A Mobile Indoor Positioning System based onWi-Fi and Bluetooth Technologies

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Abstract-Due to the lack of accuracy and robustness, Indoor Positioning System has now become a major with huge concerns worldwide especially with the rapid increase in multimedia services and data. Therefore, there is a need to enhance the accuracy of indoor localization by exploiting the capability of the available technologies. In this paper, a hybrid indoor localization system that is based on Wi-Fi and Bluetooth Low Energy (BLE) communication technologies is proposed. The main infrastructure of the proposed system is to use Wi-Fi tritleration method to determine the position of users at indoor areas based on Wi-Fi signal strengths. Then, the position obtained by the Wi-Fi tritleration method is used to check whether the user exists within one of the indoor locations supported by BLE or not. This enables the localization process with beacons to get higher indoor positioning accuracy than Wi-Fi. Experimental results show that the proposed system can achieve average error of less than one meter compared with the existing indoor positioning systems. This vindicates the suitability and reliability of the proposed system.

Keywords: Indoor positioning, Localization, Wi-Fi trilateration, Beacons

I. Introduction

Indoor spatial awareness attracts attention from both industry and academia. The contribution of indoor based localization services is of particular importance as many of us spend considerable portions of their daily lives at indoor spaces. As an example, the indoor navigation service can help in guiding users in large shopping areas to provide them with better shopping services by required time needed. Moreover it can be used as alert service in airports to notify passengers of their flights and boarding gates to avoid any departure delays or missing. Indoor localization services are getting benefit from the availability of low cost and reliable technologies available such as ZigBee, Wi-Fi, Bluetooth, RFID and Ultra-Wide Band(UWB) and other types of technology [1]. Among these technologies the targeting of both Wi-Fi and Bluetooth has major advantages because of their high efficiency [2][3]. Due to the signal attenuation when using Wi-Fi technology at indoor localizing, the shows primitive results of accuracy and requires high complex technology in order to improve the accuracy [4]. Due to the high cost of deploying beacons in large indoor spaces, Bluetooth low energy devices are only located in small areas in order to partition areas where Wi-Fi signals are weak due to the building infrastructures such as doors and walls. In this research we propose a hybrid indoor positioning system that employs both Wi-Fi and Bluetooth communication technologies. In this context, the proposed system uses Wi-Fi tritleration method to get the relative users location and further this result is used to check if the user is ranged within a BLE scope where beacons is used to enhance the accuracy of indoor localization [5].

The paper is organized as follows: section II describes the related work in indoor positioning, section III describes the system architecture of the proposed system along with the implementation details, while section IV discusses the conducted experiments and shows the results obtained. Finally the paper is concluded in section V.

II. Related Works

Indoor Positioning System Using Wi-Fi Bluetooth Low Energy Technology [6] exploited the feature of Wi-Fi signal detection using android smart-phones, where an applicationis built for user positioning in indoor environments. For testing purposes, pre-installed Wi-Fi access points and Beacon devices based on Bluetooth Low Energy (BLE) technology are used for indoor positioning using classical RSSI based trilateration algorithm. In this context, a developed Android applications is used for indoor positioning. It is based on RSSI measurements for the pre-installed Wi-Fi access points which export to BLE based technology using Estimote beacon devices (or Eddystones). Eventually, a comparative study is carried out to examine the reliability and applicability of using Wi-Fi and BLE technology for indoor positioning. Experiments show that the use of Wi-Fi gives average accuracy of 77.59% and 88.41% for x-coordinate and y-coordinate respectively. When BLE technology is used, two different scan results are obtained; the first with average accuracy of 96.61% for x-coordinate and 66.10% for y-coordinate, while and the second scan with accuracy 81.5% for x-coordinate and 80.5% for y-coordinate. On average, the overall accuracy is 89.10% for x-coordinate and73.3% for y-coordinate.

III. Proposed System

In this approach, we propose a system that uses Wi-Fi trilateration [4] technique integrated with Bluetooth beacons by partitioning to get an exact indoor position of the user, and then when the user enters his destinations the system provides a full optimal and shortest path to navigate the user to his destinations [7]. Our system consists of three components. The user interface, algorithms, techniques, and database. The user interface consists of a destination list module and a map module, which allows the user to input or search for his desired destination, and views the map respectively. The search results access the trilateration technique in order to locate the user indoor location and each product sections and this data is processed by path optimization algorithms [8] in order to give a shortest path to the user from his indoor location to the product. The database component contains Retail's inventory and Retail's floor plan modules. The Retail's inventory modules interact with the keyword search by gathering the product information and their respective location. The Retail's floor plan modules provide information to the path optimization algorithm to generate maps and locations of products [9].

