A Smart Indoor Navigation System over BLE

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***Abstract*—Navigation is the process of the user positioning and redirecting to their desired destination. Nowadays, people majority use Global Positioning System (GPS) for outdoor navigation process. However, the lack of GPS signal reception inside the buildings makes indoor navigation process an interesting challenge. In this paper, a new indoor navigation system based on Bluetooth Low Energy (BLE) is proposed. Moreover, a more efficient routing technique based on A* algorithm is utilized. Finally, a local web application for navigation through the third floor, building 8, Faculty of Engineering, Cairo University is demonstrated.**

***Index Terms*—GPS, Indoor Navigation System, Bluetooth Low Energy, A* Algorithm, iBeacon.**

I. Introduction

The Global Positioning System (GPS) is the most common satellite navigation system. However, GPS has its limitations. GPS satellites fail to accurately determine the user's position inside buildings due to the lack of the reception. Therefore, an alternate method should be considered to achieve indoor navigation on a smartphone.

Due to the rapid growth of people dependency on smartphones to solve their daily problems. One of these problems is indoor navigation. Indoor navigation systems help people, who are unfamiliar with the inner structure of the building, to move freely inside these buildings. Moreover, indoor navigation systems are very helpful, especially at tourist attractions. Tourists, for instant, will have a better experience if they can move freely and confidently inside a museum. In addition, they are very helpful in shopping malls and airports. Also, some stores can provide specific information about products on sale or available promotions while navigating users to the required destination.

It is preferable to use simple and common technology with indoor navigation systems. Using methods based on the magnetic field provides high accuracy, but it is pricey and cannot be easily made available to the public. So, most positioning systems tend to rely on Radio Frequency (RF) signals such as those emitted by Wi-Fi Access Points and Bluetooth devices. It is easy to use these methods because nowadays, nearly all mobile phones are equipped with both Wi-Fi and Bluetooth adapters.

The objective of this project is to build a robust and flexible BLE based indoor navigation system that meets the following criteria. The application should locate users' position accurately. The application also should not require any expensive infrastructural changes to obtain accurate positioning data. Clients will not be interested in large investments unless they financially benefit from it. It is also recommended to have an easy-to-use User Interface (UI) that displays navigation hints correctly based on the user's current state.

II. Background

In this section, several indoor positioning systems are discussed. Most of these systems are based on Radio Frequency technologies. One of the earliest location systems is Active Badge [1]. In this system, a badge is pinned to the user; each badge emits infrared signals every ten seconds. Certain receivers receive these signals then send them to a central server. But, there are several shortcomings of this system, the accuracy of the location depends on the number of the receivers. Also, the range of the infrared signals is short[1]. There are other location systems like mTag[1] that is based on RFID (Radio Frequency Identifier), and other famous systems such as RADAR, PlaceLab, and Herecast that use Wi-Fi[1].

There are several techniques for indoor positioning like the trilateration method, fingerprinting technique, and Cell-ID technique. There are several proposed papers that use different techniques. Tushar Gothivarekar and Ajay Motwani have presented a paper [2] for an indoor navigation system that uses a different technique. They used Wi-Fi instead of BLE and fingerprinting technique for indoor positioning. Fingerprinting technique in more accurate than trilateration, but is not accurate in determining the precise position in selected cell size.

Min-Seok Choi and Beakcheol Jang also proposed a more accurate technique for indoor positioning [3]. They used fingerprinting technique and to improve the accuracy, K-NN algorithm and moving average filter are used. They tested different techniques in the same situation. The results show that the accuracy of this method is 86%, which is better than the accuracy of fingerprinting method 72.58%, and triangulation method 45.63%.

There are other researches like "Indoor Location Tracking using Received Signal Strength Indicator" [4]. This research uses the received signal strength indicator (RSSI) from Beacons to calculate the distance from the user and each Beacon. After calculating the distances, trilateration method is applied to determine the user's location.

