Development of Handheld Directory System built on WiFi-based Positioning Techniques

Lee Pieh Wen, Chan Wee Nee, Khor Meng Chun, Tan Shiang-Yen, and Rosnah Idrus

***Abstract*—** As outdoor positioning systems have relatively well established and matured, indoor positioning and navigation systems still have great potential to grow. The researches on indoor positioning system have gained the ever increasing momentum and importance, as the needs toward indoor positioning and navigation are flourishing. With the prominence of smartphone, this paper introduces a portable indoor directory system that can be easily installed and operated on the typical smartphone; hence the system could benefit greater number of users. The proposed system is aimed to provide a new ways of providing indoor floor directory, which offers capabilities to retrieve customizable and real time information, to navigate interactively, and to enable location-awareness computing. Additionally, the proposed system is designated to cater for the needs of visually challenged persons by incorporating screen reader and improved accessibility. The whole system consists of three modules, namely mobile phone module, Kiosks module, and Website and Database module. The mobile phone module is the main frontend module which installed on users' mobile devices, whereas the Kiosks and website are to provide supports and maintenances to the main module. Users can download maps and application from the Kiosks or website. On the other hand, administrator uses the website to manage the database.

***Keywords*—** WiFi Positioning, WLAN positioning, Navigation system, Mobile Application, Visually impaired

I. Introduction

Navigation has always been an issue, especially when a person is in an unfamiliar area. Directories and maps are the vital facilities which assist visitors to reach their desired destination or to have a feel of the building layout. A common form of directories is in the form of a physical board, placed in the strategic positions which highly visible to the visitors.

It is usual that vast numbers of information and labels are shown on the directory boards. However, humans have the cognitive limitations to process huge amount of information. Visitors often need to spend long time to filter out irrelevant labels and information, in order to focus on their point of interests. They might also subject to disruption due to lost trace in the congested directory. At the same time, the physical directory board is subject to the limitation of maximum user at a single point of time. Additionally, the main inefficiency of the conventional directory board is its immobility. Users need to memorize the place of interests, route to reach the place, and it is not uncommon that users need to memorize multiple places and routes.

Approximately 314 million people are visually impaired worldwide, and about 87 percent of the world's visually impaired live in developing countries [1]. Despite of the high distribution of visually impaired persons in developing countries, the indoor facilities to assist the group is much less sophisticated compared to developed countries. The Visually challenged persons often encounter tougher issues when they newly arrive at a building. Moreover, they are almost impossible to use the conventional directory, as it does not provide the accessibility for those visually challenged. For instance, the fonts used in the directory are often small and enriched with different colors and a style in order to make the directory has more attractive appearance [2].

In relevant to aforementioned issues, an interactive and customizable directory which has the portability to be carried around would be much appreciated. Furthermore, the implementation cost of the new directory must be considerable low, in order to allow it being widely adopted and beneficial to larger groups of user. Therefore, the purpose of this paper is to introduce a handheld directory system, which allows users to use their mobile device as an interactive and customizable indoor directory. The proposed floor directory system is built on WiFi-based positioning techniques to provide the capability of real time positioning, interactive navigation, and the provision of location-triggered information. Furthermore, a kiosk with touch screen acts as a part of the whole system which not only to allows users to download maps of the area through Bluetooth, but to cater for the needs of users whose mobile device does not support WiFi connection. Additionally, the proposed floor directory system caters for the needs of visually challenged persons by incorporating dedicated features and functionalities such as screen reader and legibility of the interfaces.

Next section of this paper presents and discusses various positioning techniques. Then, the discussion narrowed down to WiFi-based positioning and various wireless positioning techniques, which form the foundation of this research. Section 3 presents the proposed directory system in terms of its overall architecture and system design. Section 4 presents the implementation of the proposed system

This work is supported in part by the Universiti Sains Malaysia (USM) under USM Fellowship schema and RU-PRGS grant.

L. P. Wen, C. W. Nee, and K. M. Chun were students with School of Computer Science, who specialize in Information Systems Engineering.

T. Shiang-Yen is a Fellow at School of Computer Sciences. His research areas are Enterprise Computing and Strategic Information System. (Phone: +60168229499; fax: +604-6573335; e-mail: tsy09_com036@student.usm)

R. Idrus is a senior lecturer with the School of Computer Sciences, National Advanced IPv6 Center, and CEMACS at Universiti Sains Malaysia, who specializes in Information Systems Development, Technopreneurship, and ERP systems for SMEs (e-mail: rosnah@cs.usm.my).

