Pocket PC Beacons: Wi-Fi based human tracking and following

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ABSTRACT
The Network-Centric Applied Research Team (N-CART) is continuing its work on an ambitious project known as the Network-Enabled Powered Wheelchair Adaptor Kit (NEPWAK) [25]. It introduces techniques for modifying and using powered wheelchairs as mobile platforms enabling communication and remote control. The wheelchair runs a PC104 based embedded server allowing both PC and PocketPC clients to connect in either infrastructure or ad-hoc mode. The clients receive audio, video and other sensory feedback from the wheelchair and can send control data for maneuvering the wheelchair. In this paper we present our preliminary work on a novel, inexpensive and coarse 'Human Tracking and Following' system for NEPWAK. Our approach uses a custom built highly directional steerable Wi-Fi antenna on the wheelchair that scans the Wi-Fi signal strength of its peer. This can be used to track and follow a person carrying a Wi-Fi enabled pocketPC.

Categories and Subject Descriptors
C.3 [**Special-Purpose and Application-Based Systems**]: *real-time and embedded systems*; J.7 [**Computers in other systems**]: *command and control*.

General Terms
Measurement, Experimentation, Human Factors.

Keywords
Human Following , Pocket PC, Wheelchair, 802.11x Wi-Fi.

1. INTRODUCTION
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 [13]. Others have instilled various levels of autonomous behavior [18,4]. Some have attempted to improve the human factors associated with their control [17].

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 [23]. 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 [2]. 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 [3,21,8].

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. One potential scenario involves remote care providers monitoring the wheelchair's occupant through the onboard camera and/or through real time data from medical equipment onboard. In essence NEPWAK could be to wheelchairs what the popular "OnStar" [22] service is to cars.

In another scenario, hospitals and elder care facilities can have a central control facility to monitor and control wheelchairs on their campuses. Also, medical personnel or supervisory staff, carrying Wi-Fi enabled pocketPCs, can form ad-hoc connections to a wheelchair and provide services such as downloading data from onboard medical equipment or maneuvering the wheelchair in cases where remote assistance is necessary. It is during maneuvering operations that NEPWAK's coarse human following ability could provide semi-autonomous assistance to medical personnel or supervisory staff. This capability could also be helpful for the individuals who are able to leave the confines of the chair for periods of time, but would find it beneficial to have the chair near at hand when necessary.

In our approach we use 802.11b Wi-Fi enabled pocketPCs as beacons. A custom made highly directional and steerable antenna on the wheelchair scans the received signal strength (RSS) from the connected pocketPC. RSS values are sampled at every 3.6° during each scan covering 120 degrees. Roughly, the angle at which peak RSS value occur providing directional information while the magnitude of the peak signal strength can measure the distance from the pocketPC.

2. RELATED WORK

The need for tracking and following a person with a mobile robot arises in many different service robot applications. Scenarios for a manned mission to Mars call for astronaut extravehicular activity teams to be accompanied by semi-autonomous rovers. These rovers must be able to safely follow the astronauts over a variety of terrains with minimal assistance [9]. Another application is the use of mobile robots as tour guides in scientific laboratories or museums [20].

Much work in the field of person tracking and following is based on vision systems [12,7,19]. However, following a human at a "natural" gate of about 1.4 m/s is a very challenging task. Previous research in autonomous navigation and obstacle avoidance using stereo vision could achieve maximum speeds around 0.5 m/s [16]. Color blob tracking [6] has proved to be a simple and fast vision process. But regardless of the method, all vision systems suffer from some common problems as extensive memory usage, and changes in lighting may invalidate vision data. The tracking target can be occluded, and background clutter can reduce preciseness. Also, in a crowded environment distinguishing one human from another is a formidable task.

Tracking people based on laser data is becoming ever more popular because of its accuracy and fast data processing, especially compared to vision [1]. Although a very good sensor, a big disadvantage of the laser is that it requires the target to be within range and line of sight. Another major problem is the difficulty in target discrimination.

