

ACCURACY ANALYSIS OF DIFFERENTIAL DISTANCE CORRECTION USING BLUETOOTH LOW ENERGY TECHNOLOGY ON INDOOR POSITIONING SYSTEM

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Abstract

With the development of wireless technologies, Bluetooth has developed to a new version 4.0 in 2010. The major innovation is called Bluetooth Low Energy (BLE). Its characteristics of low cost, low energy consumption, and interoperability bring about a suitable tool for indoor positioning. Beacon, which is the application of BLE-based technology, is capable of transmitting information and one of them is called Received Signal Strength Index (RSSI) which can be converted to distance depending on the model of signal strength. This research utilizes beacon in indoor positioning system. The distance between transmitter and receiver can be estimated through RSSI distance model. The unknown position is subsequently calculated by trilateration. However, the signal strength of BLE will be influenced by the surrounding environments, i.e. multipath effect. To improve the performance of the positioning method, this research proposes a novel method, which corrects the distance derived from the model. The proposed differential distance correction is based on the differential method which is similar to the principle used in Global Positioning System (GPS) or Global Navigation Satellite System (GNSS). The experimental results show that the positions after differential distance correction are closer to real position in terms of overall accuracy.

Keywords: Bluetooth Low Energy, indoor positioning, differential distance correction

1. INTRODUCTION

With the development of Global Positioning System (GPS) and Global Navigation Satellite System (GNSS), the accuracy of outdoor positioning has been reached to meter level. However, the positioning ability is limited in indoors or shelters because of blocked signals, which makes it an obstacle to indoor positioning. Indoor positioning system has become popular and has been widely used in Location-based Services (LBS) in recent year (Liu et al., 2012). Nowadays, many researchers are devoted to investigate indoor positioning technology, i.e. infrared, radio frequency identification (RFID) and Wi-Fi (Liu et al., 2007; Mautz, 2012). Nevertheless, some of these methods lack for sufficient accuracy and stability or need extra equipment which may cause higher cost. Therefore, this research choose Bluetooth 4.0 for indoor positioning due to its low cost, enhanced range and low energy consumption. Furthermore, a differential distance correction is proposed which is helpful for improving the accuracy of indoor positioning by utilizing this technology. In other words, this paper exploits Bluetooth technology in indoor positioning and optimize positioning accuracy using differential distance correction.

Bluetooth wireless technology is the global wireless standard that enables data exchange between devices and it has developed to a new version 4.0 which is also called Bluetooth Low Energy (BLE) in 2010 (Gomez et al., 2012; Kajioka et al., 2014). BLE is a new wireless personal area network technology. In contrast with previous Bluetooth features, BLE has the characteristics of low power consumption and long operation time for control and monitoring applications (Faragher and Harle, 2014). In addition, compared with other wireless positioning technology, the advantages of long average life and easy installation make BLE a brilliant approach for indoor positioning. On the other hand, mobile devices are common and most of the portable devices are embedded Bluetooth functionality. The widespread use of Bluetooth technology also possesses a great potential in indoor positioning system.

This research uses BLE technology to build an indoor positioning system and implement in smartphone platform. Indoor positioning is carried out by processing beacon information, which is the application of BLE-based technology. To enhance the accuracy of BLE-based positioning, this study proposes a differential distance correction, which is based on the differential method, to correct the original distance observations and the positioning result calculated by trilateration will be closer to the real position. The rest of this paper is organized as follows: A

comprehensive detailed overview of BLE and beacon along with the positioning technique are provided in Section 2. The mechanism of differential distance correction is presented in Section 3. Section 4 describes the experiment settings. The feasibility of differential distance correction and the accuracy analysis of BLE are further discussed in Section 5, and finally conclusions are given in Section 6.