II. Literature Review

A. WiFi-based Positioning System

In order to remedy the shortfall of GPS technology, many researchers have proposed alternate indoor navigation systems, e.g. ultrasonic-based system, pseudo-satellite technology, Bluetooth, RFID-based system, wireless signal positioning, TV signal positioning, and IP address positioning [3]. However, most of these positioning systems rely on proprietary infrastructure and often entail expensive deployment [4]. As a kind of the alternate navigation system developed, WLAN-based positioning system has received much attention recently. The scope of this paper is focus on the WLAN-based positioning system, which also refers as WiFi-based positioning system.

Compared to these other positioning systems, wireless positioning system (WPS) that based on Wireless Local Area Network (WLAN) infrastructure has certain advantages, including availability and readiness of infrastructure, low deployment cost, easy to implement, and signal stability. Currently, given that many buildings are equipped with WLAN access points (shopping malls, universities, office buildings, airports, etc.), WLAN based positioning system has become practical to use these access points (usually in the form of wireless routers) to determine user location in these indoor environments [4]. In other words, the WLAN based positioning system utilizes the existing communication equipment, thus significantly reduce the implementation efforts and costs. Major part of the positioning system can be implemented in software.

Moveover, provided that most of the mobile device such as cell phones are enabled with wireless radio communication network interfaces (such as Wi-Fi), protocols which to provide location estimation based on the received signal strength indication (RSSI) of wireless access points are becoming more-and-more popular, precise, and sophisticated.

Additionally, WLAN is also known as a stable system due to its robust Radio Frequency (RF) signal propagation compared with the other systems. For instance, the performance of video or IR-based positioning systems is negatively affected by line-of-sight (LOS) obstructions or light conditions, such as fluorescent lighting or direct sunlight [5].

B. Wireless Positioning Techniques

There are numbers of techniques have been developed by researchers to determine or estimate the position of the mobile device by different properties of signal from the WLAN Access Points (APs). Bose and Heng summarized various WLAN-based positioning techniques into Cell Identity (Cell-ID), Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and signal strength based method [6].

Cell identity (Cell-ID) makes use of the radio coverage of an identified cell to indicate the location of a mobile device. It does not require complex operation such as time synchronization and multiple Access Points. The main shortcoming of this technique is its accuracy since usually the coverage of a cell is wide and due to its simplicity. Moreover, the presence of high rise buildings and many stationary points in an urban setting make this method inaccurate due to multi-path propagation and signal reflection [7].

Angel of Arrival (AOA) refers to the technique which the position of the mobile device is determined by the direction of incoming signals from other transmitters whose locations are known. Triangulation technique is used to compute the location of the measured mobile device. However, a special antenna array is required on the AP and be capable of mounting them under static conditions [5].

Time of Arrival (TOA) measures a distance using the travel time of a radio signal from a transmitter to a receiver. Once the distances from a mobile device to three stationary devices are estimated, the position of the mobile device with respect to the stationary devices can easily be determined using the intersecting circles of trilateration. Its application requires very accurate and tight time synchronization of the transmitter and receiver, which is difficult to achieve for close ranges [8, 9].

As a remedy to the shortfall of TOA, Time Difference of Arrival (TDOA) was developed, which utilizes the time difference between receiver and two or more receivers [6]. Thus, TOA require time synchronization between transmitters and receivers, whereas TDOA only requires synchronization between receivers.

Signal Strength based technique uses the signal attenuation property of the radio wave – Received Signal Strength Indication (RSSI) to measure the distance from a receiver to transmitter using the distance-to-signal-strength relationship. One common approach of RSSI-based system is fingerprint approach, which entails two phases: a training phase and a tracking phase. In the training phase, the received signal strength information is filtered, interpolated, and eventually stored in a database as sample points. In the tracking phase, the position is determined by comparison with the received signal strength sample points stored in the database [10]. The accuracy of this system is a function of the sample points' sampling space, an estimation method and the structure of the database. However, such a method requires the time consuming survey procedure.

