kit (NEPWAK). We have introduced techniques for modifying powered wheelchairs to allow tele-operation over the Internet. As a prototype version, a wheelchair was equipped with a low-power laptop computer, CCD camera and wireless network card. Custom circuitry was supplied to allow control signals to be sent by the laptop to the chair's control circuit. The laptop acts as a server allowing network clients to gain access through a custom control interface that includes a video feed from the wheelchair.**

I. INTRODUCTION

Data services have become available for wireless networks. Starting with relatively simple applications, such as email they have progressed to far more complex applications involving video and control.

The desire to use more and more services across digital networks has driven the inevitable evolution of these networks, supporting increased bandwidth on wireless access networks. With the introduction of the 802.11b wireless standard [1], in-building access points have become increasingly common as institutions such as Universities, hospitals and even certain restaurants find them a viable alternative to rewiring older buildings.

the "Americans with Disabilities" Act [2] was passed by the U.S. congress to protect handicapped individuals from discrimination by private employers. The law requires that public buildings and mass transportation systems meet accessibility guidelines. Over time, the act has provided new opportunities for individuals confined to wheelchairs. This act, combined with improvements to wheelchairs [3], has provided many more people with the ability to move around their environments.

A. WHEELCHAIR INNOVATION

Research involving the use of a powered wheelchair as a mobility platform has taken place by various groups with various goals. Most endeavors relate to augmenting the mobility of the chair's occupant through the use of sensors providing input to on-board semi-autonomous or fully autonomous control systems. Typical of this approach is [4] demonstrating a low-cost robotic system in their "Tin Man" project. The system allows a rider to use various modes of control that employ several "behaviors" to navigate in an indoor environment.

The "Wheelesley" project [5] demonstrated a system with the goal of creating a complete robotic navigation system for both indoor and outdoor movement. The "NavChair" system [6] was developed with the goal of providing mobility to people who are unable to drive a standard wheelchair. To accomplish this the system employs automatic obstacle avoidance, wall following and door passage navigation techniques. Additional work has been carried out by [7] [8].

Additional work has focused on replacing the conventional joystick control with other control mechanisms more suited to the specific disability of the chair's occupant. A summary of recent work can be found in [9].

At N-CART, within the NEPWAK project, we have started an investigation into using powered wheelchairs as mobile platforms for communication and remote control. Our first effort has concentrated on providing control and video services for our lab's test wheelchair.

B. WHY

As populations grow older, providing assistance to increasing numbers of people in centralized facilities such as retirement or extended care facilities has become problematic. There are not enough facilities nor are there sufficient personnel to provide the services necessary for an ever aging population. Governments hope to reap the benefits of encouraging the elderly and the disabled to live independently [10][11][12][13].

We believe one way of assisting those in their own homes might be to provide "on demand" services that allow interaction with, and assistance from, remote care providers. Currently such services are intermittently available through visiting nurses, friends, relatives and similar aides.

A Potential scenario consists of a remote care provider monitoring the wheelchair's owner during various activities such as taking or applying medication, changing dressings, etc. In these cases, the wheelchair's camera could be used by a remote observer and aid its dismounted passenger.

II. CONCEPTUAL SYSTEM

Our system relies on existing wheelchair technology components. In essence, we have attempted to retrofit existing differential drive wheelchairs. In addition we rely heavily on experience gained in the MAX WWW robot project [14][15][16]. We also draw on concepts related to Internet Appliances as discussed in [17].

The NEPWAK provides a control adaptor interface between the joystick used by the wheelchair passenger and the wheelchair's internal controller. A laptop computer employs the adaptor to send control signals to the wheelchair through the parallel port. The laptop communicates via a wireless network and is sent control instructions from a remote computer. Feedback is provided to the remote operator via an onboard camera. The conceptual design of the system is shown in fig. 1.

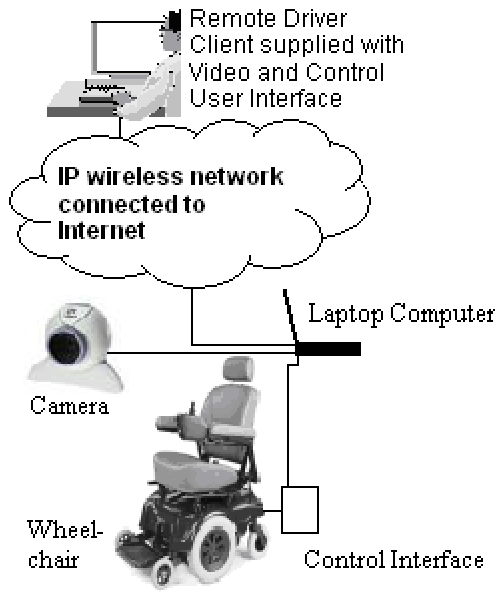

Fig. 1 System Conceptual Diagram

A. The Chair

We employ the chassis of a Fortress Scientific powered wheelchair. Similar wheelchairs are in common use throughout Ryerson's campus. Although the platform is quite old, it was sturdy, robust and most importantly available.