2. BEACONS BLUETOOTH POSITIONING

2.1. Bluetooth Low Energy

BLE is an emerging wireless technology developed by the Bluetooth (Cho et al., 2015). It transmits the data through radio waves, which is less likely to suffer from the interference of terrain or barriers. The information can be penetrated to some physical barriers such as walls and glass, unlike Wi-Fi, which is often disrupted. Besides, due to the features of low cost, high commonality and low power consumption, BLE is widely utilized in many applications such as health care, wearable devices and beacons for indoor positioning. Therefore, this study applies BLE for developing a feasible way in indoor positioning system, and proposes a differential distance correction to resolve the distance error for sufficient accuracy.

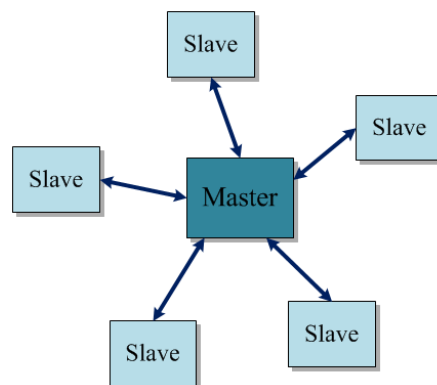
Table 1 shows the comparison of wireless positioning technologies including Wi-Fi, Bluetooth and BLE. Nowadays, the user's location in indoor environments can be provided by many wireless positioning approaches. Taking the complexity and high power consumption into consideration, many wireless technologies are not ideal for sensor networks. Based on the advantages of low power consumption, easy deployment and supported by smartphones, BLE is selected to aid the indoor positioning in this study.

Table 1: Comparison of wireless positioning technologies

Property	Wi-Fi	Bluetooth	BLE
Frequency	2.4/5 GHz	2.4GHz	2.4GHz
Data Rate	11/54 Mbps	1 to 3Mbps	1Mbps
Range	Up to 100 m	Up to 10 m	Up to 40 m
Power Consumption	High	Low	Very low
Battery life	Multiple hours	Multiple weeks	Multiple months
Cost	High	Medium	Low
Infrastructure	Existing Wi-Fi nodes	To be deployed	To be deployed
Smartphones	Supported	Supported	Supported
Accuracy	5-10 m	2-5 m	2-5 m

There are different kinds of network topologies for wireless networks such as point-to-point, star and mesh (Salas, 2014). The connection can be divided into the master role and the slave role. The former communicates with device in slave role while the latter communicates with single device in master role. BLE operates on a star network topology of Master-Slave concept, which is shown in Figure 1. Master devices can control the data transmission of slave devices and one master device can connect multiple slave devices simultaneously. In other words, a slave device can have only one link connection to one master device. In this paper, smartphones work as master devices as well as beacons, which are BLE devices, play a role of slave devices.

Figure 1: Star network topology of BLE



In order to position a user's location in indoor environments, BLE technology is needed. Only when a slave device requires a connection does a master device link to the slave one; that is to say, if the two are not connected, there will be no data transmission. So, this property brings about not only the reduction of power consumption when they are not in operation but also greatly enhances the stability and accuracy of the system.

Beacons represent the best current example of BLE technology. A "Beacon" (slave role) is an inexpensive and small wireless device that is placed at a fixed point and broadcasts radio signals to nearby smartphones and tablets (master role) (Akinsiku & Jadav, 2016).

2.2. Beacon

Beacon is a hardware transmitter that is capable of broadcasting signal to nearby portable electronic devices, containing a small amount of data. With the promotion of Android 4.3 and iOS system, this technology can be applied to most of the mobile devices, which can receive the signals from beacon. One beacon application is indoor positioning, which helps smartphones determine their

approximate location. Mobile apps can listen for the signals being broadcast and, when they hear a relevant signal, can trigger an action on the phone. Many kinds of information are in the packet and the basic information of advertising packet from beacon is shown in Table 2. Note that the RSSI value is used for further distance calculation.