III. Handheld Indoor Directory System

A. System Overview

The proposed interactive floor directory system, named “Guide Phone”, is a solution to provide floor directory and indoor navigation services, by utilizing mobile phone itself as both an interactive directory panel and as a signal processing device for navigational purpose. In other words, the proposed solution intended to change the conventional way of providing indoor directory, which usually in the form of physical directory board located inside a building. The purpose of Guide Phone is to provide interactive, portable, customizable ways to navigate within an indoor environment. The following subsections present the features of the proposed “Guide Phone”.

1) Interactivity

Guide Phone is coined as interactive directory system, given that it capable of providing richer information contents, rather than just static information as in the conventional directory board. Additionally, users can request only the information which is in their interests. In other words, information is tailored and customized according to personal needs. For instance, users can search a specific location by name, level, or other characteristics. Richer information such as products, contacts, and direction can be provided to users. This implies significant time savings, enhanced user satisfaction and improved efficiency.

2) Location-Awareness Information

As the Guide Phone use WLAN-based positioning technique, it able to provide location–awareness information to users. As the most fundamental function, users can track their current location in the map. In advance, customized information can be sent to user when they are in certain positions, to provide further description or relevant information regarding the current surroundings. Specifically, shopping mall or commercial building can capture the benefit of this functionality to customize their advertisements and to increase the flow of crowd into their premises.

3) Not Required to Connect to Access Points

Apart from that, the positioning technique does not require the mobile device to connect to a wireless access point (AP) such as wireless router, but only need to detect the signal transmitted from the access points. This feature is valuable given the reason that it is common that most of the APs are encrypted with passwords, thus make the positioning system which require connection to the APs infeasible. Nevertheless, Guide Phone only needs to detect the strength of the wireless signal in order to estimate the location of the users.

4) Flexible and Self-Contained

Flexibility represents the capability of Guide Phone to use different maps with minimal efforts by downloading the map of particular building from the Kiosk provided or the management website. In other words, the capability of the Guide Phone is expandable to cover any new building or place. The Guide Phone is a self-contented system when it is in action. The sensor, signal processing application, database are all included in the mobile phone. Thus, the phone application can operate independently without request any service from server.

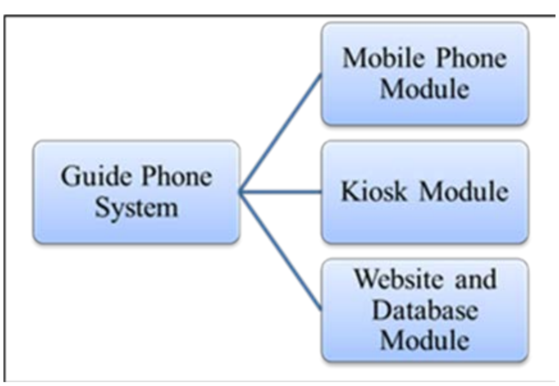


Fig. 1 Main Modules of Guide Phone System

B. Overall Architecture

The whole "Guide Phone" system consists of three main modules, namely mobile phone module, Kiosk module, and Website and Database module, as illustrated in Fig. 1.

1) Mobile Phone Module

Mobile Phone module is the application which installed on the users' mobile device. The purpose, input, operation, and output of the module are indicated as in Table 1.

Table 1 Description of Mobile Phone Module

Purpose • To enable searching of lots/rooms by user • To determine current location of user • To provide sufficient information of a lot/room.
Inputs • User's search request would be needed in order to perform the search functions. • 3 MAC address, latitudes, longitudes and signal strengths will be needed to calculate the current location of the user using triangulation. • User's selection of the lot/room will determine the result of the full details of the lot/room.
Operations • <u>Database and query function</u> A mobile database is stored internally in the mobile phone and contains all the data similar to the database of the web and the kiosk, which contain the maps and layout data. Users define the criteria used to search or filter the destination of interests. • <u>Wi-Fi detection function</u> To detect the available access points for triangulation purposes. It also includes functions to determine the access points with the strongest signal strength. • <u>Triangulation function</u> Consists of functions and algorithms to carry out triangulation based on the coordinates given in order to calculate the current location of the user based on the strength of wireless signals. • <u>Location mapping function</u> Location mapping consists of functions which enables the exact location of the user to be displayed in the form of an image so that the user can navigate around the area. Basically it displays the results of triangulation.
Outputs • List of search results. • The user's current location on a map. • Details on a lot/room selected by the user.

