International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.9 (2016), pp.165-176
http://dx.doi.org/10.14257/ijmue.2016.11.9.18

Indoor Positioning System Based on an Improved Weighted-Trilateration Algorithm with Fingerprinting Technique

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Abstract

Location Based Services (LBS) are software algorithm systems used by internet protocol capable wireless device technologies assist and/or replace Global Positioning System (GPS) with their task of acquiring and interpreting location describing data. LBS, and the data they provide, are increasingly being used by a growing number of users. As the demand for LBS grows, increasingly there is an additional requirement for more accurate indoor location position determination. Indoor localization algorithm has always been a challenge for location describing device manufacturers. This paper proposes a solution for improving accuracy while also decreasing computational requirements. Leveraging readily obtainable, cost-effective, Bluetooth Low Energy (BLE) Beacons, the research details a modified trilateration algorithm utilizing weighted nodes coupled with emitter/receiver distance measuring improvements accomplished using transmitter emission fingerprinting techniques. The proposed algorithm is evaluated through thorough experimentations that produce a reduction in difference between the real and measured location. The results found are solely obtained through algorithmic solutions utilizing standardized transmission protocols and readily available devices technologies.

***Keywords**: iBeacon, LBS, Indoor Positioning System, Weighted-Trilateration Algorithm, Fingerprinting*

1. Introduction

Location Based Service (LBS) is the service that uses wireless technology or GPS to get location data for collecting, utilizing and offering. LBS includes services that provide useful information for users using location data. Previously, it was not possible to get location when device is inside a building because it used satellite system such as GPS. As Wi-Fi technology is applied to LBS, not only it became possible to estimate indoor location but also demand of indoor LBS is growing.

As demand of indoor LBS grows, importance of technology which can estimate or measure device's location inside buildings is emphasized and the technology is widely studied around the world. However, indoor environment has complex construction of space and people and objects are movable which makes difficult to estimate accurately. This mobile wireless network environment is one of the most significant factors which reduce accuracy of indoor location estimation, which has been widely studied but it is insufficient yet [1]. Recently Apple Inc. has developed iBeacon which uses Bluetooth Low Energy (BLE) technology and makes it possible to get location data automatically and provides various LBS. Already Apple Inc. is cooperating with other companies to launch new services and iBeacon is believed to lead studies about making indoor LBS more accurate [2].

Based on BLE based Beacon on LBS, in this paper, two existing techniques are combined to produce better results in indoor position estimations. That is 'Fingerprinting

ISSN: 1975-0080 IJMUE

technique' is applied on distance estimation stage of existing 'Range-based system', which offers less computation, and weighted trilateration formula is applied on location prediction stage to increase accuracy of the proposed system.

This paper is organized as follows. Section 2 provides related work and the characteristics of Beacon devices, which is used in the paper, and the proposed indoor LBS system are presented in Section 3 and Section 4 shows the results of empirical experiments with Beacon devices in a laboratory room. Finally, the conclusion is summarized in Section 5.

2. Related Work

The importance of identifying accurate location of device has been attracting the significant interests from the public due to the development of wireless communication technique. As utilizing the RSSI (Received Signal Strength Indication), the value of wireless communication strength between two devices, the position of the unknown device can be estimated at the connected environment with AP (Access Point) whose location is clearly defined. The longer distance of transmitted signal, the smaller value of RSSI is decided. According to this nature of the RSSI value, the relationship between the value and distance can be widely used as the technique to measure the general position of device away from AP [3]. There are three typically well-known methods using RSSI for distance estimation: Range-based and range-free methods and fingerprinting method.

One of the most renowned method for wireless communication positioning is range-based localization which consists of two stages. One is the stage of measuring the distance between unknown device and AP, which is named as 'Distance Measurement step' in this paper). Also the other stage which is based on the information recognized by the previous stage is locating the specific position of the device using some techniques like trilateration, triangulation method, which is named as 'Position Specifying step' in this paper [4].