Person tracking with a mobile robot is a highly dynamic task. The sensory perception of a human subject is constantly changing as both the human and the robot might be moving. Some researchers have therefore fused data from multiple sensors for human tracking. For example, [1] tracks people based on vision and laser range data. In [10] data queues from Laser, GPS and stereo vision are fused to obtain the final pose. Using multiple sensors, although improving redundancy and reliability, require increased processing power and resources.

Human tracking techniques employing active beacons [5,11] (Infrared, Ultrasonic etc.) on the human body are simpler yet not widely supported. They are considered 'obtrusive' since they require people to carry a dedicated beacon device. Their biggest advantage however, is that they greatly simplify target discrimination as each beacon can transmit a unique identifier signal. Our approach is similar except that the chair's occupant (for self-monitoring) or the medical staff carries a pocketPC instead of a dedicated beacon. We believe carrying a pocketPC is not obtrusive. With the advent of the Wi-Fi technology, pocketPCs are commonly used as mobile communication device, organizers and also as music players.

To date, we are unaware of any investigation focused on human tracking & following using Wi-Fi devices as sensors and beacons. However there has been considerable research in the field of location estimation of mobile robots based on Wi-Fi received signal strength (RSS) maps. Generally, the technique involves building the RSS maps by profiling the site. Then for location estimation, the client reports its RSS measurements that are compared against the RSS model to locate it [15,14].

3. NEPWAK – CONCEPTUAL SYSTEM

Our system relies on existing wheelchair technology components. In essence, we have attempted to retrofit existing differential drive wheelchairs with telebotic components. The wheelchair is equipped with a PC104 Single Board Computer (SBC) running Windows XP Embedded, a CCD camera, microphone and an WiLan network card – connected to a steerable external directional antenna *(see figure 1)*. A PIC microcontroller custom circuit was supplied to interface the SBC to the chair's motor control circuit. The SBC runs a Microsoft .NET based server application that allows both PC and PocketPC clients to connect in either infrastructure or ad-hoc mode. The clients receive audio, video and other sensory feeds from the wheelchair and can send control data for maneuvering the wheelchair.

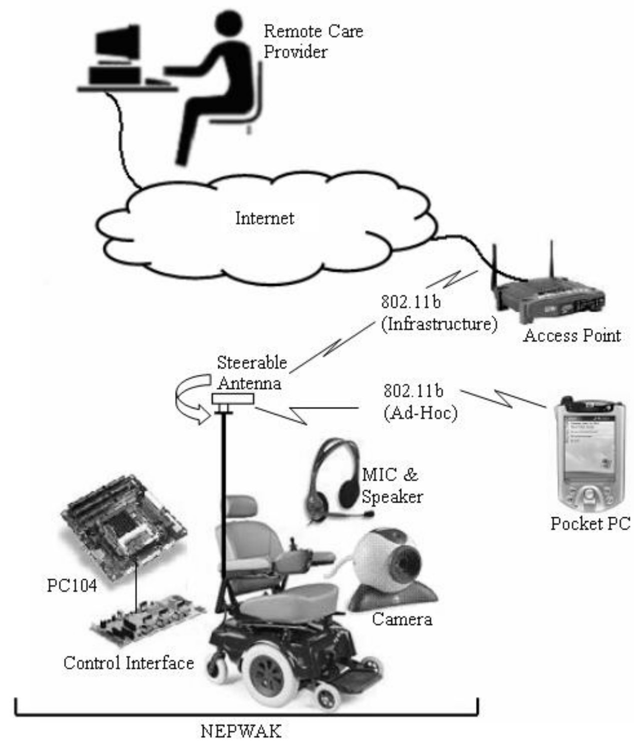


Figure 1: NEPWAK – Conceptual System

Each client whether PC or pocketPC is identified by a unique id which is maintained by a database on the server. The database also relates each client id with its associated Service Set Identification (SSID), mode (infrastructure or ad-hoc) and its priority for control. The server refers to the database for authentication during connection establishment and uses it to decide whether or not to allow 'following' mode to the client.

