Telebotic Control of a Powered-Wheelchair across the WWW -- NEPWAK

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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 telebotic control via wireless network from a wide variety of computing devices with access to the World Wide Web.

Keywords: Telebot, wheelchair, wireless, distributed system, system architecture

1. INTRODUCTION

With the passing into law of the Americans with Disabilities Act of 1990 (ADA) [1] the United States Congress set the stage for improved access to public buildings for people in wheelchairs. Unwittingly, they also improved the accessibility of these buildings to telebots. We have taken advantage of the legislated improvements in building ergonomics to deploy telebots based on commonly available differentially driven electric wheelchair platforms.

There are many advantages in employing wheelchairs as robots and many investigators have suggested their use in a wide variety of ways. They have been reported as adjuncts to other assistive devices [2]. Others have instilled various levels of autonomous behavior [3][4]. Some have attempted to improve the human factors associated with their control [5]. We use them because they are common and they are what people use to move around within buildings.

At the Network-Centric Applied Research Team (N-CART) we have taken a systems approach in deploying telebots. We seek to integrate wheelchairs into a building's support systems. We use existing infrastructure to support the movement of the wheelchairs through hallways, access points and elevators. We use wireless networks to provide communications for off-board support systems, thus making an electric wheelchair into a functional wireless video telebot, controllable from a distance through a wide range of networked computing devices. The transformation is accomplished through our experimental Network-Enabled Powered Wheelchair Adaptor Kit (NEPWAK).

2. MOTIVATION

While we believe there are many applications for wireless wheelchair telebots, we have focused on the provision of remote assistance to the occupants of the chair. As populations within first world countries grow older, providing assistance to increasing numbers of people in retirement or extended care facilities is rapidly becoming problematic [6]. There simply are not enough facilities, nor are there sufficient personnel to provide the services necessary for an ever aging population. Many governments hope to reap the benefits of encouraging the elderly and the disabled to live independently as much as possible [7][8][9].

One way of assisting otherwise confined people 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. With remote services, it might become easier to maneuver in particularly difficult or complex circumstances or provide assistance in an emergency.

One potential scenario involves remote care providers monitoring the wheelchair's occupant during certain activities such as the taking or applying of medication. These services could potentially be provided via a remotely driven wheelchair equipped with cameras and microphones. In essence NEPWAK could be to wheelchairs what the popular [10] "OnStar" [11] service is to cars. Essentially, NEPWAK provides telematic services to wheelchairs with remote control capability.

3. ARCHITECTURE

In order to provide remote telematic and telebotic services, we have developed a novel, robust and distributed architecture for our wheelchair systems.

The NEPWAK architecture is focused on 5 areas;

1. mobility,
2. communication,
3. interface,
4. computation and
5. assistive services.

The architecture is dependent on aspects of each area being available both locally--on the chair--and exhibited within the environment of the building. For example, we rely on the wheelchair as the primary provider of system mobility, however, we assume that the environment has been appropriately equipped with handicapped access facilities such as embossed door buttons, ramps and similar aids.

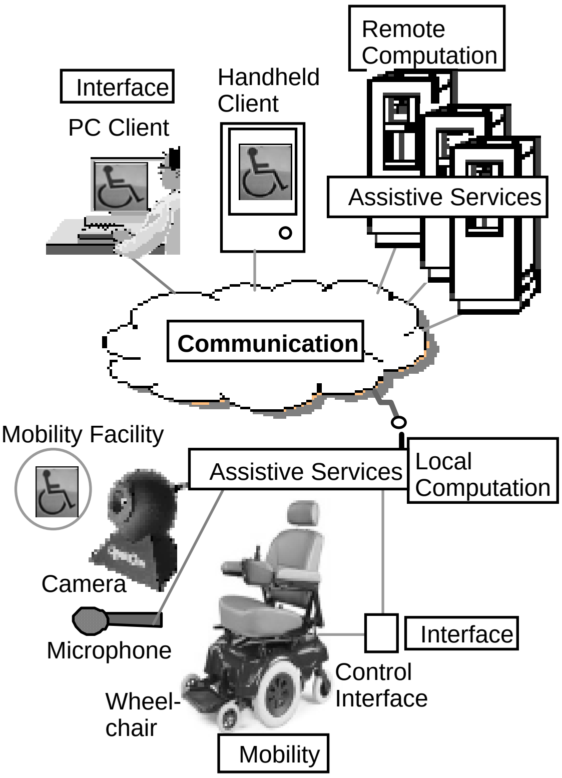

Figure 1 Abstract NEPWAK Architecture

3.1. Mobility

Currently we have deployed NEPWAK on a Fortress Scientific wheelchair acting as our primary test vehicle. Although the platform is quite old, it is a very reliable device and there are many still in service. For the purposes of testing, we have stripped the vehicle of all human niceties and replaced them with mounting surfaces to accommodate potential sensor arrays.

