RSS -Based Indoor Localization using Building Structure

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Abstract
The evolved technology of smartphones and the need of novel indoor localization and tracking system have motivated the researchers to develop and build several tracking approaches. However, the developed approaches have some limitations related to the construction of dynamic Radio Map(RM) and additional hardware requirements. In this paper, we reassess existing approaches and develop a new positioning and tracking system based on stored database called building blueprint. The initial positions are obtained using the nearest by access point (AP). Afterward, this approach traces user in an indoor environment based on smartphone sensors and the stored building blueprint database. Our results show that this approach maintains a high level of accuracy in terms of distance estimation and eliminates the need of complex search algorithms. Our approach does not require a frequent radio map, which means no need to resurvey the environment to adopt the environmental changes. In addition, the results show that the distance estimating mean error is about 3.3 m; while the detection of initial position mean error is 2.6 m.

Key words:
Building Database, Strongest Receive Signal Strength, step counting.

1. Introduction

Indoor localization based on smartphone has been extensively considered, since it improves its efficiency in several applications that utilize indoor localization techniques. Indoor applications such as health care system, tracking children, smartphone application and advertisement require indoor localization techniques since users spend much of their time in indoor environment [1] [2] [3]. Therefore, various approaches have been proposed to implement indoor localization services for localizing objects, i.e. people. Fingerprinting [4][5] is the most widely used approach that involves different technologies such as Wi-Fi radio map, Bluetooth radio or other others; however, some indoor localization approaches provide the location based on radio signal such as time of arrival (TOA) [6][7], trilateration [8] and angle of arrival (AOA) [9].
Smartphones have been evolved over time to include useful sensors such as accelerometer and compass, which enable indoor localization and user tracking; thus, many approaches have been proposed in order to involve smartphone sensors [1]. However, these techniques affected by noisy sensors and therefore inaccurate position estimation. While radio signal approaches such as TOA and AOA require at least three different signals as well as additional hardware might be required to provide indoor localization.
Fingerprinting technique has several advantages over other techniques as it proves good accuracy with no additional hardware inexpensive radio such as RSS , which is main part of the infrastructures in indoor localization; however, it suffers from major issues concerning overhead during online phase to provide the position and the need of recalibration method , which requires resurvey the environment regularly due to signals attenuation or scattering when any changes occurred to the indoor environment such as changing the furniture, newly or removed AP is detected.
In this work, we propose a new hybrid approach that involves physical location map instead of radio map based on smartphone sensors to provide user path and tracking services in indoor environment. It is important to point that our proposed work is the first approach involves the physical map, which is not tat affected by changing environment. Therefore, we call our approach" Map For Once", which creates the database only once and find the user location for to his destination.
This work contributes to eliminating recalibration method by employing a building blueprint database, which leads to static environment map and thus no need to resurvey the environment. In addition, it enhances the accuracy of the distance estimation process due to involving smartphone accelerometer sensors and the building blueprint database to provide the distance. Moreover, it improves the accuracy of direction estimation process, since it uses smartphone orientation sensor based on the building blueprint database. Next sections represent the system architecture; experiments and result analysis; conclusion and future work.

2. Related Work

Indoor localization has gained research interest over the past years, since it supports location-based services and several applications. application. Localization approaches involves different technology such as radio signal, smartphone sensors or even sound acoustic.
In these approaches, a location can be detected by distance estimation or angle estimation as in trilateration approach [8], which determines the location through the intersection of three formed circles. Angle of Arrive (AOA) [9] [10]

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requires angle estimation between sender and receiver in order to provide the location; it requires at least two reference points. Fingerprinting technique grids the target area and implements two phases; offline phase, in which a huge number of radios collected to build a radio map; and online phase, in which the radio measured online and compared with radio map using several searching algorithms to provide the nearest position.

An early technique called RADAR [11] that uses fingerprinting techniques to collect Wi-Fi signal strength during offline phase. RADAR can collect these signals from 70 locations in four directions. The collected signals are compared online to provide the nearest matches using K-nearest neighbors.

Another fingerprint passed technique developed by [12] to reduce search process overhead using a transfer function to provide constructed states from the offline radio map phase. The same transfer function used to provide an online reconstructed state which is compared with the offline reconstructed states via probabilistic weighting function.

In [13], they developed a new approach based on FM radio. Its feasibility test in indoor positioning show improved level of accuracy with local FM transmission; however, with the global FM transmitter; it dropped significantly.

