WPIN: A waypoint-based indoor navigation system

Edward T.-H. Chu[1], Shih-Chia Wang[1], Chao-Chun Chang[1], Jane W. S. Liu[2] and Jiun Hsu[3], and Hui-Mei Wu[3]

[1] CSIE Department of National Yunlin University of Science and Technology, Taiwan
{edwardchu, m10617024, m10517022}@yuntech.edu.tw
[2] Institute of Information Science, Academic Sinica, Taiwan
janeliu@iis.sinica.edu.tw
[3] National Taiwan University Hospital, Yun-Lin Branch, Taiwan
{Y00051, Y01614}@ms1.ylh.gov.tw

Abstract. Nowadays, indoor navigation technology can be used in large buildings to guide people to their destinations and improve the efficiency. Significant efforts have been made to develop indoor navigation system (INS) in the past years. However, due to the challenges of accuracy, standardization and maintenance, it is still rare that INSs have been deployed in large buildings for daily operation. In this work, we design a waypoint based indoor navigator (WPIN), also a mobile app, which can give users a direction indicator, such as turn left, turn right and go straight, at each intersection along the route to the destination. WPIN utilizes directional Bluetooth beacons, named Lbeacon, deployed at each waypoint to get the coordinate of current position. In order to evaluate the practicability of WPIN, we conducted a field trial in National Taiwan University Hospital Yun-Lin Branch. More than 75 Lbeacons were deployed in outpatient areas, over 2000 square meters, that cover two separate buildings and floors. We invited near 140 volunteers and patients to use WPIN in the daytime. Our results show that WPIN can achieve 3 to 5 meters position accuracy even in a crowded space. In addition, the average satisfaction score on a 5-point Likert scale was over 4 points.

Keywords: Indoor Positioning System, Indoor Navigation System, Smart Hospital

1 Introduction

Indoor navigation technology can be used in large buildings to guide people to their destinations and improve the efficiency [4, 7]. Examples include transport hubs, hospitals, shopping malls, exhibition halls, and airports. With the help of an indoor navigator, people can easily plan their routes to the destinations. In recent years, Bluetooth beacon has become a popular solution to helping construct an indoor navigation system because proprietors and stakeholders can utilize Bluetooth beacons to provide users not only location information but also commercial advertisements and coupons [6, 1, 5]. With the support of the

Bluetooth beacons, users can use their smartphones to detect the radio signal strength of nearby beacons and triangulate their locations. However, due to the nature of radio frequency, the radio signal strength received by smartphones can be interfered by environment factors, such as crowd density and indoor decorations, especially in crowded spaces. As a result, traditional triangulation-based methods could cause large errors in determining locations.

Maintenance is another critical issue of large indoor navigation system, which usually consists of hundreds or thousands of beacons. Existing off-the-shelf beacons, like iBeacon and Eddystone, are powered by batteries. It can be effort-consuming and impractical to manually check out the battery usage of such a huge number of beacons. In addition, since these beacons do not support bidirectional communication, they are unable to communicate with Bluetooth devices in the coverage areas. Such a limitation restricts their capability to develop active indoor positioning applications. Example applications include object tracking and geofence, in which beacons should be able to detect objects' locations and gather their status so as to trigger alerts when necessary. Further, unlike the popularity of outdoor maps, neither open nor free indoor maps are accessible. Creating indoor maps from scratch is costly, which could reduce proprietor's willingness to build up an indoor navigation system. Because of the above mentioned challenges of accuracy, maintenance and standardization, it is rare that indoor navigation systems have been deployed in large buildings for daily operation.

In this paper, we extend our previous work BeDIS [2, 3] by designing a waypoint-based indoor navigator (WPIN), also a mobile app, that can give users a direction indicator, such as turn left, turn right and go straight, at each intersection along the route to the destination. Unlike existing indoor navigators, we adopt building information model (BIM), an international standard for representing a building, to construct navigation graphs. Due to the popularity of BIM on global scale, related software tools, documentations, and on-line forums are well established and easy to follow. Using BIM to create indoor maps or navigation graphs can significantly reduce design efforts and standardize the development process. WPIN utilizes Bluetooth beacons, named Lbeacon, deployed at each waypoint to get the coordinate of current position. Lbeacons periodically broadcast to users nearby their latitude and longitude coordinates, and there is no need to do triangulation. In order to reduce interference, each Lbeacon is equipped with directional antenna that sends fewer signals from directions other than the main beam. The position accuracy is 3 to 5 meters. In addition, Lbeacons support bidirectional communication and can be used to develop active indoor positioning applications, such as object tracking.