The steerable antenna is mounted on a stepper motor which is controlled using the parallel port on the SBC. The RSS values are sampled at every 3.6° of the complete 120° scans in the anti-clockwise direction.

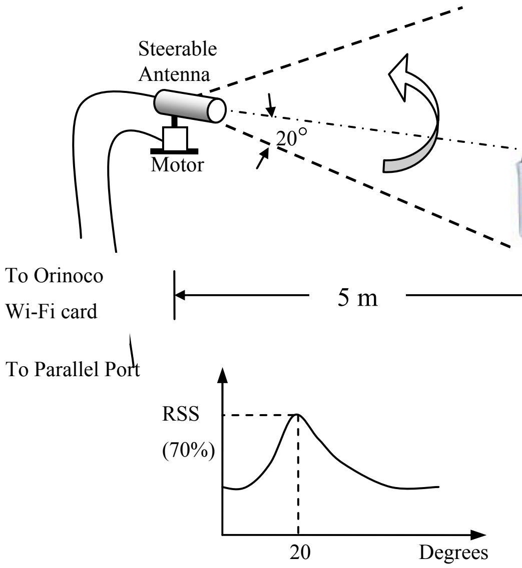


Figure 2: Concept of Human Following

4. WI-FI SIGNAL PROPAGATION

The IEEE 802.11b standard uses radio frequency in the 2.4GHz band, which allows license-free operation. Accurate prediction of signal strength is a complex task since the signal propagates by unpredictable means. Due to reflection, refraction, scattering and absorption of radio waves by structures inside a building, the transmitted signal most often reaches the receiver by more than one path; this phenomenon is called multipath fading. The signals from multiple paths combine and produce a distorted version of the transmitted signal. The received signal therefore varies with time and the relative position of the transmitter and the receiver.

In order to locate the direction of the source (pocketPC in our case) we constructed a steerable directional waveguide antenna [24] having a gain of 12dbi. Being directional it transmits and receives the signal over a very narrow beam width. Hence, the received signal strength (RSS) achieves the peak when the antenna is directly pointing to the source pocketPC.

5. WAVEGUIDE ANTENNA DESIGN

A waveguide is a material medium that confines and guides a propagating electromagnetic wave. In the 2.4 GHz frequency band, a waveguide normally consists of a hollow metallic conductor, usually rectangular, or circular in cross section such as a tin can.

A waveguide which is closed at one end acts like a short circuited coaxial cable. The incoming high frequency (hf) signal reflects from the closed end and forms a standing wave inside the waveguide. The standing wave has maxima and minima points as shown in fig. 3.

There are three different wavelengths in the waveguide. Here they are marked as Lo, Lc and Lg. Lo is the wavelength of the hf in open air.

$$\mathbf{Lo\ (mm) = 300 / f\ (GHz)} \qquad \text{(i)}$$

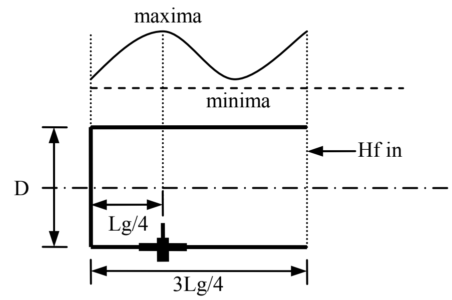


Figure 3: Waveguide antenna design

Lc is the wavelength of the low cutoff frequency which depends on the tube diameter (D).

$$\mathbf{Lc = 1706 \times D} \qquad \text{(ii)}$$

Lg is standing wavelength inside the tube; it is a function of both Lo and Lc.

$$\mathbf{Lg = 1 / \sqrt{((1/Lo)^2 - (1/Lc)^2)}} \qquad \text{(iii)}$$

It is important to note that the standing wavelength (Lg) is not the same as the wavelength of the hf signal in open air (Lo). Circular waveguides with large diameters act nearly as in the open air where Lg and Lo are almost the same. But when the waveguide's diameter becomes smaller the Lg increases effectively until it becomes infinite and the hf signal is not confined in the waveguide at all. In effect, the waveguide tube acts as a high pass filter which limits the wavelength Lc.