Table 2: Advertising packet from beacon

Beacon prefix	Fixed by the beacon protocol and makes information follow the protocol.
UUID identifier	Identifier which should be used to distinguish the different classes of beacons in a wide range.
Major	Identifier for determining a different group of beacons.
Minor	Identifier for determining individual beacons.
RSSI	The radio signal strength indicator (RSSI) is a measurement of the power present in a received radio signal.
Measured Power	The RSSI value which is measured at 1 meter away from a beacon.

2.3. Positioning Technique

After introducing Bluetooth Low Energy and the beacon, this section focuses on the positioning technique used in this paper, which is based on the characteristics of BLE technology.

2.3.1. Distance Measurement

This paper exploits trilateration, which will be described in next section, to position the user's location, and the observations of trilateration is the measurement of distance estimated through RSSI. RSSI, which is the Radio Signal Strength Indicator, has the characteristic that can decrease exponentially according to the increase of distance (Bekkelien, 2014). A beacon transfers the signal with fixed intensity, and the strength of signal is inversely proportional to squared distance. By applying a suitable propagation model, the distance between beacon and mobile devices can be transferred by RSSI. The RSSI attenuation model (Rida, 2015) is used as Equation (1).

$$RSSI(d) = RSSI(d_0) - 10n \log_{10} \left(\frac{d}{d_0} \right) + X_{dBm} \quad (1)$$

Where, $RSSI(d)$ is the received signal power with distance d ; $RSSI(d_0)$ is the signal power with reference distance d_0 ; n is the path loss exponent about multipath phenomenon; X_{dBm} is the normal random variable with zero mean. The

Equation (2) can be transformed from Equation (1) mathematically; as a result, distance can be calculated through Equation (2).

$$d = d_0 \cdot 10^{\frac{RSSI(d_0) - RSSI(d) + X_{dBm}}{10 \cdot n}} \quad (2)$$

2.3.2. Trilateration

Trilateration is the most basic and intuitive positioning technology, which uses measured distances from known reference points to determine the position of the user (Boukerche et al., 2007). To determine the horizontal position of an unknown point, at least three reference nodes are required and the intersection of three circles is solution of the unknown point which is depicted in Figure 2. However, error must exist in distance measurement, so in practice, the intersection will show an area instead of a point, as shown in Figure 3. In this paper, beacons are put at the known reference points while the smartphone is put at the unknown point that receive signals from beacons. The location of the check point can be determined by solving the following set of equations.

Figure 2: Representation of trilateration

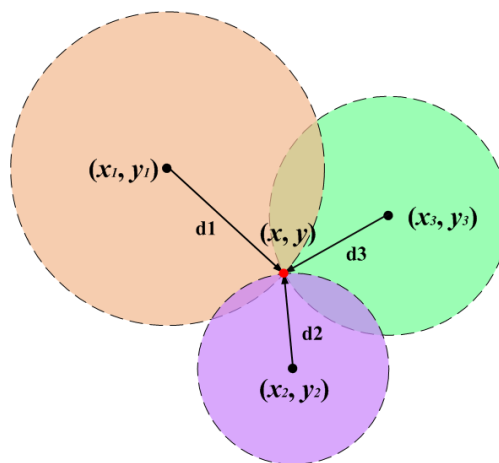
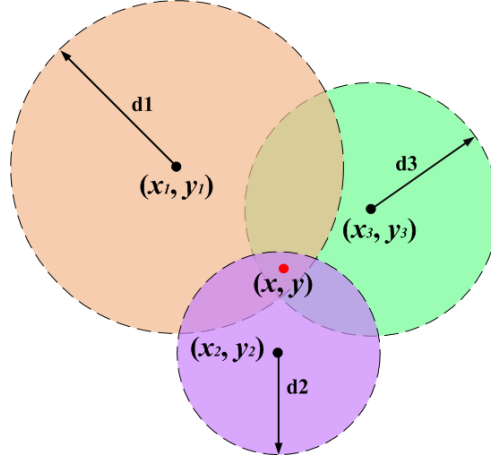


Figure 3: Representation of trilateration with multiple intersection point existence



A circle around each beacon with a radius equal to the measured distance can be represented by the Equation (3).

$$(x - x_i)^2 + (y - y_i)^2 = d_i^2 \quad (3)$$

Where, (x, y) is the unknown point; (x_i, y_i) is the position of beacon; d_i is the distance from the beacon to the target device.