Signal attenuation and scattering are the major concerns of aforementioned approaches; for instance, fingerprinting technique requires calibration, which means reconstructing the radio map in offline phase and the overhead problem during search process forms a big challenge as well. In trilateration approach, the distance estimation is the main issue to provide accurate locations; however, multipath and signal attenuation require much more effort to provide the location. As for AOA approach, it requires additional hardware to estimate the angles, which add cost when compared with other techniques.

Indoor positioning system developed by [14] employs magnetic field as location reference instead of signals. Their approach builds a magnetic map as array of e-compasses to implement the same fingerprinting technique; however, it requires additional hardware to build the magnetic map during offline phase.

Based on accelerometer and digital compass of LifeMap [1], it constructs a trajectory of investigating all user movements to avoid noisy sensors, but the initial position of the user is detected using GPS, which has limited or unavailable signal in indoor environment; thus, the user should start from outside and then move to the indoor environment to provide accurate results.

In CompAcc [15], they determine the path signature by detecting the direction and the displacement using compass and accelerometer. Afterward, they compare directional trail with path signatures to provide the user location, which is the best match; however, they need to estimate user position along the path.

Another technique called FootSLAM [16] uses foot mounted inertial sensor approach to perform localization and mapping for pedestrians simultaneously. They provide dynamic map to provide user location. Unfortunately, foot mounted is not compatible with smartphone technologies.

Additional sensors are used in Sparse Track [17] to ensure more accurate steps counting and displacement estimation in order to determine user path. However, the requirement of additional sensors is not appropriate to the current smartphones.

3. System Architecture

Based on the technique presented in [13], which builds an XML building blueprint database in order to store map information, the proposed system based on physical database instead of radio database. Therefore, our system constructs the physical blueprint database by the following steps: a) partition the physical blueprint into sections such as rooms, Corridor, where each of which represents a correlation; b) link each sub part to its AP reference.

For more details, example below explains the above steps:

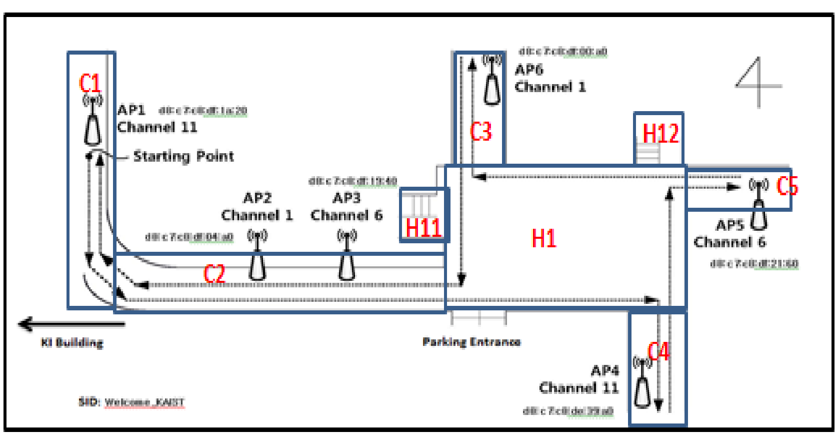

Fig. 1 blueprint example

In this part, we implement three types of correlations: 1) Main Relation(MR), which represents the main building's sections such as floors, corridor, etc. ;2) Sub Relation(SR) to represent the internal parts such as stairway, elevator and rooms'). Node Relation(NR) to represent the static parts such as APs and entrance. The following diagram, figure 2, shows the whole database flowchart.