Figure 2 Stripped Wheelchair before NEPWAK

Figure 3 NEPWAK-equipped Fortress Wheelchair and Rider

3. 2. Communication

We rely on the IEEE 802.11b WiLan standard for providing basic communication services for our chair. We employ a WiLan transceiver to connect the telebot to the Internet. All video, audio and control signals are made available through this bi-directional link.

Figure 4 WiLan transceiver on CCD Camera Mast

Video and audio are collected through off-the-shelf digital USB connected components. While the communications network provides sufficient bandwidth for our purposes, one of the concerns we continue to wrestle with is the catastrophic loss of communication.

3.3. Interface

One of the concerns we had while developing the interface was to provide a failsafe mechanism in the event of loss of communication with the wheelchair. That is, there should be a way to override the last command issued before the connection was lost in order for the wheelchair to return control to the passenger or at least stop safely. We achieve this through the use of a concept we call “resistance”.

Our notion of resistance provides a tendency to keep the wheelchair stationary. That is, it provides deceleration to any motion command. If a user presses any of the motion on their remote keyboard, this feature decelerates the resulting motion. Hence the moment the user releases the key, the wheelchair comes to a gradual halt.

We have made the interface available on a wide variety of remote computing devices including traditional workstations and various handheld devices based on the Windows CE and the Palm Operating Systems [12][13].

Figure 5 Generic Remote Interface

3.4. Computation

Our current prototype for NEPWAK employs a laptop computer running the Windows XP Embedded operating system. The laptop is responsible for all video and audio throughput and the smooth transmission of control information to the wheelchair’s motors through a custom interface circuit to the chair’s joystick port. The laptop acts as a server so that network clients can communicate with and control the chair remotely.

In our test wheelchair, the motor control voltage is an analog control signal used to control the power to the relevant drive motors. The control is scaled so that when the motor control voltage (MCV) is at approx. 5.85VDC the motor is in an OFF state. Increasing the MCV above 5.85VDC proportionally drives the associated motor forward up to a maximum MCV voltage of 8.5VDC (this corresponds to an approx. 100% duty cycle being applied to the motor PWM drive circuit). Decreasing the MCV below 5.85VDC causes the associated motor to be proportionally driven in the reverse direction.

By controlling these MCV's the wheelchair's motion can be controlled. For the computer interface, the parallel ports' 8 bit data port was broken up into two 4 bit words. Two simple 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 hand and right hand motor control lines. The wheelchair enable was connected to the "Clear to send (C0)" bit of the parallel port through an op-amp signal conditioner.

Additional computing services are available on the network for remote assistant tasks as outlined in the next section.

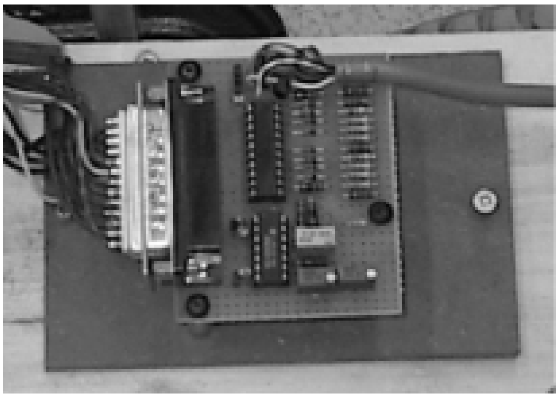

Figure 6 Serial Port to Joystick port converter board

Figure 7 Laptop N EPWAK Server

3.5. Assistive Services

In order to accommodate the traversal of all paths possible in an ADA compliant building, certain additional services have been envisioned to aid remote operators. The first service we have instantiated is designed to aid remote operators in opening internal doors using provided handicapped access buttons.

In order for a vehicle to move through a closed door, the door must first be opened. While the chair may be capable of pressing a handicapped access button by simply running into it, the task is surprising difficult to accomplish remotely. To help in this endeavor we have created a remotely executed autonomous recognition and activation service complemented by a local repositioning system. A prototype of this system is shown below. Once a user asks that a door be opened the local and remote systems cooperate to recognize the handicapped access button, through a form of constrained image recognition [14].

This is a difficult task at the best of times but we rely on a repositioning system that automatically aligns the wheelchair orthogonally to the surface the handicapped access button has been mounted on. This, with the regularity of the button’s design, increases our probability of successfully identifying a handicapped access button within a frame taken from the robots video stream by a remote recognition server. If a button is indeed found in the image the chair is again repositioned to press the button. A prototype of the system is shown in the figure below. [15].