A linear adjustment is proposed to solve the above-mentioned distance equation (Feldmann et al., 2003; Murphy et al., 2007), and this paper also used the same set of equations to calculate the position of the check point. The solution of the system is determine when the exact distances from three beacons are known. Equation (4) to Equation (6) are the linear system in matrix form.

$$AX = L + V \quad (4)$$

$$A = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix}; X = \begin{bmatrix} x - x_1 \\ y - y_1 \end{bmatrix}; L = \begin{bmatrix} \frac{1}{2}(d_1^2 - d_2^2 + D_{21}^2) \\ \frac{1}{2}(d_1^2 - d_3^2 + D_{31}^2) \\ \vdots \\ \frac{1}{2}(d_1^2 - d_n^2 + D_{n1}^2) \end{bmatrix} \quad (5)$$

$$D_{n1} = \sqrt{(x_n - x_1)^2 + (y_n - y_1)^2} \quad (6)$$

Where, d_i is the distance from beacon i to the target device; D_{n1} is the distance from beacon n to beacon 1.

In this study, Least Squares Estimation (LSE) is used to solve the equations listed above. LSE minimizes the sum of the square of the residual errors of the linear system as described in Equation (7) and Equation (8) can be derived by Equation (7). If the solution X is determined, the position of the unknown point is easily to get.

$$V = (L - AX)^T(L - AX) \quad (7)$$

$$X = (A^T A)^{-1} A^T L \quad (8)$$

3. METHODS

3.1. Data Processing

Since the transmitting RSSI is likely to be influenced by multipath effect or the arrangement of indoor environment, which will make the signal unstable, this research adopts Low Pass Filter (LPF) to solve the interference problem of high-frequency signal that is usually regarded as noise. The equation is shown as follows.

$$P_n = \alpha P_{n-1} + (1 - \alpha) R_n \quad (9)$$

Where, P_n is the n-th RSSI value after the processing of LPF; R_n is n-th receiving RSSI value; α is the parameter of low pass filter, and the value is between 0 ~ 1.

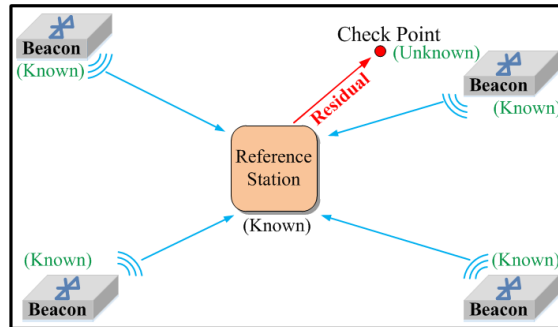
After reducing some of the noise, distance is calculated through RSSI attenuation model and the location of the check point can be determined by trilateration. However, the distance measurement still exists some systematic error, this research exploits differential distance correction which is based on the differential correction for more accurate positioning, and the processing of the differential method is described in next section.

3.2. Differential Correction

Differential correction is similar to the principle of GPS/GNSS which aims at better positioning accuracy. This research utilizes this approach to propose a differential distance correction for revising error from distance measurement. Figure 4 shows the schematic diagram of differential correction. First, the reference station (Notebook with USBeacon) is established at the reference position with a known coordinate to collect the information. As the coordinates of the reference station and the beacons are known, the respective distance of the reference station to each beacon can be calculated. Then, the residual is obtained by subtracting the reference distance from the distance calculated through the RSSI attenuation model. At last, the distance residual is transferred to another receiving station (Smartphone) in order to correct the distance observation. Once the distance of

receiving station at the check point to each beacon is revised, the positioning result derived from trilateration will be closer to the real position, which means that the positioning accuracy will be enhanced. Figure 4 shows the schematic diagram of differential correction.