In order to evaluate the practicability of WPIN, we conducted a field trial in National Taiwan University Hospital Yun-Lin Branch (NTUH-YL). With the assistance of WPIN, users can quickly find their ways to the destination, shorten the length of stay in hospitals; therefore, the nosocomial infection rate can reduced. In our field trial, more than 75 Lbeacons were deployed in outpatient areas and examination areas, over 2000 square meters, that cover two separate buildings and floors. We invited near 140 volunteers and patients to use WPIN

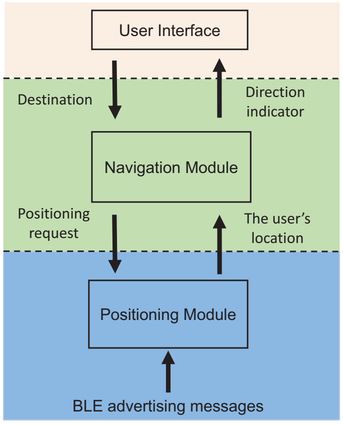

Fig. 1. The architecture of WPIN App

Fig. 2. The user interface of WPIN App

during peak hours, from 9AM to 12PM. Our results show that WPIN can give users accurate direction indicators even in a crowded space. In addition, the average satisfaction score on a 5-point Likert scale was over 4 points. Therefore, WPIN is proved to be a practical solution of indoor navigation for large buildings.

2 WAYPOINT-BASED INDOOR NAVIGATION

WPIN App consists of three layers: user interface, navigation and indoor positioning. As shown in Fig. 1, after receiving the user's input, also the destination, WPIN App executes the navigation module to determine the user's location. A positioning request is then passed to the positioning module for further processing. Inside the positioning module, the received BLE (Bluetooth Low Energy) advertising messages sent from different Lbeacons are first filtered so as to avoid possible noise effects. Each advertising message contains the coordinate of the sender. WPIN App picks up the message with highest RSSI (Received Signal Strength Indicator) value among the filtered messages to determine the user's location. Whenever the user's location is updated, the navigation module is invoked to determine whether the user has arrived a waypoint or not. In this work, a waypoint is defined as an intersection, a point of interest, or the middle of a corridor. If the user has arrived a new waypoint, the WPIN App shows user a direction indicator, such as turn left, turn right or go straight, on the screen. The positioning-navigation process stops until the user reaches the destination.

Fig. 2 lists the interfaces of WPIN App. Frequently-asked destinations are shown on the main page (Fig. 2-a). After the user selects a destination on the list (Fig. 2-b), the WPIN App determines the user's current location. At the initialization stage, WPIN will ask the user to face a specific direction before the navigation (Fig. 2-c). The direction indicators are then shown to the user

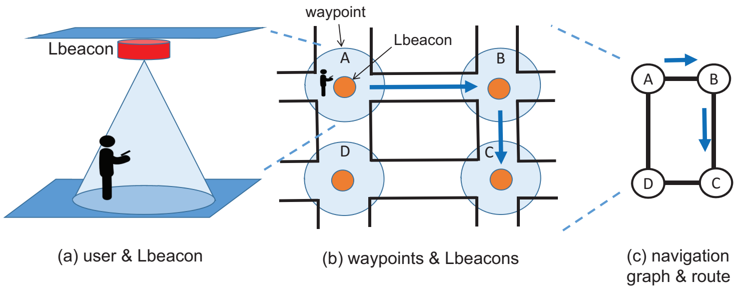

Fig. 3. The positioning method of WPIN

along the way to the destination (Fig. 2-d &Fig. 2-e). A climbing stairs icon will also be given when the user walks between floors (Fig. 2-f). In addition, a progress bar depicts the proportion of waypoints that the user has reached. If the user gets into a wrong way, recalculation will be performed automatically (Fig. 2-g). Finally, when the user arrives the destination, the WPIN App pops up a notification (Fig. 2-h).