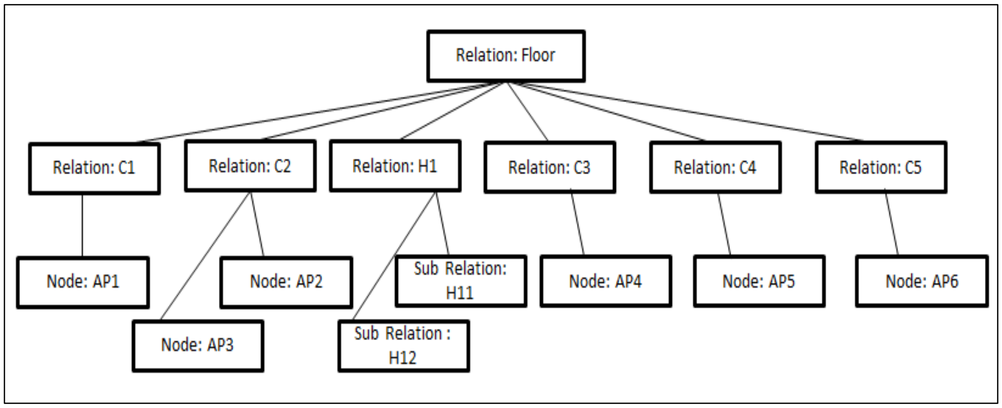

Fig. 2 Database flowchart

Our database creation is passing the following steps: a) Partition the physical blueprint; where each corridor represents a correlation with some characteristics and references to its sub section. Each sub section room inside the target corridor represents a sub correlation with the NR with certain features; b) corelated relations between the target building and its sections via a direction field, for example, C2 is southern to C1, and so on, to connect sub relation with its main relations a reference field is used again; for example, H11 represents sub relation to H1.

From figure 1, it can be inferring that H1 corelates with C1, C2, C3, C4, C5, since H1 has a relation reference to H11, H11 is a stairway inside H1, and AP1 is a located in C1 and its MAC address and location inside the corridor are known. Table 1 shows the types or relations in the aforementioned example.

Table 1: Coding table.

Correlation Name	Type	Description
MR	1	Contains sub relation and nodes with its properties
SR	2	Contains nodes with its properties
NR	3	Contains only its properties

Table 2 shows the relations with features of (Length, Width, etc…) and connected fields (Next South, Next North, …).

Table 2: Main Relations table.

Building Part ID	Building Part Name	Type	Length	Width	Next South	Next North	Next |East	Next West
1	C1	1	28	7.5	2	0	0	0
2	C2	1	67	3	0	1	3	0
3	H1	1	15	15	5	4	6	2
4	C3	1	28	2.5	3	0	0	0
5	C4	1	21	2.2	0	3	0	0
6	C5	1	21	2.2	0	0	3	0

Table 3 shows nodes properties; AP, Entrance, etc.….)

Table 3: AP Node table

AP ID	MAC Address	Location	Time Stamp1	Time Stamp2	Type
1	d8:c7:c8:df:1a:21	13	12.5	13	3
2	d8:c7:c8:df:04:a1	39	31.5	23	3
3	d8:c7:c8:df:19:41	56	45.5	9	3
4	d8:c7:c8:df:39:a1	18	9.2	12	3
5	d8:c7:c8:df:21:61	18	9.2	7	3
6	d8:c7:c8:df:00:a1	20	12	8	3

As can be seen from table 3, AP ID is an address or reference to link AP with its ancestor relation. The location field represents the distance from the root parent and the AP. Time Stamp1 is the average consumed time to access AP from the root parent. Time Stamp2 is the average consumed time to access AP from the dead end of the target building section.

In order to link sub relation of each landmarks, an ID is assigned to each sub relation and a description is provided.

Table 4 shows the assigned ID and table 5 shows the correlated sections to this ID. Table 4 shows the sub relation as follows:

Table 4: Sub Relation table

Sub Relation ID	Sub relation Name	Type	Description	Length	Width
7	H11	2	Stair Way	-	-
8	H12	2	Stair Way	-	-

In Table 4, Sub Relation(SR) ID will be assigned as a reference to SR in the next table, table 5, only when the SR and its MR are linked. Description field used to describe the SR (stair way, elevator, room, …).

Table 5: Connected table.

Building Part ID	AP ID or Sub relation
1	1
2	2
2	3
4	4
5	5
6	6
3	7
3	8

Sections ID of the target building is a reference field to the MR table to recognize which section embraces the AP, and the AP ID is a reference to AP, which is in NR.
Our approach comprises of four steps: a) initial position estimation; b) mapping process; c) user direction estimation; d) counting estimation. Figure 3 shows the system architecture of the current tracking approach.