Figure 4: Schematic diagram of differential correction



Beacon is pre-arranged in the experimental field for some at the known positions so as to pick three of them for trilateration and the reference station is also put at the known coordinate, as a result, the reference distance can be calculated. RSSI value from each beacon is mainly used for getting the distance observation between reference station and each beacon, while the signal strength will suffer from the surrounding environment, i.e. multi-path effect, which makes the signal weak and unstable. The feeble signal leads to poor accuracy of estimated distance and positioning result. In order to deal with this problem, this research proposes the differential distance correction to improve positioning accuracy. By remove the residual of distance, differential correction is adopted to correct the position of receiving stations (check point).

4. EXPERIMENT SETTINGS

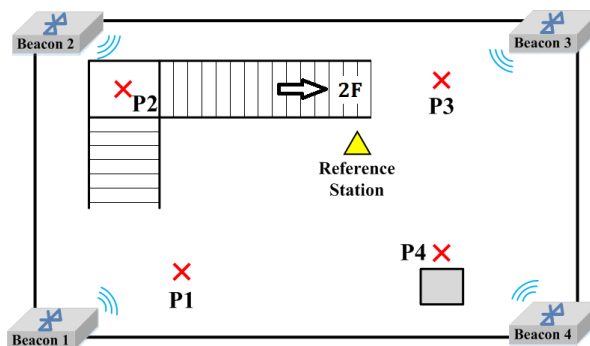
This research sets up the experimental field at the Department of Geomatics in National Cheng Kung University. Four beacons are arranged at four corners of the experimental field with the height of 2 meters so as to ensure that no shelter is on the path of signal transmission. Beacons used in this study are produced from THLight as shown in Figure 5. Note that the right one is the USBeacon which can be set in any USB ports and make the device to be a receiver; this is the beacon used at the reference station. The left one is another beacon type that is placed at the corner of the experimental field as a transmitter.

Figure 5: Beacons used in this study



To correct the distance error, the differential principle is applied to calculate the residual of distance. This research sets up a main position as the reference station close to the center of the experimental field, and the reference station consecutively received signals from the four beacons in order to compute the average residual of distance between each beacon and the reference station. The average residual is calculated by subtracting known distance from average of distance observation. The receiving station at check point can acquire more accurate distance between each beacon and the receiving station after the correction of the residual. Finally, the coordinates of each check point are obtained by trilateration which uses the corrected distance. However, trilateration only needs three reference nodes for positioning, so three beacons are selected from the four and there are four combinations of beacons are used. Figure 6 shows the experimental field arrangement. Experimental field is a closed indoor environment with length of 15 meter and width of 9 meter. P1, P2, P3 and P4 are the check points of the experimental field.

Figure 6: The arrangement of the experimental field



5. RESULTS AND DISCUSSION

To verify the accuracy of trilateration after using the differential distance correction, the Root Mean Square Error (RMSE) is employed to evaluate the performance. RMSE shows the difference between positioning result and the real position of the check point. The smaller the value of RMSE is, the closer to the real position. Table 3 shows the RMSE of the horizontal positioning result. Trilateration uses four kinds of combination of three different beacons as reference nodes to calculate the position of the check points. The four combinations include four beacons except Beacon 1, four except Beacon 2, four except Beacon 3 and four except Beacon 4, respectively. "Before" stands for trilateration results using uncorrected distance and "After" stands for trilateration results using corrected distance.