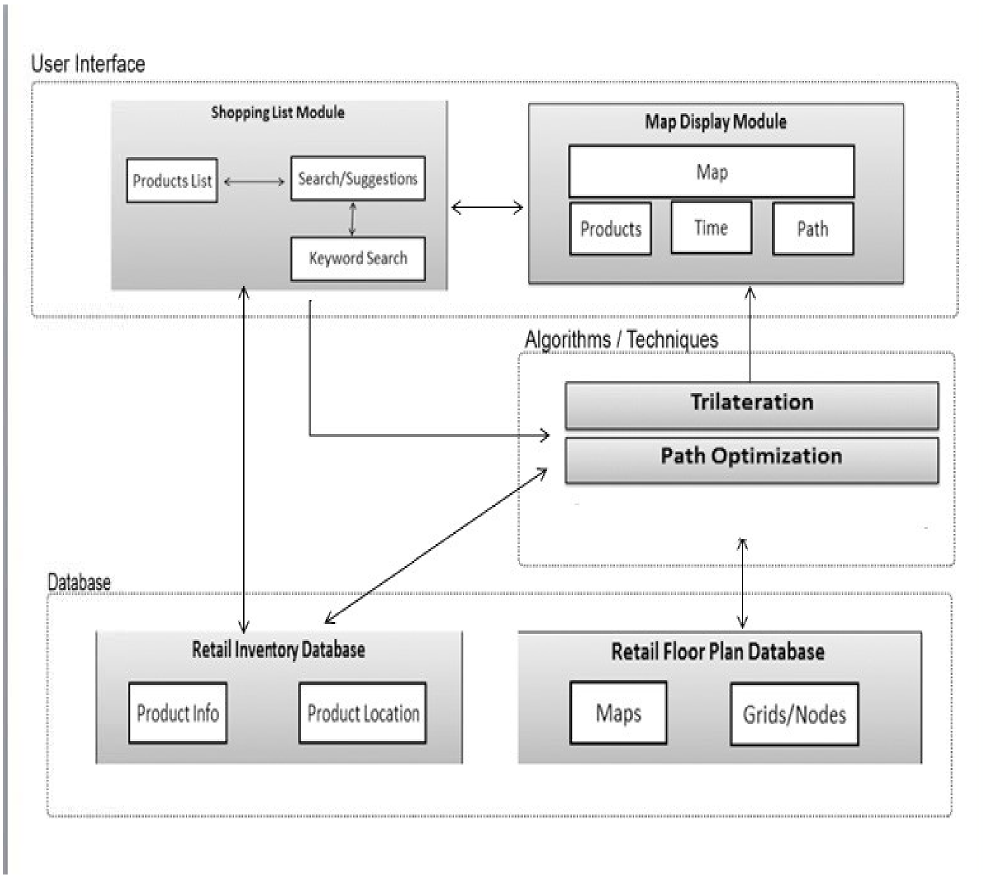

Figure 1: The proposed system infrastructure

A. Positioning Algorithm

The trilateration algorithm is able to locate a certain device in an indoor location [4]. This is achieved by determining the relative location of the user by a geometrical distance measure.The distances are calculated using various signal measurement techniques such as ReceivedSignal Strength (RSS), at least three Wi-Fi access points are needed to form a circular equation:

$$(x-a_1)^2+(y-b_1)^2=r_1^2 \quad (1)$$

$$(x-a_2)^2+(y-b_2)^2=r_2^2 \quad (2)$$

$$(x-a_3)^2+(y-b_3)^2=r_3^2 \quad (3)$$

where the $r_i$is the distance between the device and the access point $i$and is calculated by the free space pass loss (FSPL) as follows:

$$\begin{aligned} FSPL(db) &= 10log_{10}((\frac{4\pi}{c}rf)^2) \\ &= 20log_{10}(\frac{4\pi}{c}rf) \\ &= 20log_{10}(r) + 20log_{10}(f) + 20log_{10}(\frac{4\pi}{c}) \\ &= 20log_{10}(r) + 20log_{10}(f) - 147.55 \end{aligned} \quad (4)$$