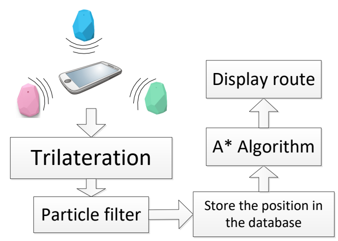

Figure 1. The proposed indoor navigation system Flow

III. Proposed Indoor Navigation System

Fig. 1 portrays the proposed indoor navigation system flow. Firstly, the scanner (smartphone) reads the packets from iBeacons where the minimum number is three iBeacons. If the scanner received less than three points, Trilateration will ignore these readings and take the previous three readings of packets, then sends it to the server to pass through the same flow shown in Fig. 1.

A. Trilateration

Trilateration[4] is used to find an unknown location from at least three known locations. Trilateration uses the distances from each of the known locations to determine the coordinate of the unknown location [4]. The distances between reference points (Beacons location) and the unknown point (User's location) can be treated as the radii of the circles with centers at every reference point. Thus, unknown location is the intersection of all the spherical surfaces as shown in Fig. 2. The distance between the beacons and the smart-phone is calculated by measuring the Received Signal Strength (RSS) that comes from the Beacons.

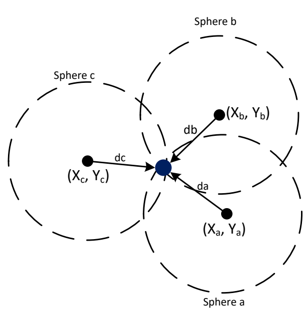

Figure 2. Trilateration Estimation which shows the concentric circles used by the RSSI ranging technique to calculate the position using R1, R2, R3. The mobile node is at the center-point of all three circles of each anchor node[4].

There are three nodes that are randomly allocated with known location R1(X_a, Y_a), R2(X_b, Y_b), R3(X_c, Y_c). Node (x, y) at unknown coordinates can be calculated using reference nodes R1, R2, and R3 and the distances d_a, d_b, d_c and between the reference nodes and the unknown target node.

B. Particle Filter

A Bayesian filter is used to determine the state of any system that changes with time using a sequence of noisy measurements made on the system [5]. The particle filter is a way of implementing the recursive Bayesian filter by Monte Carlo simulations. The key feature here is to represent the required posterior density function by a set of random samples with associated weights and to compute estimates based on these samples and weights. The particle filter is used to increase the accuracy of determining the user's position. If the trilateration is used only, the accuracy will not be high, and this might cause some problem in narrow structured buildings[3].

C. A* Algorithm

To reach the destination, knowing only the position is not enough. Thus determining the shortest route to the destination is very important.

A* algorithm[6] is an extension of the Dijkstra's algorithm. Dijkstra's algorithm[7] is slower compared to A* because Dijkstra's improves an initial approximation (cost) of each node repeatedly. Due to this, it takes more time to reach the target node.

Let's assume that we have someone who wants to get from point A (green cell) to point B (red cell). Let's assume that a wall separates the two points (blue cells). This is illustrated below in Fig. 3.

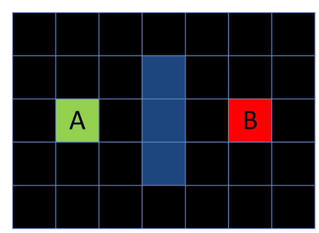

Figure 3. The map is divided into small cells; the starting cell is colored with green and the ending cell is colored with red.

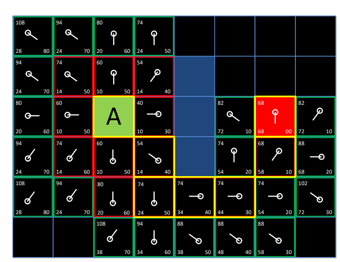

Figure 4. The map after A* Algorithm, each cell has three numbers, G is located in the lower left of the cell, H is located in the lower right of the cell and F is located in the higher left of the cell. There is also an arrow in each cell pointing towards the cell that gives it the lowest F. The shortest path is donated by the boxes with the yellow boarder.