Inverse values of Lo, Lc and Lg forms sides of a right angled triangle related through the Pythagoras equation as:

$$(1/Lo)^2 = (1/Lc)^2 + (1/Lg)^2$$

Hence, $Lg = 1 / \sqrt{((1/Lo)^2 - (1/Lc)^2)}$

We made our waveguide antenna using readily available tin-cans having the diameter of 85 mm. Using equation (i), (ii) and (iii) we calculate Lg/4 to be 62 mm, this is the distance from the closed end where the first maximum point occurs.

6. IMPLEMENTATION ON NEPWAK

6.1 Hardware

The wheelchair is equipped with a PC104 Single Board Computer (SBC) with VIA Erza 800 MHz processor and 128 MB memory. An ORiNOCO 802.11g Network Interface Card (NIC) provides WLAN connectivity. The custom made steerable directional antenna connects to the NIC through a pigtail cable with a standard MC-card connector.

A PIC microcontroller based custom circuit provides interface between the SBC and the wheelchair's motor controller. The PIC receives motion commands from the SBC serially and relays it to the wheelchair's motor controller after appropriate signal conditioning.

6.2 Software

The Single Board Computer on the wheelchair runs Windows XP Embedded operating system. A dedicated multi-threaded server application written in VB .NET provides audio, video and sensory feed to the connected client and accepts control commands over TCP/IP.

The server measures the Received Signal Strength (RSS) of the 802.11b signal from its peer through Windows Management Instrumentation (WMI). WMI is a powerful tool for gathering information about hardware, software, and operating system components. The server uses WMI to query RSS value and in response receives Received Signal Strength Indicator (RSSI) which is number between 0-100 representing the RSS. The angle of the streerable antenna at which the peak RSSI occurs is used to generate motion commands to maneuver the wheelchair towards the Pocket PC. While the peak RSSI itself is used to control speed of approach.

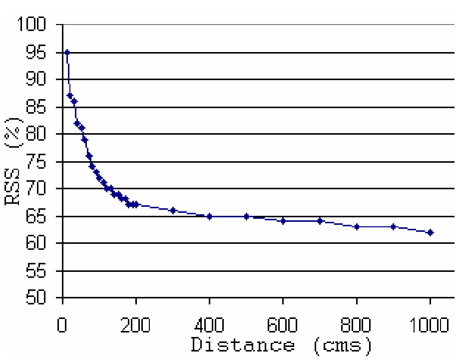
The Pocket PC on the other hand runs Windows Mobile 2003 operating system. A TCP/IP client application written in C# .NET is used to communicate with NEPWAK's server. The client receives audio, video and sensory feed from the server and sends control signals for remote control. Each client is identified by a unique id which is used for authentication during connection establishment. The server also relates each client id with its associated Service Set Identification (SSID) and mode (infrastructure or ad-hoc) for security purposes.

6.3 Integration

To implement human following on NEPWAK, motion commands have to be generated based on RSS measurements. After successfully detecting and locating a Pocket PC in range we use a very simple reactive following behavior. At present the server aims to keep the RSSI value at 65 which corresponds to a 4m separation. A simple comparison helps to decide whether the wheelchair has to accelerate or decelerate. If the signal is lost or if gets weak i.e. RSSI < 60 (corresponding to more than 10m of separation) the wheelchair is decelerated to a halt.

