Wireless Indoor Positioning System for the Visually Impaired

Piotr Wawrzyniak, Piotr Korbel
Institute of Electronics
Lodz University of Technology
ul. Wólczańska 211/215, 90-924 Łódź, Poland
Email: piotr.wawrzyniak@dokt.p.lodz.pl

***Abstract*—The paper presents a prototype radio network aiding the visually impaired to navigate in indoor areas. The main purpose of the system is to provide accurate and reliable location information as well as to enable access to location related context information. The nodes of the network operate in two modes providing basis for both rough and precise user position estimation. The data transmitted by the nodes are used to get access to additional services, e.g. to retrieve position related context information.**

***Index Terms*—Context-aware services, indoor radio communication, location services, personal communication networks, pervasive computing, radio navigation, wireless sensor networks**

I. Introduction

THERE ARE about 285 million visually impaired people living around the world [1]. The inability to sense the surrounding environment strongly affects the possibility of utilizing public spaces, including urban areas, transportation systems and public buildings [2]. Recently, a number of electronic systems aiding the visually impaired in travel and mobility have been developed [3-8]. Most of these systems require accurate information on current user location. Obtaining precise information on user location can facilitate access to public services offered in large buildings (e.g. city halls, hospitals) by aiding to locate rooms or by giving a remote guidance on how to get to the target destination. Contemporary satellite navigation systems like GPS provide positioning services sufficient for successful navigation of pedestrians in typical outdoor scenarios and thus are often incorporated in electronic travel aids (ETA) for the visually impaired. However, the use of satellite positioning systems is limited to outdoor areas only. The GPS positioning accuracy also decreases in dense urban environments where multipath propagation and strong signal attenuation result in insufficient quality of satellite beacons. Therefore, there is a need to develop dedicated systems aiding the blind and the visually impaired in urban navigation. Most of electronic mobility aids offered on the market make use of local networks of reference stations that transmit infrared [3] or radio signals [4], [5], [6]. The transmitters are used to identify various points of interest (POI) like bus stops, entrances to public buildings, etc. One of the first indoor positioning systems that used radio beacons and Received Signal Strength Indicator (RSSI) measurements was the RADAR system developed by Microsoft Research in the beginning of the 21st century [9]. From that time the problem of indoor positioning and navigation has been widely addressed around the world [10-22]. Hence maintaining low deployment and maintenance costs is among the most important objectives of the research, majority of the solutions reported in the literature rely on radio signal strength measurements. Signal strength readouts can be incorporated to location services in at least two ways. First of all, radio wave indoor propagation models can be used to determine the possible location of the terminal. This approach requires detailed description of the propagation environment and thus is difficult to implement. Another approach involves the use of database search methods to calculate user position. Therefore, it is necessary to provide reference RSSI measurements (i.e. measurements taken in predefined locations) that are stored in the reference database, and which are then used by location estimation algorithms. In the paper, we present a wireless indoor positioning system developed as a part of a complex solution aiding the visually impaired in independent travel and mobility.

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II. System architecture

The architecture of the proposed indoor positioning system consists of a local localization server, a local database server and an optional global localization server. A wide range of portable user devices (PDAs, smartphones, notebooks, etc.) operating in different wireless networks may be used as system terminals. The terminals should have the capability to measure strength of the signals transmitted by system reference stations mounted inside a building. Thus, a dedicated software or hardware is necessary to make use of the measurement data, especially to pass the results to the local positioning server. The tasks of the local positioning server are: to keep information about the layout of the area it serves (e.g. an office building), to make the use of local database engine to store reference measurement data, and to compute the probable user location based on the RSSI measurement values reported by the terminal. Moreover, the local server is also responsible for communication with the global localization server, if available. The global localization server can be also

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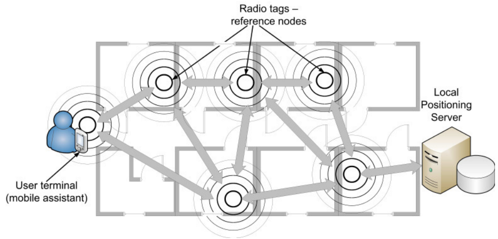

Fig. 1. Architecture of the electronic system for guidance of visually impaired in indoor areas.

used to deliver new positioning algorithms. The architecture of the proposed system is shown in Fig. 1. All the components of the system communicate using XML/JSON and SOAP-based Web Services.

III. Wireless Positioning Techniques

A variety of techniques can be employed to estimate the position of a wireless network terminal. In majority of systems measurements of signal parameters transmitted by system reference stations are used. Then, the position of the terminal is estimated based on calculation of distances of the terminal to at least some of the reference nodes. The most commonly used signal properties include propagation time, angle of arrival, and received signal strength [10].