We adopt BIM, an international standard for represent a building, to construct a navigation graph. Given floor maps in BIM format, we first determine the location of each waypoint. We then construct a navigation graph consists of waypoints. A waypoint is defined as an intersection, a point of interest, or the middle of a corridor. The area of a waypoint depends on the size of the area it represents. Take a hospital as an example, the area of a waypoint can be as large as an entrance hall or as small as an elevator. Typically, the area of a waypoint is a circular with a radius of 3 to 5 meters. We install a Lbeacon at each waypoint to broadcast its coordinate of latitude and longitude to nearby Bluetooth devices, such as smartphones. For waypoints that cover a large area, more than one Lbeacon will be deployed.

Fig. 3 shows the positioning method of WPIN, in which Lbeacons are deployed at the interaction of corridors. As Fig. 3(a) shows, Lbeacon is mounted on the ceiling to periodically broadcast its longitude and latitude information to Bluetooth devices nearby. Unlike commonly-used Bluetooth beacons, the signal shape of Lbeacon looks like a conical beam since Lbeacon is equipped with a 60-degree directional antenna. Therefore, the signal strength drops significantly in specific directions. Based on this characteristic, we can obtain a more accurate estimation of how far the user is away from the Lbeacon. The detailed hardware specification of Lbeacon is included in our previous work [2]. When the user enters the area of a waypoint, the WPIN app displays a direction indicator to guide the user to the next waypoint. Fig. 3(b) shows an example of waypoints, in which the route starts from waypoint A and ends at waypoint B. The user first receives a “go straight” indicator at waypoint A and then a “turn right” indicator at waypoint B. The connectivity of waypoints is denoted by a navigation graph, shown in Fig. 3(c), which is used for WPIN to find the shortest path.

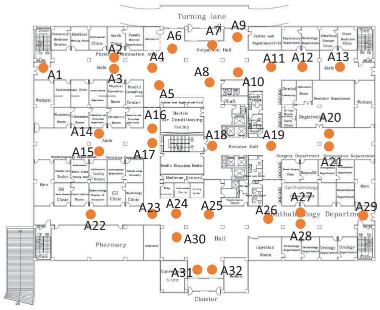

Fig. 4. Lbeacons on 1F of NM Building

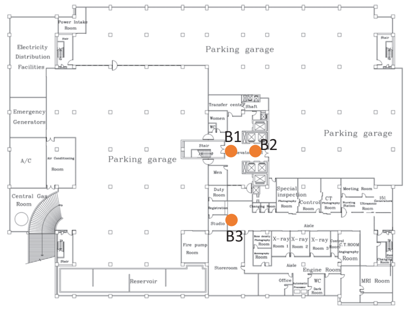

Fig. 5. Lbeacons on B1 of NM Building

3 Field Trial of WPIN

3.1 Deployment of Lbeacons

More than 75 Lbeacons were deployed in NTUH-YL. As Fig. 4 and Fig. 5 show, in the New Medical (NM) Building, 32 Lbeacons were deployed in the first floor and 3 Lbeacons were deployed in B1. In addition, in the Old Medical (OM) Building, shown in Fig. 6 and Fig. 7, there were 9 Lbeacons and 8 Lbeacons in 1F and 2F respectively. When determining the locations of Lbeacons, we first select intersections of a corridor, such as A8, A18, A25 and so on. We then pick up points of interest, such as A6 (main entrance), A11(registration desk), A30(pharmacy), and so on. If the signal coverage is not as the expected, such as decayed by sign boards and environmental objects, one more Lbeacon is added to form a group. Lbeacons in the same group represent the same waypoint. Examples include (A2, A3), (A14, A15) and so on. Fig. 8 shows some pictures of the installation of Lbeacons, in which Lbeacons are mounted on the ceilings to broadcast location information every 500 ms. In addition, wired solution was adopted to build up the indoor navigation system so as to eliminate the maintenance cost of battery replacement. For this, USB wall outlets with USB ports were installed above the ceiling to power Lbeacons. Lbeacons are low-power. Each Lbeacon consumes around 1.05 W and the average current of a Lbeacon is around 200 mA.