The first thing you should notice is that the search area is divided into square grids (cells). Simplifying the search area is the first step in pathfinding. This particular method reduces the search area to a simple two-dimensional array. Each item in the array represents one of the cells, and its status is recorded as available or unavailable. The route is found by figuring out which cells we should take to get from A to B. The first thing to do now is finding the shortest route between these two cells. Here are the main parameters for selecting the shortest path based on A* algorithm:

- G is the cost to move from the starting cell to a certain cell through the route specified.
- H is the cost to move from a certain cell to the ending cell. It is only possible to move vertically or horizontally regardless of the obstacles.
- F is the sum of G and H.

The first step is to calculate F for all the adjacent cells to the starting cell except for the unavailable cells (wall). Then move to the cell that has the lowest F. This process is repeated until the ending cell is reached.

The map after A* algorithm would be similar to the map shown in Fig. 4. Then, to determine the shortest route, start from the ending cell and move from this cell to its parent, or move in the same direction of the arrow, this should move you all the way back to the starting cell. The shortest path is donated by the boxes with the yellow boarder. Note that the pointer in a cell points towards the cell that gave it the lowest value of F.

IV. Proposed System Hardware Implementation

There are several technologies for indoor navigation, but the most used technologies are Wi-Fi and Bluetooth. Understanding these technologies is essential to choose which one to implement as a smartphone application or any other kind of micro-location system.

A Wi-Fi Technology is a good alternative to GPS inside buildings. It is preferable to use Wi-Fi because there are Wi-Fi access points already installed in many buildings. The strength of the Wi-Fi signals (received signal strength indication (RSSI)) and the MAC address (media access control) are significant. Although the Wi-Fi range is wide (up to 100m) [8], the accuracy of this technology is not high (5-15m). On the other hand, Bluetooth is more accurate.

A. Bluetooth Low Energy (BLE)

In the last few years, a lot of things happened on the Bluetooth market. The concept of this technology is not new, the Bluetooth technology itself has been well-known since the 1990s. But recently a whole new application scenario has occurred, originating from the energy saving Bluetooth version BLE (Bluetooth Low Energy). Bluetooth is another good alternative to GPS. The BLE can detect the user's position accurately up to 1m. And it is compatible with both iOS and Android. In addition, the power consumption is low. On the other hand, the BLE technology requires additional hardware.

B. Estimote iBeacons

They are tiny, low-power computers that can be attached to walls or objects. Using proximity technologies, they detect human presence through their mobile phones and trigger pre-programmed actions delivering contextual and personalized experiences [9]. Beacons are small, often inexpensive devices that provide a more accurate location within a narrow range than GPS or Wi-Fi proximity. Beacons transmit small amounts of data through Bluetooth up to 50 meters, so they are often used for indoor localization technology.

Estimote Beacons broadcast tiny packets of data containing their Mac Address and iBeacon ID. Information about the signal strength (RSSI and RSSI per Meter (A)) is defined at the scanner to be used in determining the position [10] so that the phone can determine which beacon it hears and how far it is. The size of iBeacons ID is 20 bytes and is divided into three sections:

- UUID (16 bytes).
- Major number (2 bytes).
- Minor number (2 bytes).

Each kind of beacons has the same UUID, for example, all Proximity Beacons have the same UUID (B9407F30-F5F8-466E-AFF9-25556B57FE6D) and all stickers have the same UUID, and the major and minor numbers are used to differentiate between different beacons. You can change major, minor or UUID from estimate application but you must be the owner of the beacons, or the owner can transfer the beacons to your account so that you can change any parameter. In this application, a constant number for the major of each kind of the beacons is set as follows.

- Estimote Beacons Major = 150.
- Sticker Beacons Major = 151.
- Location Beacons Major = 153.

C. Raspberry Pi

Raspberry Pi is a low-cost, basic computer that was originally intended to help spur interest in computing among school-aged children. There are several versions of the Raspberry Pi, but the version that is used in this project is Raspberry Pi 3. The Raspberry Pi acts as a scanner. The scanner code is written with Python. It receives the packet through Dongle Bluetooth USB which is connected to Raspberry PI. This dongle can detect any Bluetooth device not only Beacons. Therefore, the packets need to be filtered to consider only Beacons packets. After receiving the Beacons packets, the Raspberry Pi extracts the Beacons ID, RSSI and RSSI per meter (A), then sends them to the local host, which is the laptop in this case. The connection between the computer and the Raspberry Pi is established using SSH communication. The local host then analyses these data and then calculate the distance between the Raspberry Pi and each Beacon.

