SICE Annual Conference 2007
Sept. 17-20, 2007, Kagawa University, Japan

Target User Localization for a Service Robot Using Wireless LAN

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Abstract: This research proposes a location-based service using wireless lan and innovates by adding a robot as a service agent. The proposed system recognizes the limitation of current location-based systems of only being capable of providing information and media services. By adding a mobile robot, physical services can also be provided by this new system. This research utilizes received signalstrength from multiple wireless lan access points (WLAN APs) for the indoor localization of a Personal Digital Assistant(PDA) user; the determined location is set as the target destination of the service robot which navigates autonomously to find the user.

Keywords: mobile robot, wireless lan, localization, personal digital assistant, location based services, laser range finder

1. INTRODUCTION

Mobile devices have become part of modern living in recent decades. Mobile devices or handheld devices come in the form of mobile phones, personal digital assistants or even ultra-mobile PC's. To complete its functionality, mobile devices have wireless communication hardware supported by a wireless network infrastructure. Communication infrastructure can be in the form of a mobile phone network over a wide geographic area or a small coverage local wireless network inside buildings.

The pervasive nature of mobile devices and their network infrastructure provides not only a medium for communication but also a method for delivering various services to the mobile device user wherever that may be. This research realizes an innovative service for a mobile device user by using a wireless network.

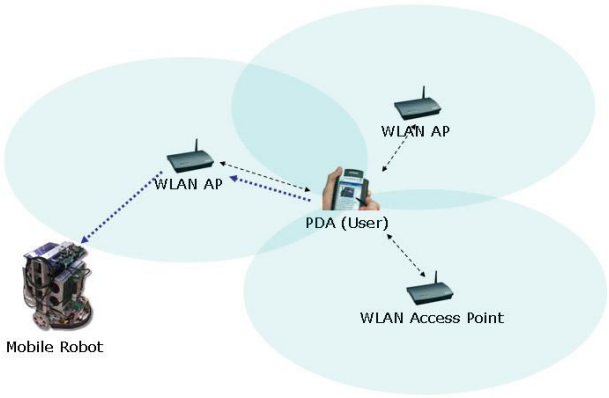


Fig. 1 System: Location-based service with a robot

1.1 Motivation

Location-based services (LBS), or location-aware systems use a wireless network infrastructure to determine a mobile device user's location and provide services to the user based on location. For example a Global Positioning System (GPS) enabled device can use the satellite system to locate users. In the case of mobile phone networks, the user location is based on the strength of signals from nearby base stations. Information and media such as lists of nearby shops, events, and area maps can be relayed to the user device via the location-based system.

For indoor localization, the widespread use of wireless lan has provided a usable infrastructure not just for communication but also for localization. Similar to the use of base stations in mobile phone networks for localization, for a wireless LAN, access points are utilized to implement a location-aware system.

Conventional location-based services can be considered limited since LBS was originally conceptualized to deliver information and media services only. On the other hand, service robots by themselves have less functionality without the support of a wireless communication interface to its user.

The motivation for this research is the inclusion of the service robot into the location-based system as mobile agents which can provide physical services to assist people. The location-based system's services are extended, as well as the robot's functionality. The system presented in this research can serve as a basis for combining location-based services and service robots. From this system's primary function of the robot locating the user as its target destination, many other applications can be developed.

1.2 Objective

This research proposes a location-based service using wireless lan and innovates by adding a robot as a service agent. By adding a mobile robot, physical services can also be provided by this new system. This research utilizes received signal strength from multiple wireless lan access points (WLAN APs) for the indoor localization of a Personal Digital Assistant (PDA) user; the determined location is set as the target destination of the service robot which navigates autonomously to find the user.