A. Proximity Detection

The most straightforward method to estimate the position of a radio terminal is to determine whether it is within the coverage of some reference station. The accuracy of positioning with this approach strongly depends on the range of reference transmitters. However, when reference stations transmit signals with relatively low power, the position of the user terminal may be well approximated by the known location of the reference transmitter. This approach is called proximity detection. Practical implementation of this positioning technique involves installation of many reference nodes, often called radio tags. However, due to simple tag's construction the overall system installation cost might remain low. This technique offers good accuracy, however it strongly depends on the number of installed reference tags. The idea of positioning system using proximity detection is shown in Fig. 2.

B. Database Search-based Indoor Positioning

Distance estimation techniques involving radio wave propagation modeling are widely used in positioning systems. However, due very high complexity of indoor radio wave propagation environment, applicability of these methods is limited to outdoor areas. In typical indoor scenarios, strong multipath propagation effects make it impossible to unambiguously relate measured signal parameter value to a distance from the transmitter. Even along short propagation paths, signal parameters may exhibit very strong variability. Another factor limiting performance of positioning methods is time variability of indoor radio channel characteristics. For example, depending of the time of the day, the offices may either be crowded or almost empty what may result in significant changes of the reported values. Therefore, there is a need to search for new positioning methods for indoor applications. One of the approaches that is adequate for indoor systems assumes the use of correlation analysis of reported signal parameter values with some reference data recorded at predefined locations. As database search methods rely on evaluation of similarity of measured signal characteristics at actual location to the reference datasets, these methods are not so prone to multipath and shadowing effects as the methods based on radio wave propagation modeling. Despite of the fact that database correlation methods may be based on analysis of any available signal parameters, most of practical implementations involve received signal strength measurements. The advantage of the use of RSSI is that most of contemporary radio receivers provide possibility to monitor RSSI level and a wide range of devices can be used with a positioning system without a need to implement any hardware modifications. The use of database search methods makes it also possible to reduce the influence of RSSI time variability by the use of normalization to the value read from a given reference signal source.

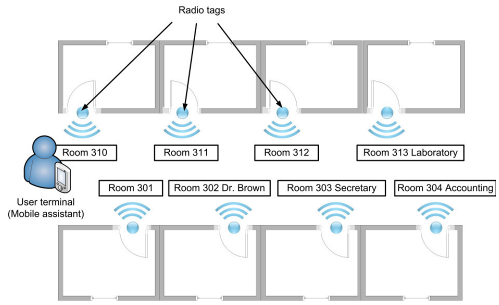

Fig. 2. Proximity detection – presentation of indoor location of the terminal and position related context information (room number).

C. Proposed Positioning Technique

The proposed implementation of a wireless indoor positioning system involves received signal strength (RSSI) measurements to estimate terminal position. It makes use of the advantages of both aforementioned approaches, i.e. proximity detection and database search methods. Hence proximity detection is most effective and accurate when area served by a single reference tag is relatively small, the tags should be equipped with radio transmitters supporting low transmit power modes. On the other hand, database search method accuracy increases with the number of sources of reference signals. In that case, the nodes should be capable to transmit reference signals over relatively large areas. Moreover, the coverage areas of neighboring transmitters should overlap. It is worth mentioning, that position information returned in the form of absolute geographical coordinates of the user is not the most expected output from indoor navigation and positioning systems. Geographical coordinates are more suitable for outdoor positioning, mainly due to easy integration with GIS systems. Moreover, in indoor applications accurate and

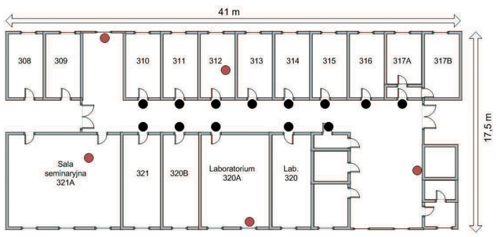

Fig. 3. Test site with reference points (black dots) and reference tags (red dots) used in the second experiment.

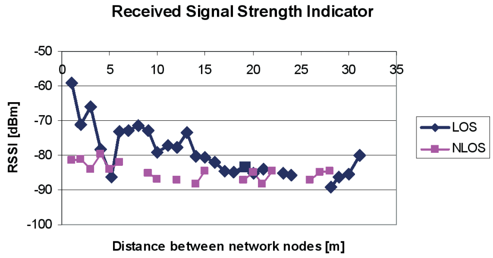

Fig. 4. RSSI as a function of distance from the transmitter.

reliable altitude estimation is required. Although in outdoor scenarios the use of absolute altitude above ground or sea level as altitude descriptor is the most convenient, in indoor scenarios floor index should be considered as the natural way of expressing in-building altitude of travelling people. Therefore, the proposed indoor positioning system makes use of area-based context-related positioning. Area-based positioning systems provide end users with context information related to the current zone of the building. The system output data set includes but is not limited to:

- floor index or name (if applicable),
- zone within a building (e.g. "north wing"),
- room or office number or its name (e.g. "kitchen" or "auditory no. 416"),
- additional site-related information (like name of current lecture in an auditory room).