The distance (*r*) is calculated in Kilometers (KM) and the frequency (*f*) in GHz. If the distance is in meters and the frequency in MHZ, the used free space pass loss (FSPL) will be as follows

$$FSPL\ (db) = 20log_{10}(r) + 20log_{10}(f) - 27.55 \quad (5)$$

By solving the above equations, the relative location of the user can be obtained as follows:

$$x = \frac{[r_2^2 + a_1^2 + b_1^2 - r_1^2 - a_2^2 - b_2^2 - 2(b_1 - b_2)y]}{2(a_1 - a_2)} \quad (6)$$

$$y = \left[\frac{(a_2 - a_1)(a_3^2 + b_3^2 - r_3^2) + (a_1 - a_3)(a_2^2 + b_2^2 - r_2^2) + (a_3 - a_2)(a_1^2 + b_1^2 - r_1^2)}{2[b_3(a_2 - a_1) + b_2(a_1 - a_3) + b_1(a_3 - a_2)]}\right] \quad (7)$$

Therefore, the relative user's location is used by the system to check whether the user has entered a specific area that is supported by Bluetooth beacons to get the exact users indoor position.

B. Minimum Spanning Tree (MST)

A minimum spanning tree (MST) or minimum weight spanning tree is a subset of the edges of a connected, edge-weighted (un)directed graph that connects all the vertices together, without any cycles and with the minimum possible total edge weight. That is, it is a spanning tree whose sum of edge weights is as small as possible. More generally, any edgeweighted undirected graph (not necessarily connected) has a minimum spanning forest, which is a union of the minimum spanning trees for its connected components. Movers will use MST in order to find a navigation route along certain path which will be based on customer product list as the MST is the optimal solution to make the customer pass by all sections in the customers desired product list; there will be graph representing (sections of products) connected by this path to represent all sections [10].

Dijkstra algorithm is used to find the optimal rout between the users position and a single destination manually entered by the user.

C. Hardware components

- Mobile smart phone based on Android connected to Wi-Fi [11].
- Wireless Ethernet IEEE 802.11 (Wi-Fi) [12]
- BLE based technology using Estimote beacon devices [14][15]

Indoor localization is about replicating the GPS technology but without satellite coverage. This can be achieved by installing a set of of location Beacons throughout the space which automatically map and create a floor plan of the UWB radio signal. In this paper, Estimote Location Beacons auto-mapping technology are used [13]. In addition, smartphones with android operating systems can gain access to precise indoor position with Cartesian coordinates [13][14]. The following points should be considered when using the Beacons:

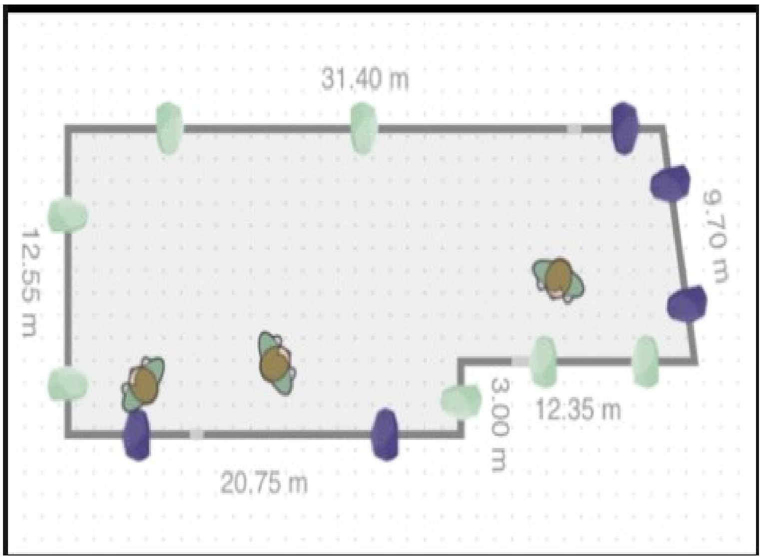

Figure 2: A map with Beacons installed

- Broadcasting Power: Broadcasting Power (or Transmit Power) is the power with which the beacon broadcasts its signal. In Estimote Beacons, one can change the power with the Estimote Software Development Kit (SDK), the Cloud interface, or a developed application. The power value ranges from -40 dBm to +4 dBm.
- Advertising Interval: Beacons do not broadcast constantly and blinking instead. Advertising Interval describes the time between each blink. Just as with Broadcasting Power, Advertising Interval on beacons can be adjusted with Estimote SDK, Cloud, and the app.
- RSSI: RSSI stands for Received Signal Strength Indicator. It is the strength of the beacon's signal as seen on the receiving device, e.g. a smartphone. The signal strength depends on distance and Broadcasting Power value. At maximum Broadcasting Power (+4 dBm) the RSSI ranges from -26 (a few inches) to -100 (40-50 m distance).
- Measured Power: Measured Power is a factory-calibrated, read-only constant which indicates the expected RSSI at a distance of 1 meter to the beacon. By combining with RSSI, it allows you to estimate the distance between the device and the beacon.
- Proximity Zone: It allows the establishment of customized proximity zones with a code and enablethe interaction when a user is gettinginside or outside each zone.

IV. Experiments and Results

A. Data collection and Localization using Wi-Fi Tritleration

In our experiments, a smartphone with Android operating system (version 6) is used as a positioning terminal and an experimental indoor site of area 171 m^2. The site has three WiFi access points (AP1, AP2, and AP3) in which the access points AP1 and AP2 are installed in different rooms, while the access point AP3 is placed in the corridor as shown in Figure 3. As shown, the access points coordinates are (4.8 , 7.5), (5 , 2.5), and (0 , 0) respectively. It should be noted that a Wi-Fi analyzer is used to monitor and record the signal strength of the access points. The localization error obtained by the tritlateration technique is ranging from 2 to 4 meters. These results are affected by the indoor surroundings such as walls, obstacles, and gates between the access points. The red dots in Figure 4 show the actual position while the green dots show the experimental results, where the average error is 2.411m.

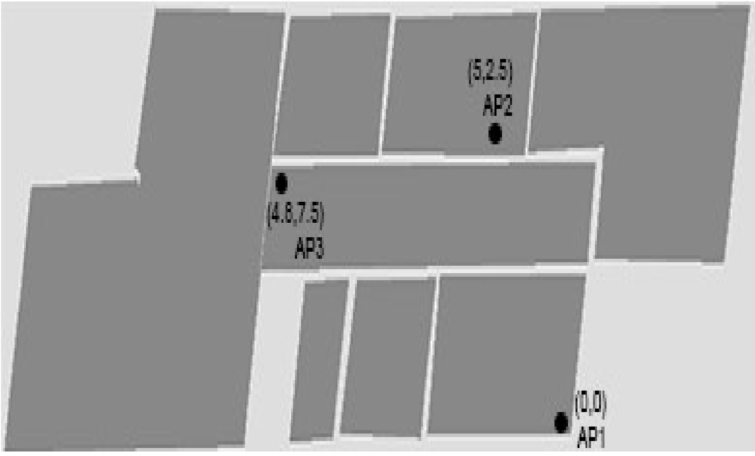

Figure 3: Access Points Coordinates

Table 1: Experimental Results with Tritleration Technique

Test Points	Actual coordinates	Estimated coordinates	Error
1	(2.50 ,1.10)	(1.60 , 2.60)	1.74
2	(4.25 , 4.20)	(6.60 , 5.50)	2.68
3	(5.50 , 6.30)	(6.70 , 7.90)	1.84
4	(6.40 , 9.10)	(7.20 , 12.7)	3.67
5	(7.90 , 11.1)	(10.2 , 13.0)	1.91
6	(8.80 , 10.2)	(9.70 , 11.4)	2.34
7	(9.20 , 12.5)	(8.10 , 11.7)	2.77
8	(9.50 , 14.7)	(8.60 , 13.1)	2.38
9	(9.80 , 11.1)	(10.5 , 11.9)	2.73
10	(9.60 , 15.3)	(9.00 , 14.8)	2.11