3.2 Experiment results of responsiveness

We define the responsiveness as how quickly the navigator reacts when a user is approaching a waypoint. In our experiment, the area of a waypoint was set at a radius of 5 meters. If the navigator pops up the instruction before the user enters the area of a waypoint, we mark it as fast. On the other hand, if the instruction shows up after the user passes through the center of the waypoint, it is too slow. Further, the responsiveness is regarded as moderate if the instruction pops up when the user is on the way from the boundary to the center of the waypoint.

Fig. 6. Lbeacons on 1F of OM Building

Fig. 7. Lbeacons on 2F of OM Building

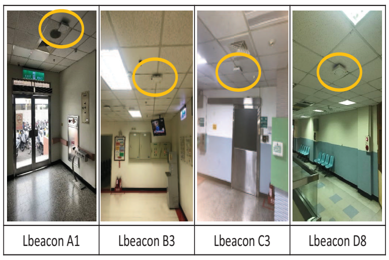

Fig. 8. The installation of Lbeacons

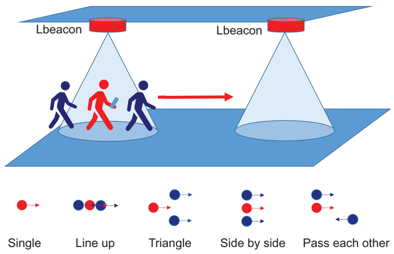

Fig. 9. Different walking patterns

We evaluated the responsiveness of the navigator along the route: Entrance Hall(A7) → Registered counter(A11) → Outpatient clinic(A14) → Cashier(A11) → Examination room(D5) → Pharmacy(A32) → Entrance Hall(A7). There were in total 27 waypoints on the route. As shown in Fig. 9, five different walking patterns of pedestrians were evaluated. The walking speed was around one meter per second. According to our results, shown in Table 1, in the single mode, most smartphones performed well except Samsung Galaxy Note 2. There was an 18% possibility that broadcasting messages sent by Lbeacons will not be received by Samsung Galaxy Note 2, while that of other smartphones was lower than 3%. The possible reason may be the poor design of antenna since Samsung Galaxy Note 2 was produced 6 years ago. Our results also show that our navigator reacted moderately in 82%(=133/162) of the test cases of single mode. Thus, the positioning accuracy of WPIN is 3 to 5 meters in average. In addition, the responsiveness of line up and triangle mode is similar to that of the single mode. On the other hand, the portion of "fast" cases increases in the side by side mode. The possible reason is that the test's smartphone has a higher possibility of receiving broadcasting packets reflected from pedestrians nearby. It is also found that passing each other could decrease the success rate of receiving broadcasting packets and result in a lower response of the navigator. The possible reason may be that they were too close when passing by each other so that the signal was blocked temporarily. Decoration, such as hanging sign boards, could also affect the effectiveness of broadcasting packets. According to our experiment results, the Bluetooth signals may decay faster than we expected when Lbeacon was deployed close to sign boards. Also, the phenomenon of multipath propagation is significant in the area of stairway. In order to avoid improper reaction of the navigator, Lbeacons should be deployed carefully in the areas mentioned above.

Table 1. Responsiveness of different smartpohones

		No signal	Slow	Moderate	Fast
Oppo AX7	Single	0	1	26	0
	Line up	0	1	23	3
	Triangle	1	0	26	0
	Side by side	1	1	23	2
	Stagger	1	1	22	3
Samsung Galaxy Note2	Single	5	7	15	0
	Line up	1	8	18	0
	Triangle	1	4	22	0
	Side by side	2	4	20	1
	Stagger	0	10	17	0
Samsung Galaxy A9	Single	0	3	23	1
	Line up	0	7	19	1
	Triangle	3	3	19	2
	Side by side	1	4	18	4
	Stagger	0	6	20	1

		No signal	Slow	Moderate	Fast
Samsung Galaxy S5	Single	0	1	25	1
	Line up	0	1	26	0
	Triangle	1	2	23	1
	Side by side	1	1	24	1
	Stagger	0	10	17	0
Sony Xperia XA2	Single	1	3	21	2
	Line up	0	2	23	1
	Triangle	0	3	19	5
	Side by side	0	2	16	9
	Stagger	0	2	22	3
ASUS Zenfone5	Single	0	3	23	1
	Line up	0	1	18	8
	Triangle	1	0	22	4
	Side by side	1	0	19	7
	Stagger	1	2	17	7