7. Results and Conclusion

In our first experiment we plotted the variation of the received signal strength (RSS) with distance. A person carrying the pocketPC was positioned in the middle of a corridor 275cm wide. Using our directional antenna RSSI values were recorded at every 10 cm for the first 2 m and thereafter, at every meter for 10 meters. The antenna was pointed towards the pocketPC at all times. The results were plotted in Graph 1. We observed that the RSS does not vary linearly with distance. It decreased rapidly in the first 3 m and then showed a very gradual decrease.



Graph 1: Variation of RSSI with distance

In our next set of experiments, we mounted the directional antenna on a stepper motor and performed 120° RSSI scans at various distances and positions from the pocketPC. Figure 4 illustrates the case when the steerable antenna was placed at a distance of 4 m from the pocketPC (position 1). A 120° scan was performed in anti-clockwise direction and recoded RSSI values were plotted against angular positions of the antenna (see graph 2). A second scan was performed when the pocketPC was placed at position 2. The recorded values were plotted in graph 3.

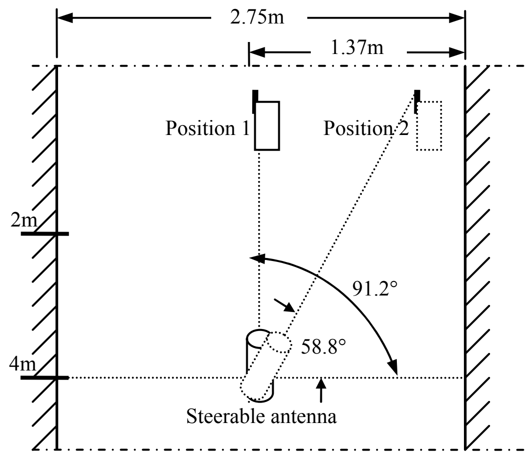
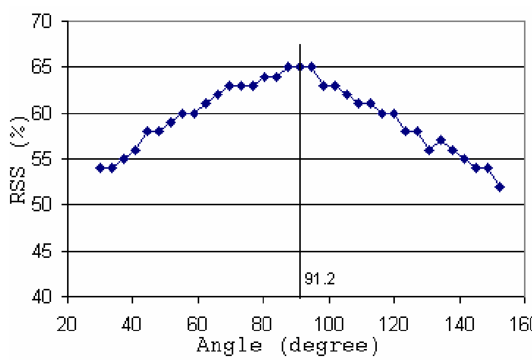
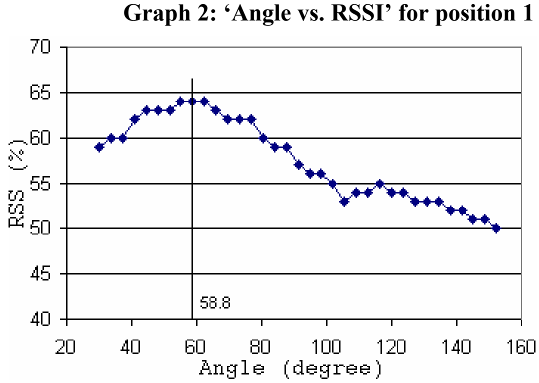


Figure 4: RSSI scan setup



Graph 2: 'Angle vs. RSSI' for position 1



Graph 3: 'Angle vs. RSSI' for position 2

The graphs clearly show a shift in the position of the peaks with the change in position of the pocketPC. The direction of the pocketPC at positions 1 and 2 were accurately derived by locating the peaks in graphs 2 and 3 respectively. However, we observed that estimating the distance based on the peak RSS value does not provide very accurate results. The reason being that beyond 3 m of separation the RSS value shows a very gradually decrease with distance, as shown in graph 1.

Our results are promising, while we have not created an effective mechanism for following yet, we feel confident that employing this methodology with another form of distance measure possibly related to measuring the slope of the peaks will lead to the development of a successful mechanism for NEPWAK to operate semi-autonomously in cooperation with the chair's occupant or care provide.

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