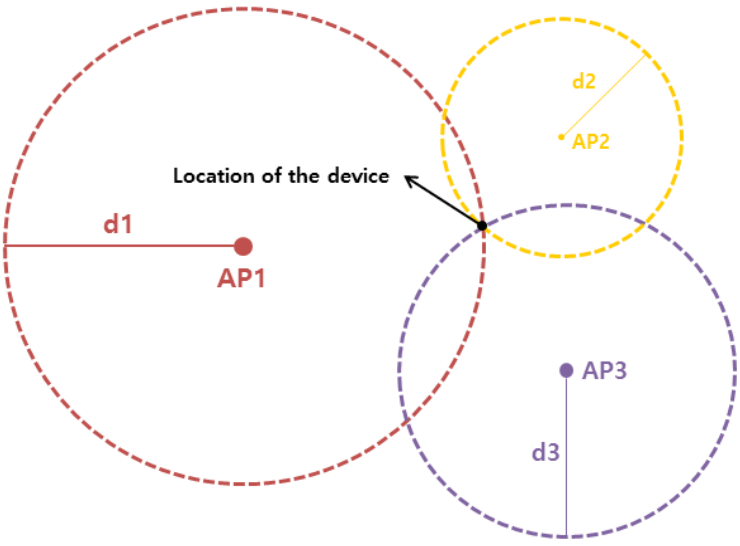

Figure 1. Distance Measurement Step of Range-Based Localization, Assumed Position of Device

Let d_i, $i = 1, 2, 3$, be estimates of distances between virtual location of device and each APs which are on known positions, central point of the circles indicated by certain range of signal. As we can see in Figure 1, circles with the radius, estimated value of distance, would intersect each other on a single point, the assumed location of the device. Distance Measurement step determines approximate value of distance, d_1, d_2, d_3, by applying the Friis transmission equation [5]. This formula calculates the amount of signal attenuation depending on the distance that wave could reach using ratio of received RSSI.

$$d = \frac{c}{4\pi f} \cdot 10^{\log(\frac{10 \cdot P_{TX}}{RSSI})/2} \because d = \frac{\lambda}{4\pi} \cdot 10^{\frac{L}{20}} = \frac{c}{4\pi f} \cdot 10^{\frac{L}{20}}, L = 10 \cdot \log(\frac{10 \cdot P_{TX}}{RSSI}) \tag{1}$$

The Friis transmission equation in Equation (1) was derived from the ideal environment that there is not any disturbance or obstacle which could cause any jamming or blanketing. In reality, however, indoor environment has higher possibility to be interrupted by the structure of space, people or objects, temperature, humidity and so on. Also the room which is full of these kinds of barriers is not possibly positive condition to estimate the distance only with the degree of signal deduction [6-7]. In the step of Position Specifying, as we previously mentioned, to identify the specific position of certain device, it is necessary to apply the trilateration formula based on the calculated distance information which needs at least 3 APs in 2-demensional domain or more than 4 Aps in 3-demensional space. These results from the fact that there will be more than one intersection point, if the number of circles is equal or least than the size of dimension.

Range-free localization is the method that does not require any kind of distance information. It is usually used for measuring the wireless network system, on the other hand unfamiliarly used for indoor identifying location up to the present [8]. The method calculates the number of hops in network between devices to estimate the distance, applies trilateration to find the correct location of the device like range-based method.

Fingerprinting method enables the desirably estimated area to be separated by a number of cells, check the strength of wireless signal received from APs, and organize the 'Radio map' for each cells. The power of sign will be compared with the similar value collected later before defining the location of device with cells in radio map. This is so-called experienced pattern precognition technique [9-10].

Because the most distinguishable aspects of fingerprinting is the 'Radio map' which is carefully considered general situations of wireless sign transferring among unlike range-based methods which needs strength of signal should be converted to distance afterwards.

In this paper, we proposed a new approach to apply the fingerprinting method at the Distance Measurement step on Range-based method to achieve much less computation overhead, and to apply the fingerprinting method again at the Position Specifying step to make trilateration to enhance the accuracy. Then, the weighted value is applied in the proposed approach at the location in indoor position measurement system to estimate the final location.

3. Proposed Indoor LBS Design and Application

3.1. Characteristics of Beacon Based Bluetooth Low Energy Devices

RECO Beacon which is used in this paper is a Bluetooth Beacon device [11] that meets the criteria defined by Apple Bluetooth Beacon iBeacon received certification. RECO Beacon is generate these that can be recognized within the available area is reached signals with data packet, and the structure of depicted in Figure 2.