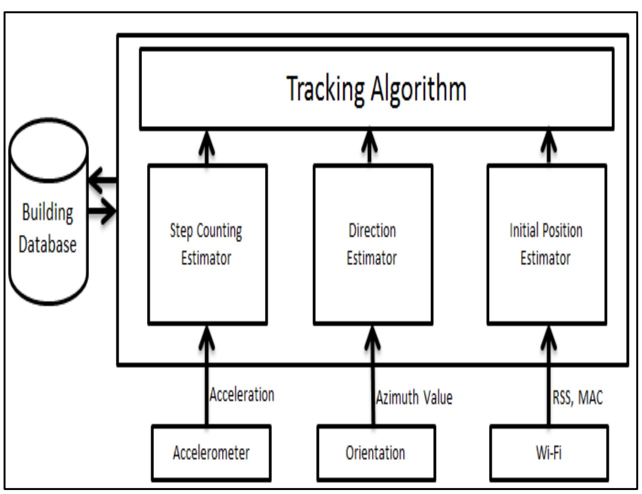

Fig. 3 System Architecture

This approach detects the Strongest Receive Signal Strength (SRSS) and the MAC address as an input to mapping process to detect user initial position. Therefore, the feasibility of SRSS, which means nearest AP, is examined by several experiments during peak time, which means too many pedestrians, and night time, which means few number of pedestrians. Figure 4 depicts the result of the feasibility test.

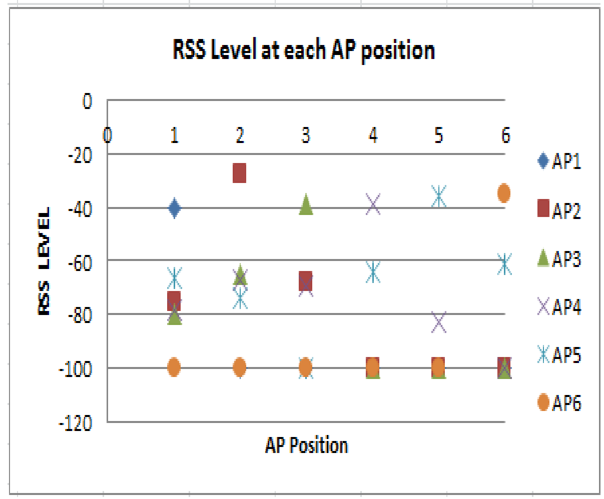

Fig. 4 RSS level at each AP location.

Figure 4 shows that SRSS is a reliable indicator to provide nearest AP, and thereby the initial position; however, an unexpected result might be presented, where the strongest RSS is not for the nearest AP because of private AP or newly installed one. Therefore; to avoid these results, the current approach restricts the search process to the pre-defined database; it implies to ignore unregistered APs. Figure 4 shows only APs which are stored in the database. This procedure allows providing accurate initial position, which is a critical and important step, as wrong initial position leads to system failure. Afterward this approach starts the Mapping Process(MP) to provide the initial position; the mapping process is implemented in four steps as presented in algorithm 1:

Algorithm 1: Mapping Process.

1.Closest_AP_MAC= getStrongestAPMAC from WIFI.ScanResult.
2.Closest_AP_ID = Select AP_ID from NodeTable where MAC = Closest_AP_MAC.
3.Current_Building_ID = Select Building_Part_ID from ConnectedTable where AP_ID= Closest_AP_ID.
4.From MainRelation Table find all information about the building part using the Current_Building_ID field computed by step 3.

As for User Direction, the built-in smartphone digital compass is literally exploited for detecting the user direction.

Finally, the inertial smartphone accelerometer sensor is used to find the step counting using Peak Detection Algorithm(PDA)[18] to provide Step Counting Estimation(SCE) , which is an accuracy issue in indoor positioning system. PDA represents a step by the acceleration values measured by accelerometer sensor. However, this technique is affected by irregular smartphone movements; besides that, the step length is dynamic; thus, PDA is not accurate enough in certain cases. Therefore, to overcome these problems; this approach develops algorithm 2 to use the real stored distance in the database to correct distance estimation by the following steps:

Algorithm 2: PDA algorithm
1. Calculate the distance using peak detection algorithm.
2. Find the length of the current building part (e.g. if user is in C2, then Length=67).
3. Keep scanning for strongest AP (e.g. C2 has AP2 after 39 and AP3 after 56).
4. When new stored AP becomes the strongest, check its location inside the building part.
5. Correct the distance to be as AP location (e.g. if distance=33 and we receive AP2 as strongest then distance will be 39 since AP2 located at 39m inside C2).

To represent the tracking process, this approach developed the following algorithm, as shown in algorithm3.