2) Kiosk Module

As part of the whole Guide Phone system, touch sensitive kiosks are provided in the building. Users can download the Guide Phone application and maps of the building from the Kiosk through Bluetooth or USB connection. Moreover, the Kiosks act as complementary facilities to cater for the needs of users whose mobile device does not has WiFi adapter. It provides the identical functions available to Mobile Phone module, with exception of the positioning tracking system. This is due to the reason that as the Kiosks are fixed in certain location, it does not make sense to provide the real-time positioning function.

3) Website and Database Module

The website and database can be described as the backend portion of the Guide Phone system. The main purpose of this module is to allow administrators to manage the maps and other data such as location of wireless points, details of rooms or premises, and so on. However, users can access to the frontend of this module to perform the exact same functions of Kiosk module, which are to download map, mobile module application, and search functions.

C. Hardware and Software Architecture

Fig. 2 indicates the overall hardware and software architecture of the Guide Phone system.

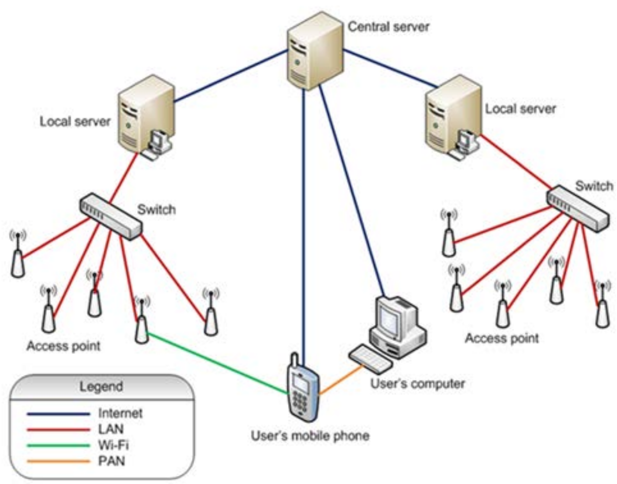


Fig. 2 Overall System Architecture

The central server will be the server hosting the website and database of Guide Phone. The central server will also store the latest Guide Phone application which can be downloaded by the user. The central server will provide access to the data stored to the local servers. The central server will be administered by an administrator who has access to all the local servers as well as the data stored in them.

The local servers reside on the location itself. For example, a shopping complex will have its own local server which will control many access points in the area. Therefore, the more areas implement the Guide Phone, the more local servers will be connected to the central server. The local server will be administered by the area's administrator who can edit and update the details regarding that area only.

The access points function as a guide for triangulation. Each access point will have its own location and with this information, triangulation for a user's current location can be determined. The access points can also function as a gateway for users to access the local server to get the Guide Phone application as well as the database and maps of that specific area.

There are two ways for the end user to download the Guide Phone application. One of it would be through direct download whereby the user can connect their phone to the Internet and then download the application to their mobile phones. Another method would be to access the website on the central server using a computer, download the application and transfer the application to the phone. After downloading the application, the user can now use the Guide Phone application.

D. Process Flow for End User's Operations

Firstly, a mobile user must turn on his mobile phone's Wi-Fi connectivity. After it is turned on, the user will start the Guide Phone application.

If the application is not yet available in the mobile phone, the user can download the application and the mobile database containing a location's data from the website. After the application is loaded, the user selects the database of his current location. If the database is not available, he can download it. Once the database has been loaded onto the application, the user can now access the functions of the application. The user can choose to search for a lot/room or search for his current location.

If the user wants to search for a lot/room, the user can search either by category, name or level. Once the search is complete, the list of search results will displayed in the user's mobile phone. The user can then select the exact lot/room he was looking for or search again. If the user selects a lot/room, the lot/room details would then be displayed along with the lot/room's picture. After getting the information needed, the user can opt to search for his current location, conduct a search again or end the application.

If the user selects to search for his current location, the application will then detect the access points available in the area and extract 3 access point's MAC address. If the access points cannot be detected, the application will refresh until a few access points are detected. These 3 access points have the strongest signal strength. The MAC address will then be stored into the phone and the mobile database will be accessed to find the coordinates of the access points based on their MAC address. With the coordinates, the current location of the user will be calculated using triangulation. The results will then be displayed to the user. The user can then opt to end the application or continue to browse around the application. The overall system use case diagram is shown in the appendix session, which provides the overall view of the system functionalities.

IV. System Implementation

The proposed system has been implemented in a building located in a university. The following subsection presents the main modules of the system.