A device distinguishes a Beacon by UUID, the major and minor values of Bluetooth data packet. The UUID is used for distinguishing the Main Category of the application, while the major value is used for classifying the Middle Category, and the minor is used to classify the Smaller Category [12-13]. The distance can be measured through the strength of the signal generated by the Beacon when RSSI (Received Signal Strength Indication) is used. The distance can then be calculated based on a comparison between the signal strength value measured at 1 meter distance, which is denoted and RSSI value.

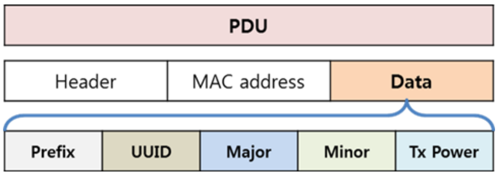

Figure 2. Packet Structure of iBeacon

However, the strength of the wireless sensor signal is less accurate indoor space because the interference may occur due to obstacles such as people, objects, and even temperature and humidity [13]. It is known that BLE signals have accuracy about 68% according to an official documents of the manufacture Apple Inc. [14]. For this, if Beacons are used to implement the Indoor Positioning System then the system should perform extra calibrations considering those interferences.

3.2. Fingerprinting Technique

As mentioned above, range based localization includes distance measuring stage and location prediction stage. On existing distance measuring stage, it is necessary to compute distance whenever RSSI value is sensed, even if the value is the same or similar to previous values. In this paper, fingerprinting technique is implemented to offer less computation on distance measuring stage by comparing new signal and radio map and at while minimizing range of possible location of device.

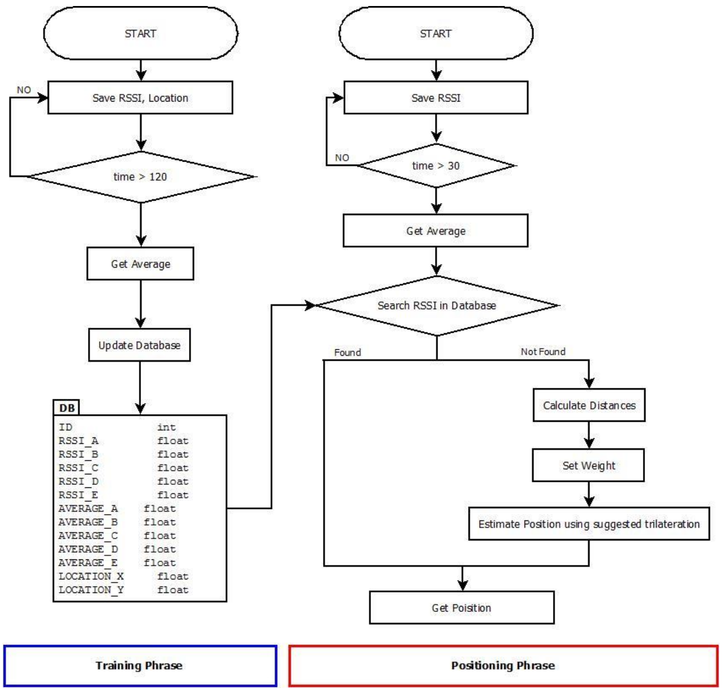

Figure 3. Algorithm of Fingerprinting Technique

Fingerprinting technique consists of two stages. The first stage is called training phrase which is building database using experimented result to make radio map. The second step is positioning phrase that is getting distance with device by comparing radio map and RSSI signals. Figure 3 shows how fingerprinting algorithm performs.