Algorithm 3: Tracking process

1. Detect the initial position from *Initial Position Estimator*.
2. Detects the user direction from *Direction Estimator*.
3. Count the number of user steps
4. User Path length = length of the current building section (retrieved from the database database).
5. If distance>User path Length, then
Send the result in to the result database.
Current building = next building.
Number of user steps= 0.
endif
6. If distance< User path Length, then
if new stored AP is available
User path Length = User Path length – AP Location (position of AP in the database).
Current MAC = New Strongest AP.
End if
Send the result to the result database.
Number of user steps= 0.
End if

Steps 1, 2 and 3 are the inputs of the algorithm come from MP, smartphone accelerometer and PDA During user movement, the orientation sensor collects values until predefined time threshold, i.e. 5 seconds. Thereafter, the direction can be estimated by the average of azimuth angles, which can be used to indicate the next section using direction fields implemented in the MR table. For example; if the estimated direction is south, then Next South field in MR table is involved).

However, if the traveled distance is less than user path length, step 5, then the algorithm must check if there is newly installed AP, if so, then the user path length becomes the difference between its position and the position of newly installed AP; and the current MAC address is set changed to the new AP MAC address. All changed values are saved to the result database as new update. Figure 5 shows an example of updating results database when new AP is detected.

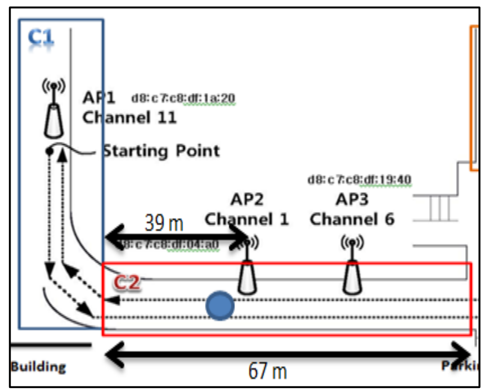

Fig. 5 updating distance when new AP received, blue circle represents a user.

Based on the example presented on Figure 5, algorithm 3 works as follows:

1. User current Position = C1 (user has started moving near to AP1 in C1).
2. Current_MAC = AP1 (WiFi scan result).
3. Orientation = South.
4. Next_building section = C2 (Next_South field MR Table).
5. When the user moved inside C2.
6. User path Length = 67 (Length of C2).
7. “WiFi survey result” detects newly installed AP (AP2).
8. The detected AP is stored in database and located 39m from the of C2 entrance.
9. Updating the current length to be (user path Length = user path Length – AP lecation; user path Length = 67-39=28.
10. Current_MAC=AP2.
11. Number_of_Steps=0
12. Repeat all above steps until traveled distance become greater or equal than user path length, which means

going to next building section based on directions fields in the database.

4. Experiments and Results

To evaluate the proposed system, a real environment is blueprinted, as shown in Figure 1, as well as a Galaxy S1 smartphone, Android based operating system, which is equipped by Accelerometer, Orientation and Wi-Fi sensors. The experiments are conducted during the day time, where the corridors are crowded with students order to check the feasibility of our system. Figure 6and figure 7 show the results

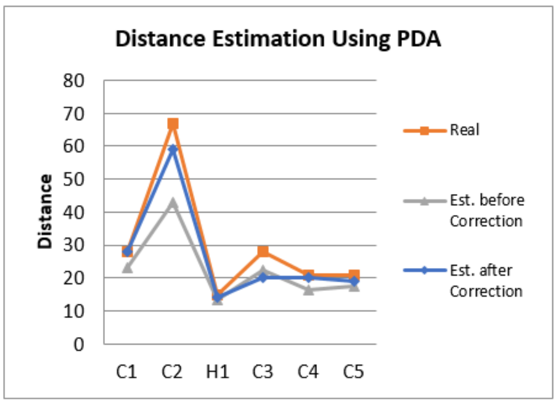

Fig. 6 Distance Estimation using PDA.

From Figure 6, the estimate of the distance was closer to the real estimate after applying the proposed approach; where the results indicate a significant convergence between the real and estimated distance after the correction process carried out by the proposed approach.
In the experiment, a user starts to move from C1 where AP1 is the nearest AP; he is heading to C4 by walking through C2 and H1, as shown in figure 7. The result of the proposed approach is summarized in table 6.