1.3 Approach

Wireless lan localization is achieved by initially performing a survey of the service coverage area before system operation. A database of measured signal strengths of all access points within range for predetermined locations is created. During operation, the system locates the user by correlating measured signal strengths by the PDA to the database. Since localization by wireless lan has an inherent amount of error, it is considered an estimate location by the robot. The robot navigates to the estimate location and improves user localization by using an URG SOKUIKI sensor. The URG is a small scanning laser range sensor which scans the area to exactly determine the location of the user.

2. METHODOLOGY

Based on the approach, the methodology of the system to locate the user and navigate the robot to the target position involves the following steps:

1. Survey area
2. User call and locate
3. Robot navigation
4. Robot finds user

The details of this methodology are further discussed in the following subsections.

2.1 Survey Area

Before the actual system operation, the wireless lan coverage area is initially surveyed with the PDA to measure access point signal strengths and build a location-signal strength database. The scanning will take place at predetermined locations around the coverage area. At each location the signal strengths of all access points within range are measured. Multiple measurements are done at each location to build the database.

The survey procedure is automated by placing the PDA on the robot during the survey. When the survey mode begins, the robot first moves to a predetermined location. After it stops on the first location, it sends a trigger to the PDA so scan all APs for that location. Once the scan is complete the PDA sends back the data which is saved by the robot. This process is repeated for the next predetermined location.

2.2 User Call and Locate

During system operation, the PDA user calls the robot for service and the system references the database for estimate localization. The location of the PDA user is first estimated by referencing the database built during the area survey. The signal strengths readings of the current user position is compared to each position data in the database. Comparison is done by correlation.

Correlation is commonly used in probability theory and statistics, it indicates the strength and direction of a relationship between two variables. It is given by the following equation:

$$R = \frac{N\sum xy - \sum x \sum y}{\sqrt{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]}} \quad (1)$$

where N is the number of positions correlated, x is the signal strength data for on position in the database, y is the signal strength data for the current position, and R is the correlation of the signal strength data for current position with each position in the database.

The range of correlation varies from -1 to 1. Correlation approaching 1 suggests that the two variables are linearly related. As correlation nears zero, the relationship diminishes. Correlation of -1 suggests that the two variables are a mirror image on the xy plane or perpendicular in relationship.

For this research the current location signal strength data is correlated with signal strength data of each location in the database. The best estimate location is selected by determining the position with the highest correlation with the database.

2.3 Robot Navigation

Since the area and survey locations are predetermined, way points are also preprogrammed into the robot navigation system. The robot navigates using odometry between waypoints to reach the estimated location.

For the mobile to move from one survey location to another, the navigation system determines sequence of way points which plans a route with the shortest distance between the two points. Shortest distance between the start location and target location is determined by using Dijkstra's algorithm.

2.4 Robot Finds User

The robot combines the use of the WLAN antenna and URG to find the user accurately. Once the robot reaches the first estimated position determined from the correlation of access point signal strengths, the location is again estimated a second time by using the WLAN antenna. The robot and PDA compares the signal strength readings between their wireless lan adapters. This is done while the robot rotates in place to determine the best orientation towards the user.

Finally, the PDA user is detected from the environment by the robot using the URG sensor to scan objects within range. The location of the user must be sensed while ignoring other objects which are part of the environment. This entails identifying the shape of legs of the user in the directed orientation determined from the WLAN antenna.

3. IMPLEMENTATION

This section describes the hardware used and the modes of system operation. The implementation of the software is also discussed.

The system is divided into 3 major components:

1. Personal digital assistant
2. Wireless local area network
3. Mobile robot

These are discussed in detail in the following subsections.