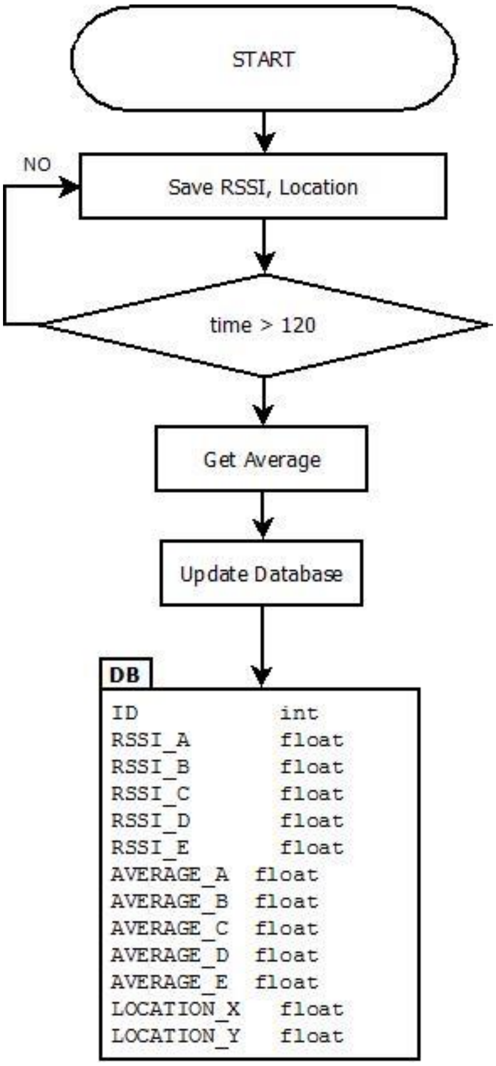

Figure 4. Training Stage of Fingerprinting Technique

In the training stage, a radio map is constructed by following steps in Figure 4. Correction for Beacon's signal instability is handled by repeatedly measuring RSSI values over a period of 120 seconds in 1 second intervals. Equation (2) is used to calculate distance from average of RSSI values and the value is updated in database for further processing. After constructing the database of each section is done, the positional section in which the device is located and the distance between the device and each Beacon can then be estimated.

Figure 5 shows overall flow of positioning stages. A device may move around and does not stay long time on one position Beacon signals are therefore collected in positioning stage for 30 seconds continuously. At the moment, if RSSI value is within allowable error bounds for radio map, the location data is obtained from the radio map in the previously constructed database. Due to beacon signals in 68% accuracy, error bounds can be defined as 68% at confidence intervals, *i.e*. confidence coefficient is 1. In Equation (2), $RSSI_C$ is RSSI value on current position and $RSSI_{DB}$ is RSSI value in the database.

$$\overline{RSSI_{DB}} - \frac{\sigma_{RSSI_{DB}}}{\sqrt{30}} \leq \overline{RSSI_C} \leq \overline{RSSI_{DB}} + \frac{\sigma_{RSSI_{DB}}}{\sqrt{30}} \quad (2)$$