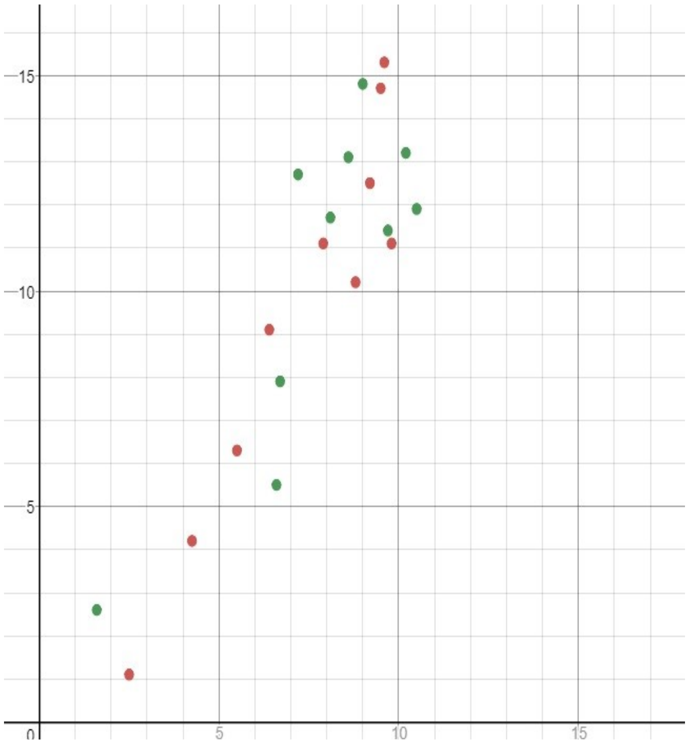

Figure 4: Tritleration Results

B. Proposed Data collection and Localization

Similar experiments are carried out with the same setup for a room with area of 12 m^2 covered with beacons as shown in Figure 5. The results collected from the previous test has helped in detecting the region in which the beacons are placed inside the room and the below test compares between localization of Wi-Fi Tritleration and Bluetooth inside the room.

Table 2: Testing results using Wi-Fi with two meter average error

Test Points	Actual coordinates	Estimated coordinates	Error
1	(0.0 , 1.0)	(1.80 , 1.60)	1.99
2	(2.0 , 2.0)	(3.8 , 3.1)	2.11
3	(2.5 , 3.0)	(3.5 , 4.8)	2.05
4	(3.5 , 2.7)	(5.0 , 3.9)	1.92
5	(4.0 , 3.3)	(6.0 , 4.5)	2.33

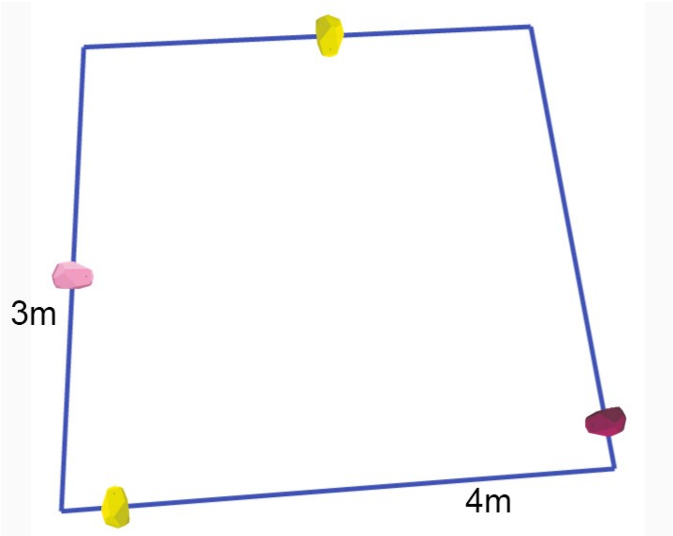

Figure 5: A room with Beacons installed

Table 3: Testing results using Beacons with one meter average error

Test Point	Actual coordinates	test coordinates	actual error
1	(0.0 , 1.0)	(1.2 , 2.0)	1.5
2	(2.0 , 2.0)	(2.8 , 3.1)	1.3
3	(2.5 , 3.3)	(3.5 , 4.5)	1.6
4	(3.5 , 2.7)	(4.8 , 3.9)	1.7
5	(4.0 , 3.3)	(4.9 , 3.5)	1.0