The seat has been removed in order to provide a clear area for prototyping our system. The wheelchair alone and being remotely driven are shown in the figures below.

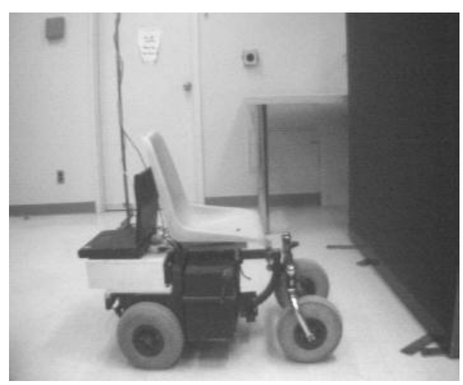

Fig. 2 Prototype Wheelchair

Fig. 3 NEPWAK in a busy hallway

B. Laptop Server and Control Interface Adaptor

The onboard laptop computer communicates with Ryerson's campus-wide wireless network through an appropriate network card. Once online, a remote computer can connect to the wheelchair by running a terminal service client software based on the Windows 2000 operating system. After the wireless connection to the wheelchair is established, the laptop serves a video stream to the connected client. In addition, the laptop accepts the control commands from the client and sends appropriate control data to the parallel port.

Fig. 4 Laptop Controller

The parallel ports' 8 bit data port is divided into two 4 bit words. Two 4 bit Digital to analog converters (DAC's) were connected to these data ports and the DAC outputs, after appropriate signal conditioning, were connected to the left and right motor control lines. The wheelchair enable was connected to pin 1 of the parallel port (bit C0 of the control lines) through an op-amp signal conditioner.

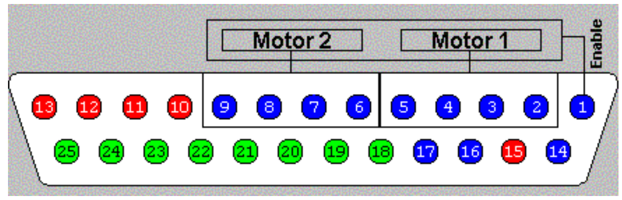

Fig. 5 Motors to parallel port connection

C. Network and Video

Network access was provided via an IEEE 802.11b wireless interface card communicating with Ryerson's campus-wide wireless network. The laptop server communicates with the controlling client via a fixed IP address--valid across the entire campus. As the wheelchair moved between network "hot spots", it could re-establish communication with the controlling client without being supplied with a new network address.

The video stream was provided via a USB connected CCD camera. For test purposes, the camera was mounted on a mast above the wheelchair's passenger and was aimed to allow a field of view several meters beyond the front of the wheelchair and included a view of the forward extremities of the wheelchair's occupant to provide the remote operator contextual information.

Fig. 6 Camera and Wireless Network Mast

D. The Interface

We developed a human interface for the NEPWAK as illustrated in the diagram.

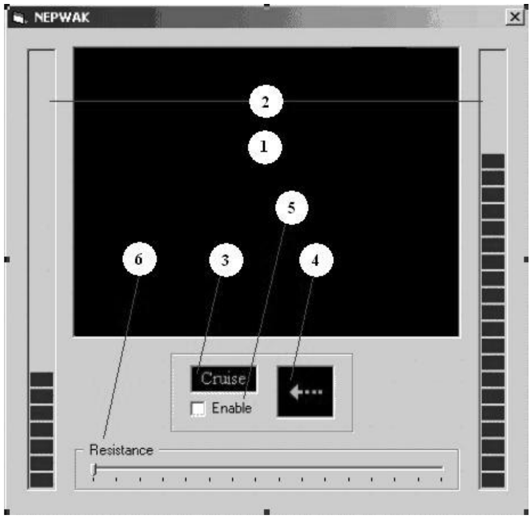

Fig. 7 User Interface

Item 1 is one of the status bars indicating the power levels of the wheelchair's left and right motors. Here, the right motor is being supplied with more current than the left, thus running faster. Item 2 is the video display from the video feed coming from the wheelchair's camera. We have provided a "cruise" setting in item 3, allowing the remote driver to continue moving in a certain mode. Item 4 is a direction indicator, here the wheelchair is turning left. Item 5 is an "enable" switch, when it is checked power to the wheelchair motors is turned on. Item 6 is the resistance slider bar described allowing a degree of momentum to be simulated in the motor responses.