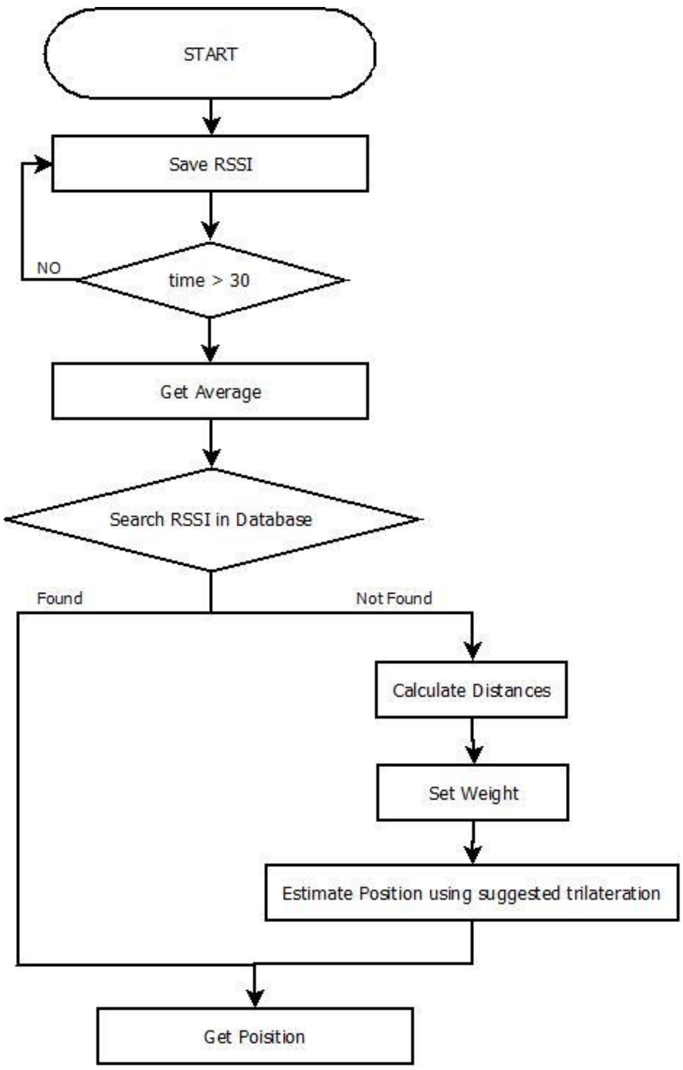

Figure 5. Positioning Stage of Fingerprinting Technique

3.3. Improved Weight Trilateration Method

In this paper, a new approach based on improved weight trilateration method is proposed to improve accuracy of predicting location of a device after dividing entire range of area into smaller regions by fingerprinting method. Typically, general trilateration method is applied where a device exists at a point within the intersection point of the signal from each nodes. Measuring the distance between a device and each node inevitably results in a certain level of errors during the calculation. In the proposed approach, we assumed that the position of the device should be located inside the intersection of a number of nodes not at the exact point. The scope of possible location of a device by the proposed approach is shown in Figure 6.

In the figure, the smaller radius of signal strength must be addressed in such condition thus the higher accuracy can be obtained. Therefore, the weights by Beacon should be set to high to improve the accuracy.

Assume that the desired location of device define as $\hat{X}(x,y)$. The received RSSI signal from a Beacon could be considered as a shape of a circle due to the fact that the range of certain strength of signal can be minimized to a circular shape. Among N Beacons, the location of k-th Beacon is assumed to $R_k(x_{Bk}, y_{Bk})$. This circle of k-th Beacon has its own radius values calculated by the strength of each signal. The equations for the circles derived by Beacons' signal dispersion, where the total number of circles is N, are shown below in Equation (3).

$$\begin{cases} (x - x_{B1})^2 + (y - y_{B1})^2 = {r_{B1}}^2 \\ (x - x_{B2})^2 + (y - y_{B2})^2 = {r_{B2}}^2 \\ \vdots \\ (x - x_{Bk})^2 + (y - y_{Bk})^2 = {r_{Bk}}^2 \\ \vdots \\ (x - x_{Bn})^2 + (y - y_{Bn})^2 = {r_{Bn}}^2 \end{cases} \tag{3}$$

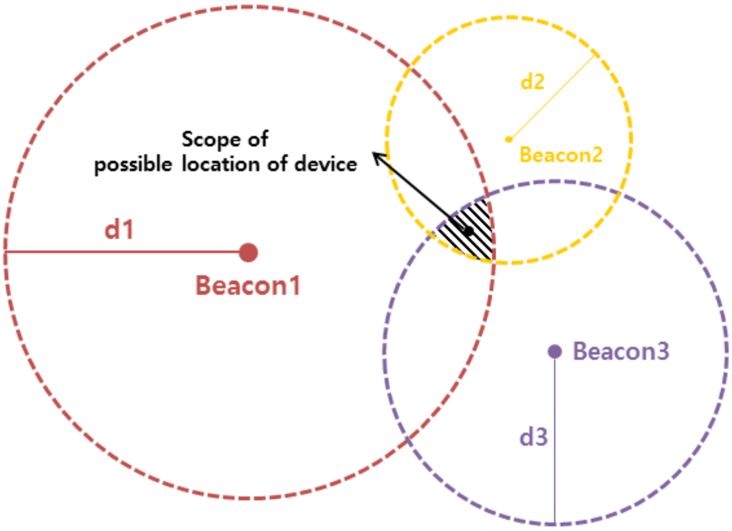

Figure 6. Estimated Scope of Possible Device Location in Distance Measurement Step

In Equation (3), the linearized equation which passes the intersection points of two circles is derived as the circles cross each other. The rest of equations can then be obtained as in Equation (4) by subtracting each circular equation one by one at a time.