A. Location Detection Module

If the users select to search for current location, the application will detect the signals of access points available in the area. If no access points can be detected, the application will keep refreshing until at least three access points are detected. In the case that at least three access points are detected, MAC addresses of the three strongest signals will be extracted and stored in the application.

The method used for access point detection is a method which uses the .NET Compact Framework for Windows Mobile. The first step would be to enable the application to detect the adapter used by the phone for Wi-Fi connection. After that, the application will then start detecting access points and it will keep refreshing until all access points needed are detected.

After that, the application will then extract the BSSID and the RSSI to be passed to the triangulation codes. In other words, after the access points are detected, the top three access points with the strongest signal strength will be selected and its information extracted from the database as indicated in Table 3. The information such as the location of the access point and the signal strength which will indicate the distance between the user and the access point will be passed to the triangulation function

B. Triangulation Function

Triangulation is the main concept that enables the detection of the user's current location. In order for triangulation to work, a minimum of three access points are needed to locate the exact location of the user. These three access points will provide the MAC address needed in order to get the location of each access point for triangulation purposes.

The most common triangulation or location detection method would be the one implemented by the Global Positioning System (GPS) system. The GPS utilizes its 27 satellites to determine the location of a person. It uses trilateration in a 3-dimensional way. A normal 2-dimensional trilateration uses the concept of determining a specific location by calculating the intersection point between three circles as illustrated in Fig. 4.

The d represents the radius of the access points. The access points are the centre of the circles. Thus, as seen above, there are three access points and the intersection of these three access points will determine the location of the user.

There are three basic methods in determining a specific location. However, each method would require a certain situation/ scenario in order for it to work. These scenarios are:

1. Angle and distance between the user and an established access point is known.

2. Angles are known but the distance between the user and the access points are unknown.
3. Distances between the user and the three access points are known but the angles are unknown.

Based on the above three scenarios, the most likely scenario would be the third scenario. Thus, the third method of implementation is to be carried out. The method used is similar to the method used by seismologist in determining the epicenter of an earthquake. The common GPS also uses a similar concept of triangulation. In order for the third method to work, the following requirements must be met.

- A minimum of three coordinates (coordinates of the access point) are needed to determine the location (coordinate) of the user.
- Distance between the user and the access points.

With the above information in hand, equations of circles are used to determine the intersection point of all three circles which will determine the location of the user. The trilateration algorithm used can be separated into 4 main parts. Table 4 shows the logics of the trilateration algorithm. The full implementation source codes are presented in Appendix B.

C. Location Mapping

Location Mapping is the function to display the coordination of user on the interface based on the coordination values retrieved from the database. There are a few methods available to enable mapping of the results from triangulation. Mapping is needed to display the result of the triangulation of the user's current location in a clearer way.

One of the methods would be to use Flash. Tiny SVG is a flash file that can be uploaded into a mobile phone as part of the application. However, it takes a lot of time to create applications using Tiny SVG and there are some issues with it when it comes to merging with C# applications.

Another method would be to hard code the function using the classes available from the Windows Mobile library. There are a few functions provided by the library for developers to create a Windows Mobile application.

The function for location mapping is coded from the library for Windows Mobile application. This method is easier as it ensures compatibility and it saves time. The triangulation codes will return a coordinate (in pixels) which indicates the current location of the user. The coordinates will then be plotted on the layout of the building and it will display to the user where they currently are. The sources codes for displaying the location map are presented in Appendix C.

D. Mobile Database

The main consideration in implementing a database in this system is the data storage and space needed by the database. Should the database be hosted on the server or downloaded along with the phone application itself? There are pros and cons to each method.

A database hosted on a server can be less taxing on the storage space of the phone as the user will merely need to access the server to obtain data from the database through a website. However, this method is susceptible to a single point of failure whereby the server will not be accessible to all its users. If too many users access the server at a time, the server may return results later causing the application to lag. Users who have the application in their phone but do not have internet connection will not be able to use the application as it requires connection to the database.

Downloading the phone along with the application brings about issues such as taking up too much storage space and it may cause the phone to lag. However, with an embedded database in the phone, the user is able to use the application anywhere regardless of whether the area has Wi-Fi connection or not for him to access the database server.

The chosen method of implementation is to enable users to download the application with the map itself. The logic behind this selection lies in the ease of accessibility for the end users. With a database inside the phone along with the application, the user can use the application again and again without having to download the map again or access the server multiple times.