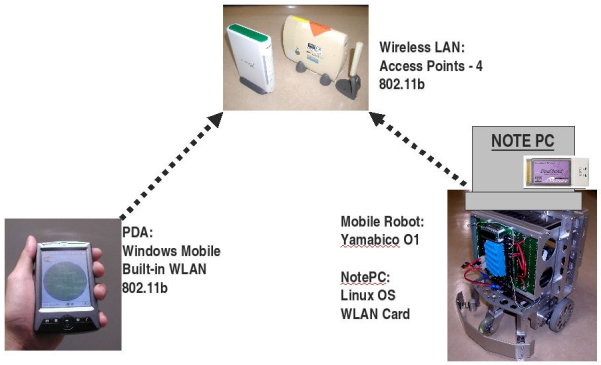


Fig. 2 System Hardware

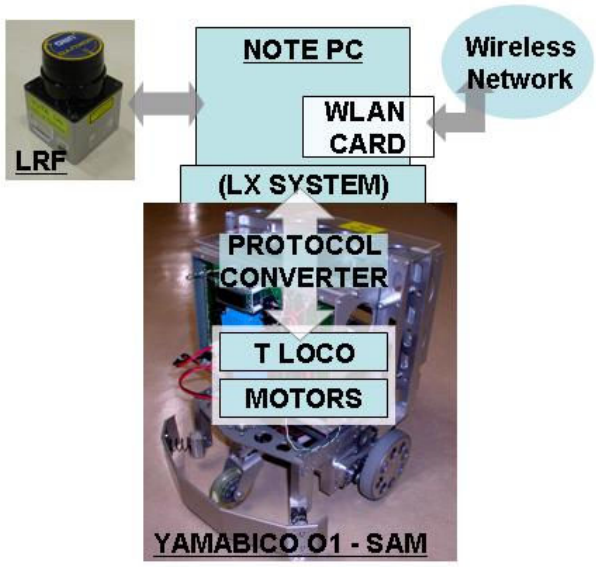


Fig. 3 Mobile Robot System

3.1 PDA

The PDA used is the HP iPAQ rx3715 with Windows Mobile 2003 for Pocket PC Second Edition as its operating system. The iPAQ rx3715 has a Samsung S3C2440 400 megahertz processor, 128 megabyte RAM and a 8.9 cm TFT color screen. It has a built-in IEEE 802.11b wireless lan adapter for connectivity. Other features include bluetooth, infrared, a SD/MMC card slot and a 1.2 megapixel camera

3.2 Wireless LAN

Since the PDA used has an IEEE 802.11b WLAN adapter, compatible WLAN access points and devices (peers) can be detected.

Four access points are used to build the communication network of the system. These are Buffallo AirConnect and AirStation models which support IEEE 802.11b/g. Other IEEE 802.11b/g capable access points within range are also utilized not as part of the network but as location reference.

The wireless lan card used on the mobile robot is the IO-Data WN-AG/CB based on the atheros chipset capable of IEEE 802.11b/g/a standards.

3.3 Mobile Robot

The mobile robot hardware is composed of:

1. Yamabico Mobile Robot Platform
2. Notebook PC
3. WLAN Antenna
4. URG Sensor

The mobile robot platform used is the Yamabico, developed by the Intelligent Robot Laboratory of the University of Tsukuba. The specific type is the O1. It weighs approximately 10 kilos and has dimensions of 320mm by 400mm by 400mm (length x width x height). It is driven by two independent wheel motors controlled with the Yamabico TM and T-Loco boards. These boards control locomotion and provide fairly precise odometry of the robot.

The notebook PC used is a NEC Versa with a 600 megahertz processor, 172 megabyte RAM, and a 30 gigabyte harddisk. It runs Linux kernel 2.6.11.10. The notebook PC is mounted on the robot and is interfaced to the robot control boards with the Lx system through a USB port. The notebook PC can access the wireless lan with the attached PCMCIA wireless lan card. An improvised WLAN antenna is attached to the WLAN card.

The URG sensor is a compact, lightweight and precise laser range finder developed by Hokuyo Automatic. It is connected to the notebook PC via another USB port. Drivers especially designed for the URG have also been developed in the Intelligent Robot Laboratory for sensor control and data access.

3.4 Modes of System Operation

There are two modes of operation of the system:

1. Survey Mode: Survey performed to build WLAN localization database.
2. User Service Mode: Database used to locate and serve the user.