3.3 User experience event

In order to evaluate the effectiveness of WPIN, we hosted a tea party and invited around 140 volunteers, including patients, visitors and staffs, to try WPIN. The volunteers were from 20 to 60+ years of age. Most popular smartphone brands in the market were evaluated, including Samsung, Asus, OPPO, HTC, Huawei, Xiaomi and Sony. Each volunteer first randomly selected a destination and then used WPIN for navigation. After finishing the route, the volunteers graded the WPIN from three different aspects: accuracy, responsiveness, and easy-to-use. The accuracy index is used for evaluating the correctness of direction indicators. The responsiveness index is used for evaluating how well the WPIN App reacts when a user enters the area of a waypoint. The easy-to-use index is used for evaluating the user interface. Our results show that the score of accuracy on a 5-point Likert scale was 4.00, the responsiveness was 3.73 and the easy to use is 4.10. The overall satisfaction score was 4.23. The lowest index is responsiveness because some Bluetooth receivers of legacy smartphones did not perform well as expected in receiving advertising packets. Thus, users may not get instructions when entering a new waypoint. A compromise solution is to lower the threshold of RSSI. Our results also show that over 77% of the users were willing to use the WPIN App again and 79% of them were willing to recommend the WPIN App to their friends. Overall, the feedback is very positive and valuable. We were suggested to integrate indoor and outdoor navigation so that visitors can plan a route from outdoor to indoor, such as from outdoor parking lots to an examination room.

4 Conclusion and Future work

In this paper, we present WPIN, a waypoint-based indoor navigation, to guide users to their destinations inside a building. WPIN is easy to configure, deploy and maintain. A field trial was conducted in National Taiwan University Hospital Yun-Lin Branch for daily operation. More than 75 Lbeacons were deployed in outpatient areas. In order to evaluate the effectiveness of WPIN, we hosted a tea party and invited around 140 volunteers, including patients, visitors and staffs, to try WPIN. Our results show that WPIN can achieve 3 to 5 meters position accuracy even in a crowded space. In addition, the average satisfaction score on a 5-point Likert scale was over 4 points. WPIN is proved to be a practical solution for indoor navigation. In the future, we plan to further improve the functionality WPIN by integrating WPIN with hospital information system to manage outpatient flow.

Acknowledgement

This work was supported by National Taiwan University Hospital Yun-Lin Branch Project, Academia Sinica Project AS-105-SS-A03 and Ministry of Science and Technology (MOST), Taiwan. We thank Bo-Chen Huang, Zi-Zhe Huang, Kai-Jie Chen, and Kun-Hsiang Lin for their help in measuring Bluetooth signals.

References

1. Aoki, R., Yamamoto, H., Yamazaki, K.: Android-based navigation system for elderly people in hospital. In: 16th International Conference on Advanced Communication Technology. pp. 371–377 (2014)
2. Li, C.C., Su, J., Chu, E.T.H., Liu, J.W.S.: Building/environment data/information enabled location specificity and indoor positioning. IEEE Internet of Things Journal **4**(6), 2116–2128 (2017)
3. Li, C.C., Wu, P., Wang, H., Chu, E.T.H., Liu, J.W.S.: Building/environment data/information system for fine-scale indoor location specific services. In: IEEE 2nd International Conference on Fog and Edge Computing (ICFEC). pp. 1–8 (2018)
4. Liu, H., Darabi, H., Banerjee, P., Liu, J.: Survey of wireless indoor positioning techniques and systems. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews) **37**(6), 1067–1080 (2007)
5. Moder, T., Reitbauer, C.R., Wisiol, K.M.D., Wilfinger, R., Wieser, M.: An indoor positioning and navigation application for visually impaired people using public transport. In: 2018 International Conference on Indoor Positioning and Indoor Navigation (IPIN). pp. 1–7 (2018)
6. Satan, A.: Bluetooth-based indoor navigation mobile system. In: 2018 19th International Carpathian Control Conference (ICCC). pp. 332–337 (2018)
7. Zeinalipour-Yazti, D., Laoudias, C., Georgiou, K., Chatzimilioudis, G.: Internet-based indoor navigation services. IEEE Internet Computing **21**(4), 54–63 (2017)