Every different area that is mapped out using the Guide Phone application has their very own customized map. Users can choose a different map to download for every different area and they can delete the map that they no longer wish to use or are already obsolete. This will enable users to save storage space in their phone. The user is able to select the database based on the area they are currently at. The application will automatically connect to the selected database and the user can now use the application.

The software used to enable mobile database is SQL Anywhere 11 and MySQL Sybase SQL Anywhere Import, Export & Convert Software. The SQL Anywhere 11 is database management software that enables developers of Guide Phone to manage the database of a certain area. Along with MySQL Sybase SQL Anywhere Import, Export & Convert Software, the developers can export the database into a .udb file which can be saved into a mobile phone and is accessed by a mobile application.

There are a few downsides to the method implemented. One of it would be that the user would have to use a computer to transfer the database into the phone and the user will need to store the database in the same folder as the application in order for the application to detect the database. In order to ensure that the database is stand alone, the database has to be stored manually. Else if the application is packaged with the database, the end user will have to download a new application each time for a new location. This will bring up memory space issues.

E. *Interface of Mobile Phone Module*

The application is developed to run on Windows Mobile, using C# language. Fig. 5 shows one of the main interfaces which users can see the description of the building, and a menu of available actions is provided at the bottom. Fig. 6 illustrates the interface of search by category. Relevant results will be shown according to the category pre-assigned to the rooms.

Challenges faced for triangulation would be the conversion from the actual algorithm into the codes itself. There has been certain aspect that causes the algorithm to function incorrectly in the application. There has also been an accuracy issue with the triangulation as the results given may not be fully accurate or as precise as it should be. This may be due to the algorithm used. A more accurate algorithm would be needed.

F. *Interfaces of Kiosks and Website*

The Kiosks and website interfaces which accessible to the users are similar in terms of functionality. Fig. 9 shows a sample of the user interface on Kiosks. The functions available are identical to the functions offered in mobile phone module, with the exception of search by current location.

The option “search by level” implies the function will query the database to retrieve the room which on the level or floor that match the criteria selected by users. With the “search by name”, it provide the flexibility for user to customize the search by typing in the keywords that related to the room. The search current location shows the map with the real-time position of users, which shown in Fig. 7. By clicking on the area in the map, user can view the details of the particular selected area, as illustrated in Fig. 8.

A user can view the directory for the location. Upon hover over any lots, the area will be highlighted and the name for the lot will appear. User can also click on the lot to view further details. To make the kiosk accessible by even the blind users, a screen reader (NVDA, an open source screen reader for Windows) is used. Alternate texts are used for images to allow blind users to visualize the items which appear on the kiosk screen.

V. CONCLUSION

Although the implementation involves the most fundamental functionalities, but it is resulted in sufficient data and information for the purpose of assessing the practicality and technical feasibility of the Guide Phone system.

The proposed Guide Phone as a handheld directory system is promising innovation. Provided the pervasiveness of WiFi access points in current buildings such as shopping malls, office and administrative buildings, and tourism spots, the proposed Guide Phone system can be implemented with low cost by utilizing the existing infrastructures. In addition, Smartphones with WiFi adapter have penetrated the market in developing countries than ever before. WiFi or WLAN adapters have become necessities of modern mobile devices which not limited to mobile phone but also other devices such as tablet PC, netbook, and iPod. These imply that the proposed system can be implemented not only in Window Mobile platform, but can be used in other platform in the future.

Nevertheless, one of the limitations of the proposed directory is that the triangulation algorithm used to estimate the position of mobile device requires at least three WiFi access points in order to successfully function. Moreover, more sophisticated functions such as location-specific message, voice guided direction to destination, and inter-users connectivity can be introduced into the Guide Phone system in future.

REFERENCES

[1] WHO. (2009). *Visual Impairment and Blindness*. Available: http://www.who.int/mediacentre/factsheets/fs282/en/

[2] A. Hub, J. Diepstraten, and T. Ertl, "Design and Development of an Indoor Navigation and Object Identification System for the Blind," *SIGACCESS Access. Comput.*, pp. 147-152, 2004.

[3] B. Köbben, A. Bunningen, and K. Muthukrishnan, "Wireless Campus Lbs: Building Campus-Wide Location Based Services Based on Wifi Technology," in *Geographic Hypermedia*, E. Stefanakis, *et al.*, Eds., ed: Springer Berlin Heidelberg, 2006, pp. 399-408.