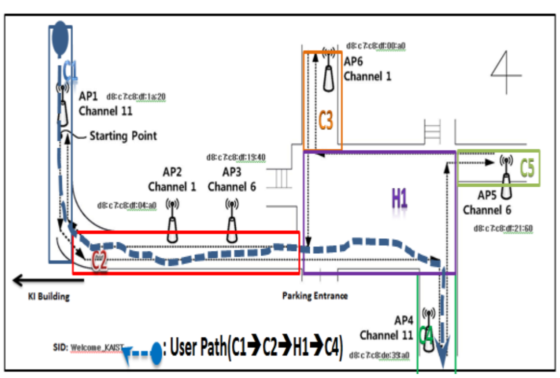

Fig. 7 experiment 1 result

Table 6: Experiment 1 Results

Current direction	Distance after correction	Direction	Next Section	Notes
1 (C1)	13	South-East	2(C2)	C1 Initial point
1(C1)	15	South-East	2(C2)	C1 finished, current = C2
2(C2)	34	South-East	3(H1)	
2(C2)	1	South-East	3(H1)	NewAP received, reset number of steps and start again.
2(C2)	20	South-East	3(H1)	C2 finished, Next =H1
3(H1)	15	South-East	4(C4)	H1 finished, Next=C4
4(C4)	2	South-Westt	0(Nothing)	
4(C4)	1	South-Westt	0(Nothing)	(Newly installed AP
4(C4)	15	South	0(Nothing)	User Stop

5. Result Analysis

Based on the user path, see figure 6, the user moved 15 m from the initial position, which is the end of C1, thus the length of C1 is 28m. The next direction is going to be C2, since the algorithm checks the direction of South -East based on RM table. In C2, to get the newly installed AP (AP2) is detected; therefore, the distance is updated, and the number of steps is reset. These steps continued to the other sections when the next building field equal 0, which ensures that each next section has different direction for example , when a user moves to the North-East starting from C5, there is no next building section at that direction, but when a user changes his direction to North-West starting from C5, the next building section becomes H1 (Next_West field from MR Database).

5.1 Accuracy Test

Distance Estimation(DE) and Initial Position Estimation(IPE) are the main concerns in terms of accuracy; therefore, the relation between estimated initial point and real point is examined as shown in figure 8, which shows the DE using PDA. The error standard deviation is 3.6; while the error mean is 3.3. As for IPE error, which occurs when RSS measured before or after the AP; thus, our approach provides the position from the nearest AP Location (e.g. AP1 located at 13m from C1, but sometimes it measures RSS before we reached AP1 by 3 m, then the start position = 13, but in real is 10, figure 8 demonstrate our experiment.

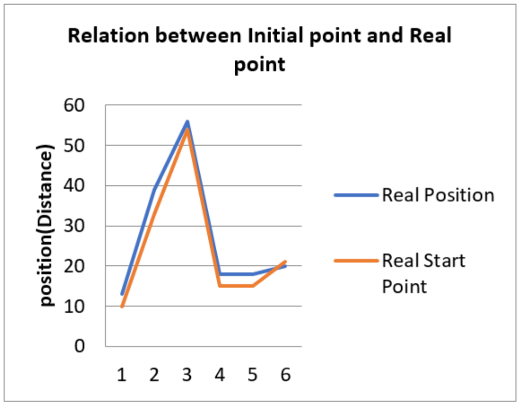

Fig. 8 relation between initial and real points

It is obviously noticed, from figure 8, that the starting point, which represents the real location of the user is close to estimated starting point obtained by the proposed approach with error standard deviation 2.2 and error mean 2.6.

6. Conclusion

In this work, we have introduced "Map For Once ", a new indoor positioning and tracking approach. The proposed approach maintains a building blueprint database by splitting the building sections into sub sections and links them to a certain relational map. This approach determines the initial user's position according to the nearest AP based on SRSS. The search technique of the proposed approach restricts the searching process on stored APs to solve the problem of RSS instability. As for user direction, it is estimated based on the average of the orientation sensor readings to improve the accuracy during user gait .In addition , PDA is used to provide the travel distance by counting the number of user steps based on accelerometer sensor data. The problem irrelevant movement of smartphone, which leads to false step detection, is solved by involving the location of APs inside the building section to reduce the error rate in distance estimation. The proposed approach has been evaluated by several experiments carried out in real environment. The experiments have shown promising results in terms of DE and IPE with error of (3.3m) and (2.6) respectively. Typically, this can be contributed to the ability of this approach to overcome the problem of signal attenuation; searching overhead; and the need for resurveying the target environment frequently as required by previous approaches.

As a future work of our system, it is important to investigate the performance of this approach in multi floor environment, which contains stairways and elevators.

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