V. Proposed System Software Implementation

A. Backend

The backend or the server side is basically how the site works, updates and changes. This refers to everything the user can't see in the browser, like database and servers. Backend development is essential in creating a dynamic site. A dynamic site is a site that changes continuously and updates in real time. A database is required for a dynamic site to work properly. PHP is the main language used in web developing. It is the server-side programming language. Since the database understands this language, PHP helps us to send and get requests from and to the database like MySQL.

1) LAMP: The LAMP platform consists of four components that are structured in a layered way [11] as shown in Fig. 5. Each layer or component is essential for the entire software stack to work.

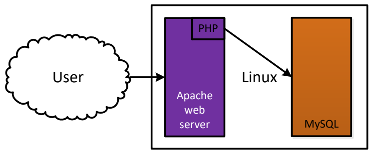

Figure 5. LAMP platform

- Linux is the lowest-level layer in the LAMP platform. It provides the operating system and runs each of the other components.
- Apache is the web server. Apache provides the mechanics for getting a web page to a user. It is used together with PHP to create dynamic pages.
- MySQL provides the data-storage side of the LAMP system.
- PHP is a simple and efficient programming language that provides the glue for all the other parts of the LAMP system.

PhpMyAdmin is used to create the database. PhpMyAdmin is a free and open source administration tool for MySQL. MySQL database is used to store information about the places inside the building and their coordinates and the number of people who visited these places. The database is written with PHP and JavaScript.

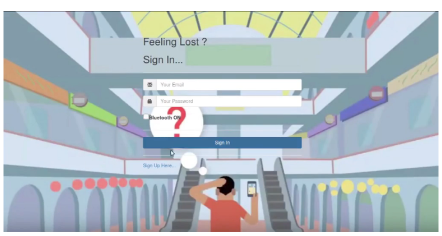

Figure 6. Locally Hosted Website Interface Page

B. Front End

The front end is considered as everything the user sees. When the user opens the web page to use BLE indoor navigation system, the web page detects his place and asks him to enter his destination. Then the system will show the path he will go through to reach his destination easily. The web page is designed with PHP and JavaScript. It is created on a local host. The web page is capable of communicate with the database to find the user's location and his destination; then through the A* algorithm code, which is written with Python, it detects the shortest path then displays it to the user.

VI. Experimental Results

The proposed indoor navigation system is launched as a pilot trial on the third floor, building 8, Faculty of Engineering, Cairo University. Firstly, the users need to sign in/sign up on a locally hosted website as shown in Fig. 6. Following that the web application asks the user for the required destination; then the shortest path is calculated. Moreover, Fig. 7 shows the shortest path between two points where the user is being tracked by Beacons to make sure that he/she is following the shortest path for the destination. And Demos are located at (https://youtu.be/DAG6lTr0Wt4 - https://youtu.be/kk1UsJZOqT0).

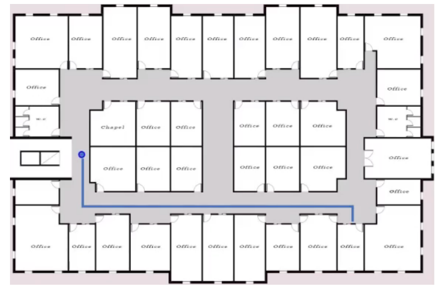

Figure 7. The shortest path displayed. This is the map of the third floor, building 8, Faculty of Engineering, Cairo University

VII. Conclusion

Indoor navigation systems have a promising future, especially with the increased use of smartphones. In this paper, a smart indoor navigation system over BLE is demonstrated. The proposed system utilizes a Raspberry Pi board as a scanner. While using estimote iBeacons for floor planning the scanned area. Moreover, the users' position is determined then navigated based on A* algorithm. Finally, a low-power consumption is achieved using BLE and iBeacons with a good navigation accuracy using A* algorithm.

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