Moreover, the proposed system returns absolute coordinates of the user terminal to ensure backward compatibility.

IV. Experiment Results

The prototype system was built with the use of Texas Instrument's CC1110 radio transceivers operating in 868 MHz unlicensed band and transmitting with output power ranging from -30 dBm to +10 dBm. The reference nodes and the user terminal were equipped with omnidirectional antennas having +2.2 dBi gain. The receiver sensitivity was -110 dBm. The reference nodes were mounted in an office building as shown in Fig. 3. All network nodes were utilizing SimpliciTI protocol to communicate with each other. The test premises consisted of about 41 meters long and 3.5 meters wide corridor with doors leading to several offices and laboratories. In order to evaluate the positioning accuracy of the implemented methods a number of experiments have been conducted. The goal of the first experiment was to estimate the size of the zones covered by the reference nodes when packets are being sent with the lowest available transmit power, i.e. -30 dBm. During the experiment one of the tags has been placed in the building entrance area while the second one served as data receiver. Measurements of Received Signal Strength Indicator (RSSI) have been recorded along 36 meter long path. The experiment was repeated twice in order to examine system behavior in Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) conditions. The results of the first phase of experiments have been summarized in Fig. 4. As the result of the experiment the maximum radius of the zone covered by a single reference tag was estimated to be about 25 meters for LOS, and about 10 meters for NLOS conditions. In practical system application, node proximity will be detected only when the RSSI values exceed predefined threshold values. It must be also noted that the use of miniaturized radio tag modules equipped with ceramic antennas will result in significant decrease of the coverage area of a single tag. The goal of the next experiment was to evaluate door identification accuracy with the use of database search methods. Reference Points of Interests (POI) have been distributed at the entrance doors to the rooms as shown in Fig. 3. The database search algorithms has been used to determine the user position on the basis of RSSI measurements from five reference tags distributed in the test premises. Results of the experiment have been summarized in Table I and Fig. 5.

TABLE I
Summary of Experiment Results

Indicator	Result
Average positioning error (25 %)	0 m
Average positioning error (50 %)	2.38 m
Average positioning error (75 %)	3.23 m
Average positioning error (100 %)	4.47 m

As presented in Table I database search method resulted in mean positioning error of 4.47 meters and 2.38 meters for 50 % of cases. It is worth to mention that for 29.76 % of analyzed test cases user position was determined correctly (therefore 25 % error rate counts 0) and for another 15.48 %

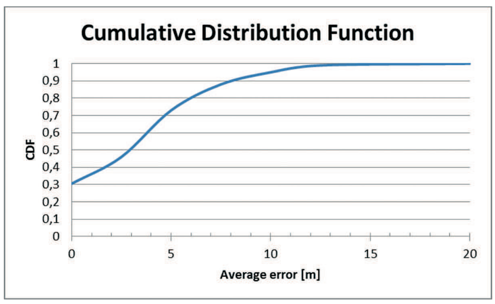

Fig. 5. Cumulative Distribution Function of positioning error from conducted experiment.

of cases user position was estimated at neighboring door. Cumulative Distribution Function is presented in Fig. 5. It can be noticed that maximum positioning error in conducted experiment reached 20 meters (for a single case) and for 90 % of cases positioning error was lower than 8 meters.

V. System user interface

Indoor positioning system presented in the article is a part of a complex solution designed for aiding the blind and the visually impaired in independent mobility and travel. Therefore, described positioning system shares components like reference tags or user terminals with the remaining part of the system. The use of Text-To-Speech enabled smartphone as a mobile electronic aid makes it possible to provide the visually impaired users with voice messages presenting position related information e.g. description of rooms the user is passing by. Moreover, an interactive plan showing part of the building where user was localized is simultaneously displayed on the screen of the mobile phone. This function makes the system suitable for a wider group of target users. Displaying additional context-related information may be helpful in effective navigation in large and unknown buildings.

VI. Conclusion

In this paper indoor positioning system for short range radio communications network has been proposed. The system is a part of complex solution designed for aiding navigation of visually impaired in independent travel and mobility. The positioning system combines proximity sensing and database search methods. The experiments conducted in a large office building resulted in average positioning error not exceeding 4.47 meters. Positioning results are returned as contextual information regarding the area where the user was localized. The use of smartphone as a user terminal makes it possible to present the results to the users in the form of voice messages. Future development works assume incorporation of multi-system positioning. As the result, the positioning methods implemented in the system will benefit from the use of data from generally available radio networks, like public Wi-Fi or mobile cellular telephony networks.

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