The two modes also results in different corresponding software on the PDA and service robot for each mode. In survey mode, a wireless lan scanner is implemented on the PDA to build the database. The signal strength of all identified access points within range of the PDA are measured for different predetermined locations under the network coverage to build the database.

The survey procedure is automated by placing the PDA on the robot during the survey. When the survey mode begins, the robot first moves to a predetermined location. After it stops on the first location, it sends a trigger to the PDA so scan all APs for that location. Once the scan is complete the PDA sends back the data which is saved by the robot. This process is repeated for the next predetermined location.

In the User Service Mode, using the database created during survey mode, user location is determined by the robot to serve the user.

The user service mode begins with the user calling the robot for service. The scan data of access points is then sent to the robot which correlates this to the database. Af-

ter correlation, the robot moves to the estimate location. It next uses sensors to approach the user, this is discussed in the followin subsections. Once it reaches the target destination, it sends an end message to the user for confirmation.

3.5 Software

The implementation of the software is described here.

The communication architecture of the system is designed such that the PDA is the client and the robot is the server for either mode of operation. Communication is facilitated by implementing a common data packet structure to be used by the PDA and robot.

The packet structure is composed of the necessary data components for the functionality for the system:

1. int status - indicates the connection status between the PDA and Notebook PC; 1 for connect, 0 for disconnect
2. int counter - packet counter for checking received packets
3. int RSSI - the received signal strength of the current AP being scanned
4. string MACAdd - the MAC address of the current AP being scanned
5. string SSID - the SSID of the current AP being scanned
6. string location - variable to store current location

3.6 Survey Mode Program

A PDA survey program is implemented for the survey mode operation. As discussed in the methodology, this procedure was automated by utilizing the robot.

The PDA survey program was implemented with the following options:

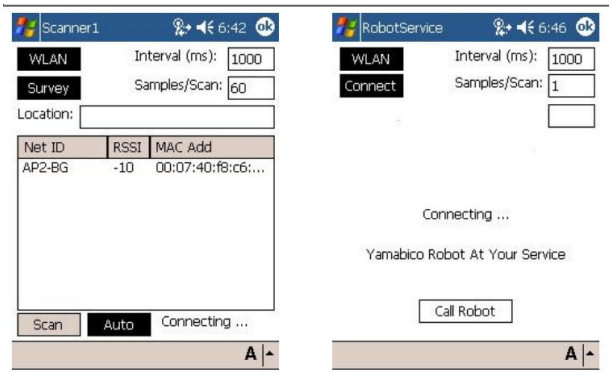
1. WLAN Scanner: Scan N number of times with a certain interval (N is samples/scan, and interval in milliseconds)
2. Auto Scanner: Continuous WLAN scanning with a certain interval
3. Manual Survey: Set with Survey ON, scan data is saved to a file
4. Auto Survey: Set with Survey ON, Auto ON, scan data is saved to a file and also sent to the robot server program

3.7 User Service Mode Program

The user service program is the basic interface for the user to the robot. It shows a call button to be pushed when robot service is requested. A status display shows the status of the robot, if connection is possible and if it is on the way to the user.

4. EXPERIMENTS

Initially, a complete area survey was performed to build the database for localization. For the survey, the tenth floor of the Laboratory of Advanced Research Building B at the University of Tsukuba was chosen as the experimental area. The survey was performed by using the PDA to measure the signal strengths of all the



Survey Program User Service Program

Fig. 4 PDA Survey and User Service Program

access points at 24 selected positions around the experimental area.