$$\begin{cases} (a_{B1} - a_{B2})x + (b_{B1} - b_{B2})y = c_{B1} - c_{B2} \\ (a_{B1} - a_{B3})x + (b_{B1} - b_{B3})y = c_{B1} - c_{B3} \\ \vdots \\ (a_{B1} - a_{Bn})x + (b_{B1} - b_{Bn})y = c_{B1} - c_{Bn} \\ (a_{B2} - a_{B3})x + (b_{B2} - b_{B3})y = c_{B2} - c_{B3} \\ \vdots \\ (a_{Bi} - a_{Bj})x + (b_{Bi} - b_{Bj})y = c_{Bi} - c_{Bj} \\ \vdots \\ (a_{B(n-1)} - a_{Bn})x + (b_{B(n-1)} - b_{Bn})y = c_{B(n-1)} - c_{Bn} \end{cases} \quad \begin{matrix} a_{Bi}=2x_{Bi}, b_{Bi}=2y_{Bi}, c_{Bi}=x_{Bi}^2+y_{Bi}^2-r_{Bi}^2 \\ a_{Bj}=2x_{Bj}, b_{Bj}=2y_{Bj}, c_{Bj}=x_{Bj}^2+y_{Bj}^2-r_{Bj}^2 \end{matrix} \tag{4}$$

To make equations simplified, the straight lines are represented in the form of linear equation model in Equation (5). In this manner, the matrix X is defined as the set of all points which existed on the line passes the intersections of two circles. Thus the intersection points are obviously on the line. Also the distance between center point of circle and the intersection point is the same to the size of radius. Finally, the coordinates of intersection points, denoted by X', can be derived by Equation (5) and (6).

$$BX = c \tag{5}$$

$$B = \begin{bmatrix} a_{B1} - a_{B2} & b_{B1} - b_{B2} \\ a_{B1} - a_{B3} & b_{B1} - b_{B3} \\ \vdots & \vdots \\ a_{B1} - a_{Bn} & b_{B1} - b_{Bn} \\ a_{B2} - a_{B3} & a_{B2} - a_{B3} \\ \vdots & \vdots \\ a_{Bi} - a_{Bj} & b_{Bi} - b_{Bj} \\ \vdots & \vdots \\ a_{B(n-1)} - a_{Bn} & b_{B(n-1)} - b_{Bn} \end{bmatrix}, \quad c = \begin{bmatrix} c_{B1} - c_{B2} \\ c_{B1} - c_{B3} \\ \vdots \\ c_{B1} - c_{Bn} \\ c_{B2} - c_{B3} \\ \vdots \\ c_{Bi} - c_{Bj} \\ \vdots \\ c_{B(n-1)} - c_{Bn} \end{bmatrix}$$

$$\begin{gathered} \sqrt{(x_{B1} - x_{1,2})^2 + (y_{B1} - y_{1,2})^2} = r_{B1} \\ \sqrt{(x_{B1} - x_{1,3})^2 + (y_{B1} - y_{1,3})^2} = r_{B1} \\ \vdots \\ \sqrt{(x_{B1} - x_{1,n})^2 + (y_{B1} - y_{1,n})^2} = r_{B1} \\ \sqrt{(x_{B2} - x_{2,3})^2 + (y_{B2} - y_{2,3})^2} = r_{B2} \\ \vdots \\ \sqrt{(x_{Bi} - x_{i,j})^2 + (y_{Bi} - y_{i,j})^2} = r_{Bi} \\ \vdots \\ \sqrt{(x_{B(n-1)} - x_{n-1,n})^2 + (y_{B(n-1)} - y_{n-1,n})^2} = r_{B(n-1)} \end{gathered} \tag{6}$$

In other words, the matrix $X_{i,j}$ is the linearized equation deducted from the circle of i-th Beacon and the one of j-th Beacon. The intersection points $X'_{i,j}(x_{i,j}, y_{i,j})$ can now be computed by the Equation (5) and (6). The scope of the area formed by the set of intersection points $X'_{i,j}$ is the point where the device is located at, which is the distance, $d_{Bk,i,j}$. Note that the distance between $R_k(x_{Bk}, y_{Bk})$ and $X'_{i,j}$ must be shorter than the size of radius, r_{Bk}. Equation (7) shows the obtained distances to be distinct.