V. Conclusion

Due to the shortage of accuracy and strength, Indoor Positioning System has been suffered from severe worldwide issues especially with the fast increase in transmission services and information. The goal is to boost the accuracy of indoor localization by exploiting the potential of various technologies offered. As demonstrated, we have proposed a hybrid indoor localization system that uses Wi-Fi and BLE communication technologies. As shown, the infrastructure of the proposed system uses s partitioning criterion that combine low power communication technologies to achieve accurate indoor positioning. In this context, Wi-Fi tritleration method is used to get the position of users at indoor areas supported by wireless fidelity signal strengths. This is employed to ascertain if the user exists within one of the indoor locations supported by BLE. This enabled the beacons to start the localization to achieve higher indoor positioning ac curacies. Experimental results show that the proposed system is inevitably provided lower average errors compared with other competitive indoor positioning systems.

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VII. References

[1] DemetriosZeinalipour-Yazti, Kyriakos Georgiou, Georgios Chatzimilioudis, and ChristosLaoudias. Internet-based Indoor Navigation Services. IEEE Internet Computing, May 2016.
[2] M. Altini, D. Brunelli, E. Farella, and L. Benini. Bluetooth indoor localization with multiple neural networks. 51th International Symposium on Wireless Pervasive Computing, 2010.
[3] R. Hansen, and B. Thomsen Efficient and accurate WLAN positioning with weighted graphs. International Conference on Mobile Lightweight Wireless Systems, pp. 372 386, 2009.
[4] MohdEzaneeRusli, Mohammad Ali, and Norziana Jamil An Improved Indoor Positioning Algorithm Based on RSSI-Trilateration Technique for Internet of Things (IOT). International Conference on Computer and Communication Engineering (ICCCE), pp. 72 - 77, July 2016.
[5] Luca Mainetti, Luigi Patrono, and Ilaria Sergi. A survey on indoor positioning systems. 22nd International Conference on Software, Telecommunications and Computer Networks (SoftCOM), pp. 111 - 120, 2014.
[6] V. Varshney, R. K. Goel and M. A. Qadeer. Indoor positioning system using Wi-Fi Bluetooth Low Energy technology.30th IEEE International Conference on Wireless and Optical Communications Networks (WOCN), pp. 1 - 6, 2016.
[7] W. Joanne, S. Taking, N. Isa and K. Chao, Indoor navigation and localisation application system. 3rd IEEE International Conference on Electronic Design (ICED), pp. 327 - 333, 2016.
[8] JulinVillegas , and Shoma Saito Assisting system for grocery shopping navigation and product recommendation. 6th IEEE Global Conference on Consumer Electronics (GCCE), pp. 1 - 4, 2017.
[9] K. Georgiou, T. Constambeys, C. Laoudias, L. Petrou, G. Chatzimilioudis and D.Zeinalipour-YaztiAnyplace: A Crowdsourced Indoor Information Service. 16th IEEE International Conference on Mobile Data Management, pp. 291 - 294, 2015.
[10] A. A. Mamun and S. RajasekaranAn efficient Minimum Spanning Tree algorithm. 2016 IEEE Symposium on Computers and Communication (ISCC), pp. 1047 - 1052, 2016.
[11] The Official IDE for Android Android Studio. Google I/O, 2018.
[12] Andrew YongGwon Lee, Abhishek Kumar, Pawel Wilk, WitoldChmielowiec, WojciechJaworski, Marcin Skorupa, and Pawel ZborowskiHigh accuracy indoor localization with low cost based on wireless LAN, mobile sensors and floor layout. 2016 IEEE International Conference on Consumer Electronics-Asia (ICCE-Asia), pp. 1 - 6, 2016.
[13] Jakub Krzych, and Lukasz KostkaEstimote Location Beacons. Estimote Cloud, 2012.
[14] H. Hoshi, H. Ishizuka, A. Kobayashi and A. MinamikawaAn indoor location estimation using BLE beacons considering movable obstructions. 2017 Tenth International Conference on Mobile Computing and Ubiquitous Network (ICMU), 2017.
[15] M. Tern, J. Aranda, H. Carrillo, D. Mendez and C. Parra IoT-based system for indoor location using bluetooth low energy. 2017 IEEE Colombian Conference on Communications and Computing (COLCOM), pp. 1 - 7, 2017.