III. THE TRIAL

The goal of the first test of our system was to demonstrate that the remote driving of such a system was at least feasible. Our intent was to remotely control the occupied wheelchair from an internal office to a student lounge approximately 200m from the starting location.

The test was performed on a heavily used floor of Ryerson's Rogers Communication Centre. The hallway selected was in constant use by students exiting and entering a series of labs along its length. Two network "hot spots" were located near the middle and start of the hallway we used, providing the wheelchair connectivity throughout the test.

Over a period of about thirty minutes, the wheelchair was maneuvered from the office to the goal location.

Fig. 8 Achieving the Goal

While we managed to complete the course, we experienced several problems with the system. We had anticipated many of the concerns expressed in [18] however we also observed several other system shortcomings. We will discuss these in the sections below.

A. Signal Reduction and Loss

Because we were testing the system in a hallway served by two network transceivers, there was a transition zone between the transceiver base stations that became a source of difficulty for our system. The problem is related to signal handoff. While cellular networks commonly employ techniques for handing off calls to the next cell [19][20] there is no similar concept for a wireless data network that is designed to serve mostly sedentary laptop users.

The network transceiver we employed connects to the access point that exhibits the strongest signal and keeps communicating with that access point. No rescanning of signal strength occurs until a connection is dropped. As the wheelchair traveled further away from the first network hot spot, the signal strength diminished and the network delay became far more pronounced until the signal was lost. However, this did not occur until the wheelchair had come to a complete halt. This is problematic if the system is to be used across many hot spots as each transition would require an extended halt as communications are reestablished with a new transceiver base station.

B. Human Interface

The two motor strength bars did not indicate the actual speed of the motors but instead indicated the amount of voltage allocated to each. When our driver saw the bar of each motor increasing on the user interface, they assumed that the speed of the chair was relative to the height of these bars. This was not the case and ended up being rather disconcerting since there is no other indication of wheelchair speed other than what could be surmised from the video feed. This was of particular concern when signal strength was weakest and timely video feedback was minimal.

C. Physical Plant

Another problem we faced was related to the physical plant of the wheelchair. Our trial chair employs freely turning castor wheels on the front of the chair--as do many other powered chairs. If the driver wished to go straight after turning the wheelchair, the castors would still be in the turned position, as a result the castors would carry the wheelchair in that direction until it had traveled a sufficient distance forward to straighten the castors out thus unexpectedly skewing the path of the chair. This became a source of concern, as the remote driver could not see the castors in the video feed.

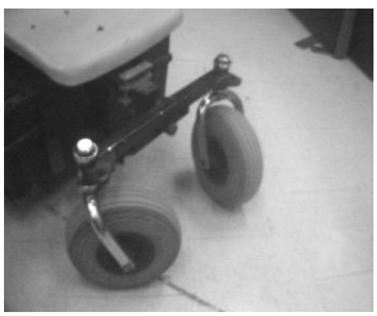

Fig. 10 Castor wheels on the front

D. Inadequate Visual Information

Because we employed a single camera the remote driver was provided with minimal information about the path the wheelchair was following. In fact, the chair's camera was pointed so as to provide a view several meters beyond the chair. This was done for collision avoidance purposes.

Despite the help the driver received from assistants and the fact that the driver was very familiar with the hallway, the chair had several collisions with walls, people and the safety rails of the path. Clearly this is an area requiring additional work.

Fig. 9 Unexpected Collision

IV. FUTURE WORK

We believe the techniques demonstrated in our NEPWAK trial can be extended to other domains using powered wheelchairs as highly reliable tele-operated devices.

In the future we intend to extend this work through the introduction of MAX technology in order to make communication and control more robust and reliable.

In addition, it has become clear that it is desirable to make provisions for connections to secondary networks through the use of existing cell phone networks. This could potentially mitigate the signal loss problem and avoid concerns over wheelchairs being "stranded" due to do dropped connections.

While our interface worked reasonably well, it did not allow for manual joystick override, nor did it have good low speed resolution. These areas will be addressed in later work.

An area which we believe might have considerable applicability is that of intelligent network support subsystems related to doorway access as discussed in [21] and [22]. These could be employed to provide assistance to wheelchair passengers having difficulty maneuvering in certain passageways on an "on demand" basis.

REFERENCES

[1] For IEEE standard see http://grouper.ieee.org/groups/802/11/index.html

[2] U.S. Department of Justice, Civil Rights Division, Disability Rights Section booklet, "A Guide to Disabilitiy Rights Laws", August 2001, available from http://www.usdoj.gov/crt/ada/publicat.htm.