$$\begin{cases} r_{B1} > d_{B1,i,j} = \sqrt{(x_{B1} - x_{i,j})^2 + (y_{B1} - y_{i,j})^2} \\ r_{B2} > d_{B2,i,j} = \sqrt{(x_{B2} - x_{i,j})^2 + (y_{B2} - y_{i,j})^2} \\ \vdots \\ r_{Bk} > d_{Bk,i,j} = \sqrt{(x_{Bk} - x_{i,j})^2 + (y_{Bk} - y_{i,j})^2} \\ \vdots \\ r_{Bn} > d_{Bn,i,j} = \sqrt{(x_{Bn} - x_{i,j})^2 + (y_{Bn} - y_{i,j})^2} \\ (k = 1,2,\cdots,n,\ k \neq i, j) \end{cases} \tag{7}$$

To improve the accuracy of position of a device, the weights for the intersection points are applied which satisfies Equation (7). The distance between center point of i-th Beacon, $R_i(x_{Bi}, y_{Bi})$, and intersection point, $\ddot{X}_{i,j}(x_{i,j}, y_{i,j})$, is r_{Bi}. Also, the distance between center point of j-th, Beacon, $R_j(x_{Bj}, y_{Bj})$, and the intersection point, $\ddot{X}_{i,j}(x_{i,j}, y_{i,j})$, is r_{Bj}. In this paper, we define the weight as r_{Bi}, which is smaller value between r_{Bi}, r_{Bj}, denoted by the weight $P_{i,j}$ in Equation (8).

$$P_{i,j} = \frac{1}{r_{Bi}} \quad (\ r_{Bi} < r_{Bj}\ ) \tag{8}$$

Finally, the location of a device, $\tilde{X}(x, y)$ is further refined by not only using formula to calculate the center of mass in N polygon but also applying the calculated weight value to Equation (9).

$$X_{i,j} = (X_x, X_y) \tag{9}$$

$$Area = \frac{1}{2} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (X_{x_i} X_{y_j} - X_{x_j} X_{y_i})$$

$$\tilde{X}(x, y) = \tilde{X}\left(\frac{1}{6 \cdot Area} \cdot \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (P_{i,j} X_{x_i} + P_{i,j} X_{x_j})(X_{x_i} X_{y_j} - X_{x_j} X_{y_i}), \frac{1}{6 \cdot Area} \cdot \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (P_{i,j} X_{y_i} + P_{i,j} X_{y_j})(X_{x_i} X_{y_j} - X_{x_j} X_{y_i})\right)$$

5. Experimental Results

Table 1 describes the experimental setup in this paper.

Table 1. Environment of the Experiment

Location	Embedded Software laboratory
Equipment	RECO Beacon
	Nexus7 2nd generation
Tool	RECO SDK Android v0.2.3
	JAVA for programming and Android Studio 1.3.1 for measurement

For the experiments, we arbitrarily established virtual environment at the ceiling of a laboratory room which is the exact square sized of four meters and made five beacons attached at each vertexes and the center of the square. Also, the coordinate system in the square whose gap of each point is 0.5 meters was designed for composing the radio map to apply Fingerprinting method. In this condition, the beacons are located at the points of (0,0), (0,8), (8,0), (8,8), and (4,4). The location information, position of device as a point (x, y), and the calculated average by RSSI values from each beacons for 120 seconds are stored at the database.