[4] G. Zàruba, M. Huber, F. Kamangar, and I. Chlamtac, "Indoor Location Tracking Using Rssi Readings from a Single Wi-Fi Access Point," *Wireless Networks*, vol. 13, pp. 221-235, 2007.

[5] S. Woo, S. Jeong, E. Mok, L. Xia, C. Choi, M. Pyeon, and J. Heo, "Application of Wifi-Based Indoor Positioning System for Labor Tracking at Construction Sites: A Case Study in Guangzhou Mtr," *Automation in Construction*, vol. In Press, Corrected Proof, 2010.

[6] A. Bose and F. Chuan Heng, "A Practical Path Loss Model for Indoor Wifi Positioning Enhancement," in *Information, Communications & Signal Processing, 2007 6th International Conference on*, 2007, pp. 1-5.

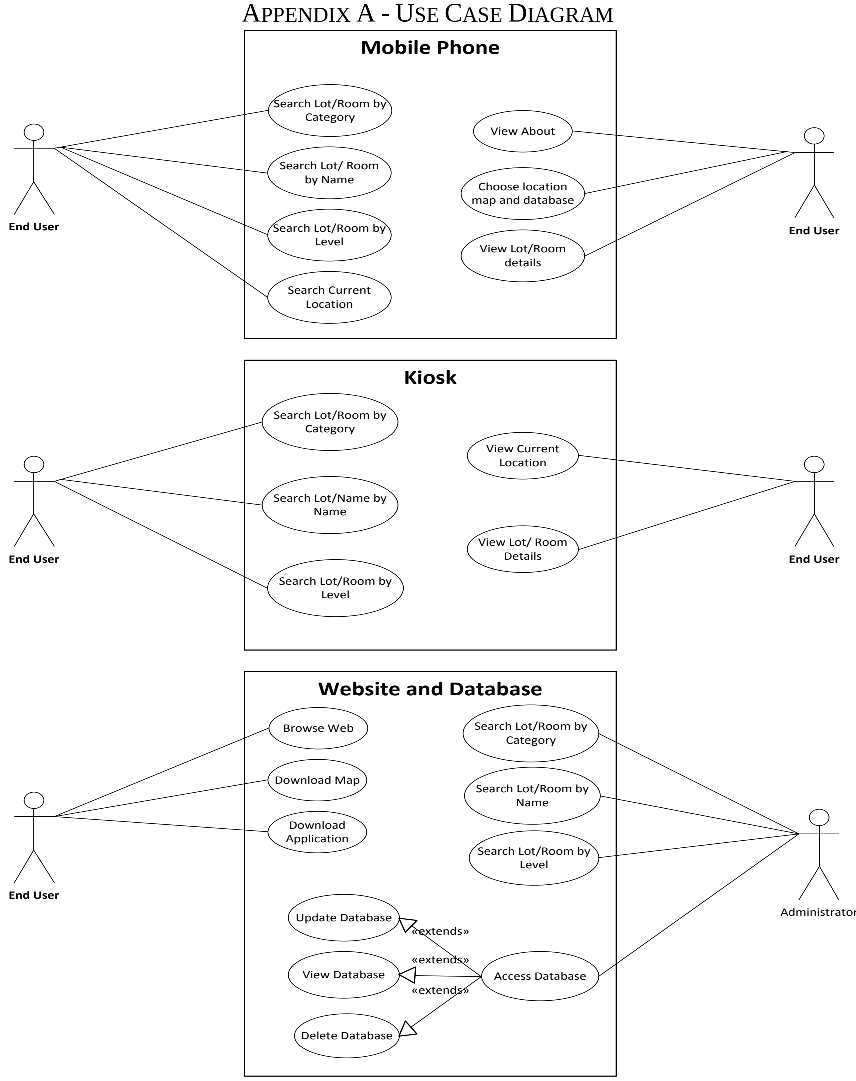
[7] A. Kotanen, M. Hannikainen, H. Leppakoski, and T. D. Hamalainen, "Positioning with Ieee 802.11b Wireless Lan," in *Personal, Indoor and Mobile Radio Communications, 2003. PIMRC 2003. 14th IEEE Proceedings on*, 2003, pp. 2218-2222 vol.3.