[3] Woods, B. and Watson, N. "Missing Histories: The Development of the Wheelchair during the 20th Century", BON Issue 26, Autumn 2002: 50.

[4] Miller, D.P., and Slack, M.G. 1995. "Design and Testing of a Low-cost robotic wheelchair Prototype", Autonomous Robots, 2:77-88.

[5] Yanco, H.A., and Gips, J. 1998. "Driver performance using single switch scanning with a powered wheelchair: robotic assisted control versus traditional control.", Proc. of the Rehabilitation Engineering and Assistive Technology Society of North America Annual Conference (RESNA '98), pp. 298-300, RESNA Press, 1998

[6] Simpson, R.C.; Levine, S.P.; Bell, D.A.; Jaros, L.A.; Koren, Y. and Borenstein, J. "Navchair: an assistive wheelchair navigation system with automatic adaptation", In Assistive Technology and Artificial Intelligence. V,I, Mittal, H.A. Yanco, J.Aronis, and R. Simpson (Eds), Springer-Verlag Berlin, Heidelberg, 1998..

[7] Madarasz RL, Lorren C, Cromp RF, Mazur NM. "The design of an autonomous vehicle for the disabled", IEEE J Robot Automat 1986;RA-2(3):117-26.

[8] Chase, J., Bailey D.M. , "Evaluating the potential for powered mobility". Am J Occup. ther.. 1990;44(12):76-9.

[9] Yanco, H.A., "Integrating robotic research: a survey of robotic wheelchair development", AAAI Spring Symposium on Integrating Robotic Research, Stanford, California, March, 1998.

[10] Larsson, A., "Europe: an Active Society for all ages, for all Europeans", speech given at the Finish Presidency Conference on Independent Living for Elderly and Disabled People, Helsinki, 6-7 October 1999, available at http://europa.eu.int/comm./dg05/index_en.htm.

[11] Active Living Alliance for Canadians with Disabilities pamphlet, July 12, 2002, "Specialized Equipment with Low Cost Modification ideas". Available from http://www.ala.ca/pdf/SpecializedEquipment.pdf

[12] McMaster, G., "Helping the Elderly Stay Active", University of Alberta Folio Newsletter, Jan 29, 1999

[13] Report of Group of Organizations Concerned with the Future of Long Term Care, "Long Term Care-In Limbo or Worse", May 2001, available from The Ontario Coalition of Senior Citizens' Organization at http://www.ocsco.ca/.

[14] Ferworn, A., Roque, R., and Vecchia, I., "MAX: Teleoperated Dog on the World Wide Web", Proc. of the 2nd International Workshop on Presence, The University of Essex, Colchester, UK, 6-7 April 1999.

[15] Ferworn, A., Plataniotis, K., "Effective Teleoperation Over the World Wide Web", Proc. of the IASTED International Conference for Robotics and Applications (RA'99), Santa Barbara, USA, October 28-30, 1999.

[16] Ferworn, A., Roque, R., and Vecchia, I., "MAX: Wireless Teleoperation via the World Wide Web", Proc. of the 1999 IEEE Canadian Conference on Electrical and Computer Engineering, Edmonton, Alberta, Canada, May 9-12 1999.

[17] Ferworn, A., Torres, B. D., Patel, S., Kanellis, S., "The Internet-Enabled Furnace", Proc. of the IASTED International Conference for Intelligent Systems and Control (ISC'01), Clearwater, Florida USA, November 19-22, 2001.

[18] Ferworn, A., Coleshill, J.E., "Challenges for Mobile Internet Appliances", Proc. of the IASTED International Conference for Robotics and Applications (RA'01), Clearwater, Florida USA, November 19-22, 2001.

[19] Rappaport, S.S., "Models for call hand-off schemes in cellular communication networks, Third generation wireless information networks", Kluwer Academic Publishers, Norwell, MA, 1992

[20] Acampora, A., and Naghshineh, M., "An architecture and methodology for mobile executed hand-off in cellular ATM networks", IEEE Journal on Selected Areas in Communications (October 1994) 1365-1375.

[21] Ferworn, A., Shiu, W., Lu, W., "Constrained Image Understanding Using Lossy Compressed Images", Proc. of the IASTED International Conference for Robotics and Applications (RA'01), Clearwater, Florida USA, November 19-22, 2001.

[22] Ferworn, A., Shiu, W., Plataniotis, K., "Constrained Image Understanding for an Internet Robot Supporting Telepresence", Proc. of the 2001 IEEE Canadian Conference on Electrical and Computer Engineering, Toronto, Ontario