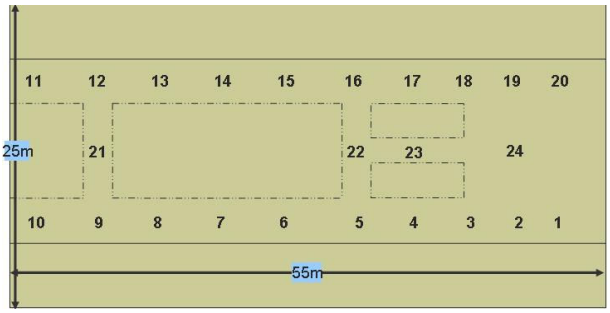


Fig. 5 Map of the 24 Survey Locations

4.1 Locating the User

The user was located by finding the position from the database with the highest correlation to the signal strength of the current location. Access points with no readings were ignored when measuring correlation. As shown in the correlation map, the highest correlation value (with biggest circle diameter) is at position 1, which was correct for this experiment.

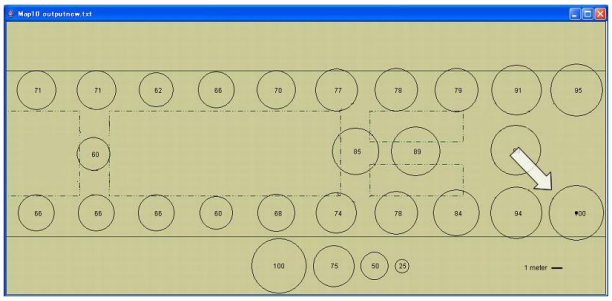


Fig. 6 Correlation Map: User at Position 1

After the localization using WLAN, sensors are used to improve the location estimate of the user. For this experiment, the URG sensor was used to scan an area with visible human legs. Detection assumes that the scan area is composed of mostly walls.

The algorithm used in this experiment detects legs by checking adjacent points in the scans with large changes

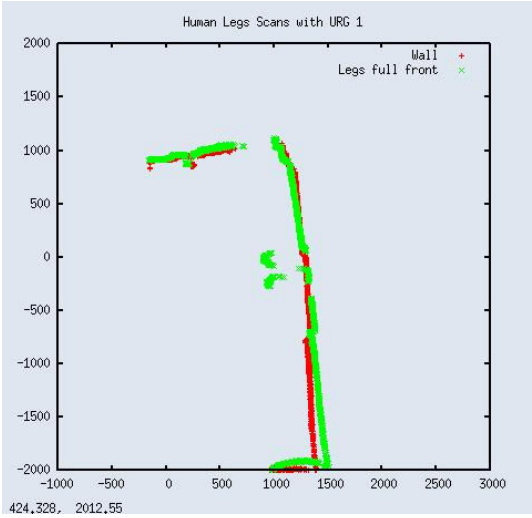


Fig. 7 URG Sensor Leg Scan: 2 legs visible

in distance based on a threshold. This is used to group points, groups which are about the width of one leg to two legs are marked as possible detected legs. The range used is from 100mm to 350 mm. Using the URG sensor the final estimate of the user position is determined and the robot can approach the user for service.

5. CONCLUSION

This research has realized a new location-based system with the inclusion of a mobile robot as a service agent. The PDA and robot programs were successfully implemented for WLAN localization. The use of sensors to improve localization overcame the large resolution of WLAN localization. There can a number of improvements in the localization process by WLAN with the use of probabilistic techniques and sensor fusion. Increasing the database size and samples would also greatly improve the effectivity of the system.

From this basic system a number of possible applications may be developed. For example, once the mobile robot locates and meets the user, it can guide the user as they roam around the coverage of the WLAN. The mobile robot, with its on-board computer, can serve information directly to a handheld Personal Digital Assistant (PDA) of the user such as relevant text and images as guidance information.

Another possible application for the system would be security, a specific case of which is WLAN security. A mobile robot can be used to find users connected to the WLAN to verify their location and identification. This can prevent unauthorized users accessing the WLAN compromising the security of the network. While roaming, the mobile robot can also continuously monitor the wireless network coverage. The data collected can be used to check if base stations are properly placed and improve network design.

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