[8] R. Yamasaki, A. Ogino, T. Tamaki, T. Uta, M. Matsuzawa, and T. Kato, "Tdoa Location System for Ieee 802.11b Wlan," in *Wireless Communications and Networking Conference, 2005 IEEE*, 2005, pp. 2338-2343 Vol. 4.

[9] M. Ciurana, F. Barcel, and S. Cugno, "Indoor Tracking in Wlan Location with Toa Measurements," presented at the Proceedings of the 4th ACM international workshop on Mobility management and wireless access, Terromolinos, Spain, 2006.

[10] Z. Xiang, S. Song, J. Chen, H. Wang, J. Huang, and X. Gao, "A Wireless Lan-Based Indoor Positioning Technology," *IBM J. Res. Dev.*, vol. 48, pp. 617-626, 2004.

APPENDIX A - USE CASE DIAGRAM



APPENDIX B - SOURCE CODES: TRILATERATION ALGORITHM

```
public class Triangulation
{
 public Triangulation()
 {
        int dist_1, dist_2, dist_3;     //variable for the distances
        int x1, x2, x3;                 //coordinates of x
        int y1, y2, y3;                 //coordinates of y
        int final_dist1, final_dist2;   //final distance after calc

        dist_1 = 1;
        dist_2 = 2;
        dist_3 = 3;

        x1 = 5; //test inputs
        x2 = 2;
        x3 = 4;

        y1 = 2;
        y2 = 2;
        y3 = 5;

final_dist1 = ((dist_1 * dist_1) - (dist_2 * dist_2) –
                     (x1 * x1) + (x2 * x2) - (y1 * y1) + (y2 * y2)) / 2;
final_dist2 = ((dist_2 * dist_2) - (dist_3 * dist_3) –
                     (x2 * x2) + (x3 * x3) - (y2 * y2) + (y3 * y3)) / 2;

        initial_a1 = x1 - x2;
        initial_a2 = x2 - x3;
        initial_b1 = y1 - y2;
        initial_b2 = y2 - y3;

//----------------------STEP 1------------------------------------

        int a1 = initial_a1 / initial_a1;
        int a2 = initial_a2 / initial_a1;
        int b1 = initial_b1 / initial_a1;
        int b2 = initial_b2 / initial_a1;
        final_dist1 /= initial_a1;
        final_dist2 /= initial_a1;


//----------------------STEP 2------------------------------------

        a2 = a2 -a2;
        final_dist2 = -(initial_a2) * final_dist1 + final_dist2;

//----------------------STEP 3------------------------------------
        a2 /= b2;
        final_dist2 = final_dist2 / b2;
        b2 /= b2;

 //-----------------------STEP 4----------------------------------

        b1 = b1 - b1;
        final_dist1 = -(initial_b1) * final_dist2 + final_dist1;
 }
}
```

APPENDIX C - SOURCE CODES: LOCATION MAPPING

Location Mapping

```
private void Retrieve(double coord_x, double coord_y, int lvl)
        {

            double valueX = Math.Abs(final_x);//get triangulation coord
            double valueY = Math.Abs(final_y);
            coord_x = (int)Math.Round(valueX);
            coord_y = (int)Math.Round(valueY);
            lvl = macLvl;

            try
            {
                using (ULCommand cmd = ConnUL.CreateCommand())
               //for later use in calling location
                {
                    String db = dbname.Replace(".udb", "");
                    String imagepath =
(System.IO.Path.GetDirectoryName(System.Reflection.Assembly.GetExecutingAssembly().GetName().CodeBase)
+ "\\Maps\\" + db + "\\level" + lvl + ".png");
                    //get the level map and display
                    try
                    {
                      // load image
                        Bitmap image1=new Bitmap(imagepath);
                        int x, y;

                        for (x = 0; x < image1.Width; x++)
                          {
                           for (y = 0; y < image1.Height; y++)
                             {
                                 if (x == coord_x && y == coord_y)
                                  //mark the coords
                                  {
                                    usericon.Location = new          System.Drawing.Point(x, y);
                                   }//end of internal for
                               }//end of external for
                             }

                       // Set the PictureBox to display the image.
                                    LevelImg.Image = image1;
                    }
                    catch (FileNotFoundException e)
                    {
                        MessageBox.Show("Error: " + e.Message + "No level image found.");
                    }

                }
            }
            catch (Exception err)
            {
                MessageBox.Show("Error: " + err.Message);
            }
        }
```