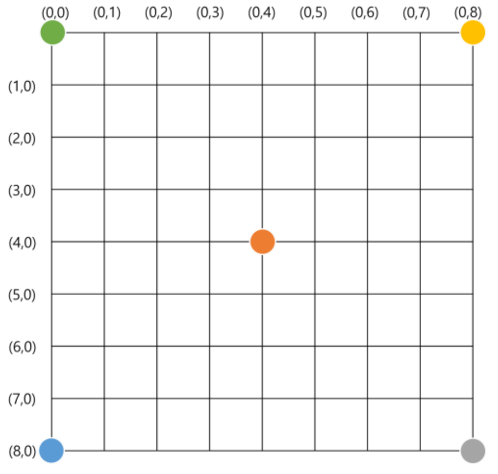

Figure 7. Composed Coordinate System and the Actual Placement of the Experiments

After the whole process of composing the radio map, we obtained the average values of each points calculated from the collected RSSI values measured by each beacon for 30 seconds. If the average value lies within the allowable range of error in Equation (2) compared to radio map in database, a given location information will be used, otherwise, the distance to each beacon will be calculated by Friis [5] transmission equation based on RSSI. Finally, we conducted the experiments in the environment as shown in Figure 7, which applies the improved weight trilateration method proposed in this paper. The experiments which measure the predicted indoor positions with the random locations are conducted and the results are presented in Figure 8 and Figure 9.

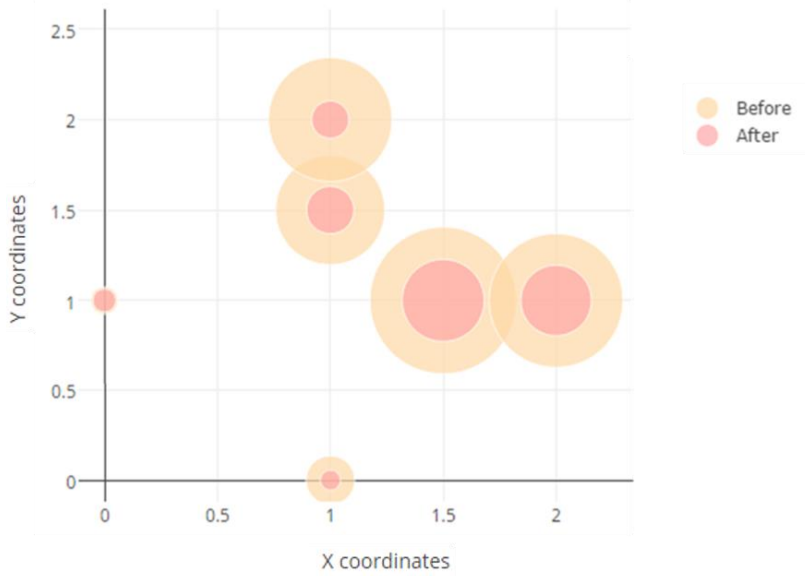

Figure 8. Experiment Result Represented as Circles (A Radius is an Error)

Regarding Figure 8, the graph visually demonstrates the circles at each coordinates whose radius is within the error derived from the experiments. By applying the proposed approach in the paper, we can identify that the error is obviously reduced compare to the previous method.

Figure 9. Experiment Results Focused on the Average of Error Reduction

Further, the radius of circle and the different between original method and the proposed method are presented in Figure 9. The difference between methods is denoted by error reduction in the figure. The coordinate which is located at the same distance from the beacons, such as (0,1) and (1,0), is used to derive the average of error reduction. As shown in the figure, the further distance from the beacons, the higher average of error reduction increases. Consequently, the proposed method in this paper provided better results in the indoor positioning than the previous method.

6. Conclusion

In this paper, we proposed a new approach which follows two steps with conventional methods to enhance the performance of the indoor location calculations. First, fingerprinting technique is applied to the distance measurement step of conventional range-based method in order to reduce the amount of computation for position calculations. Second, an improved weight trilateration method is applied to the position specifying step of conventional method which improves the accuracy of measuring the original position of a device.

The experiment results show that applying fingerprinting technique and then improved weight trilateration method subsequently reduce the error in distance estimations compared to the conventional method. We also verify that the distance is further from the beacons, then the average error reduces higher. In conclusion, the proposed approach in this paper is much effective for the indoor position awareness. In addition, there is an advantage that the proposed algorithm can be used both outdoor and indoor, wherever with the installed Beacon. Consequently, the paper's proposed positioning system is a means to measure definitely accurate position compared to the traditional system and to overcome space constraints.

Acknowledgements

This work was supported by the National Research Foundation of Korea funded by the Korean Government (NRF-2014S1A5B6037290). Sangsoo Park is the corresponding author.

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