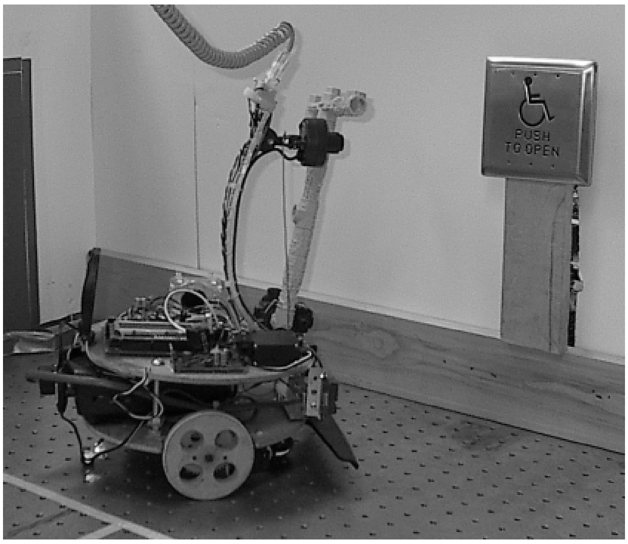

Figure 8 Constrained Image Understanding and Repositioning Prototype

In the future we must instantiate several more services to make the system robust. A similar service will be designed to manipulate elevator buttons in order to allow NEPWAK chairs to move between floors.

Because of the distributed nature of the services it may be possible to add components for automatic path planning or other more traditional services at a later time.

4. INITIAL RESULTS

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 approximately thirty minutes, the wheelchair was maneuvered from the office to the goal location.

Figure 9 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 [16] however we also observed several other system shortcomings. We will discuss these in the following section.

4.1. Litany of Woes

Because we were testing the system in a hallway served by two network hot spots, 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 [17][18] 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 the connection is actually dropped. As the wheelchair traveled further away from the first network hot spot, the signal strength kept dropping and the network delay became more and more pronounced until the signal was lost completely. However, this did not happen until the wheelchair had come to a complete halt. This is a problem if such a system is to driven across many hot spots as each transition would require a corresponding extended halt as communications are reestablished with a new transceiver base station.

Some of the problems we faced were related to the physical plant of the wheelchair. Our trial wheelchair 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 thus unexpectedly skewing the path of the chair. This became a source of concern as the remote driver could not see the castors in their video feed.

We also observed that traveling in a straight line was rather difficult to accomplish. When traveling forward, the driver was required to constantly make small adjustments towards the left or the right to try to straighten out the chair. The problem was compounded if there was any network delay as the chair would continue to veer off course while the remote driver remained unaware of what was happening.

One of the more pressing problems faced by the remote drivers was the extremely limited visual field available from the CCD camera. We had purposely aimed the camera forward and down after we discovered that the remote drivers complained of a loss of context if they could not see a component of the chair in the video image.

Unfortunately when the camera was repositioned the driver could only see approximately two meters in front of the chair. While this proves adequate for avoiding collisions it does not provide enough context for navigational purposes. In other words, if our drivers had not known the floor plan well they would have been unable to find their way through the building.

Another aspect of the visual field problem was related to interacting with physical objects to either side of the chair. Since the driver could not see these components of the environment, we observed several collisions that went unnoticed by the driver.

Figure 10 Unexpected Collision

While these collisions were annoying they did not have the potentially dire consequences of approaching a set of stairs acutely--another concern that is not well addressed by our current camera system.

4.2. The Promise of Success

Despite many problems the task was eventually accomplished. The physical communication system provided sufficient throughput to complete the task, the computing elements employed provided the functionality we required and, with experience, the drivers reported that they felt more in control the more they used the system.

5. FUTURE WORK

We believe the techniques demonstrated in our NEPWAK trials can be extended to other domains using common powered wheelchairs as highly available and reliable tele-operated devices. We are adapting techniques gleaned from our experience with the MAX [19] and WAX [20] projects in order to make communications and control more robust and reliable. Our initial results indicate a great deal of promise for assistive services distributed remotely on the available network.

We are endeavoring to reduce the size of NEPWAK components and simplify their interaction. We will be replacing the current laptop-based server with a far smaller and more cost effective embedded device based on the PC104 standard. This will reduce the package size of the control hardware and make it possible to more easily accommodate its physical footprint on a wider range of chairs.

We are working to replace the existing commercial CCD video camera system with an array of several cameras arranged to allow panoramic video viewing in real time. We intend to employ a system developed within N-CART and described in [21] that takes advantage of panoramas of multiple images being stitched into a single video stream. This will allow for greater flexibility for the driver as they can pan and tilt their point of view through software manipulation rather than through selecting different video streams. In essence, the bandwidth utilization will be virtually identical to our current prototype but a seamless video panorama will be available to the driver.

One of the concerns that plague most wireless applications is the loss of communications. It has become clear that it is desirable to make provisions for connections to secondary networks through the use of existing cell phone services. This could potentially mitigate the signal loss problem and avoid concerns over wheelchairs being left “stranded” due to communication failure.

We have started work on providing a sensor skirt and providing a local reactive system to deal with various problems including avoidance of collisions with environmental objects, wall following support for hallway traversal and emergency precipice avoidance.

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

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