Table 3: RMSE of the horizontal positioning result

RMSE(m)	Except Beacon 1		Except Beacon 2		Except Beacon 3		Except Beacon 4	
	Before	After	Before	After	Before	After	Before	After
P1	2.80	2.66	3.43	2.68	3.88	2.67	3.32	2.57
P2	7.68	6.72	9.87	8.41	6.84	5.30	2.44	0.91
P3	5.12	5.30	4.52	4.07	0.73	0.79	2.58	3.59
P4	4.27	5.57	3.70	4.47	1.93	2.40	2.94	4.19

As the Table 3 shows, it is obviously that the horizontal positioning results of P1 and P2 are closer to the reference station since the RMSE values are smaller than the original value after the differential distance correction is used and the improvement is about 1 m. However, P3 and P4 are not significantly improved or even getting worse, which means that the horizontal positioning result is distant from the real position. In next paragraph, this paper will focus on discussing whether the results of P4 can be used for accuracy analysis or not.

The last row of Table 3 shows that the positioning result of P4 is worse after using the differential distance correction. Since a pillar is near P4, the surroundings of it are different from the reference station where the environment is quite spacious. The residual of distance is relative to the surrounding environment, so that the horizontal positioning result of P4 is poorer than the original one. Therefore, P4 should not be considered to verify the reliability of differential distance correction due to the dissimilar respective surrounding environments of the P4 and the reference station. Although the unconsidered P4 shows poor positioning result after correction, it is evident that the similarity of surroundings at reference station and check points impacts the positioning accuracy. The feasibility of purposed differential distance correction can reach to three over twelve, which is 75%, when P4 is not taken into account, as shown in the Figure 7. Improvement means that the value of RMSE is smaller after correction, and deterioration means that the

value of RMSE is larger after correction. The detail of improvement and deterioration at P1, P2 and P3 is also shown in Figure 8.

Figure 7: The feasibility of differential distance correction

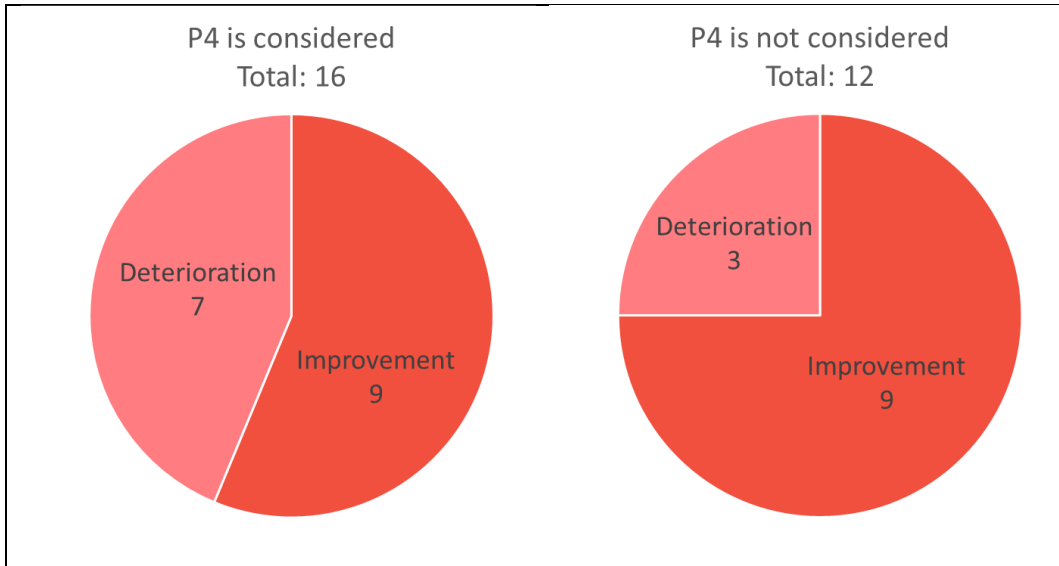


Figure 8: Improvement and deterioration at P1, P2 and P3

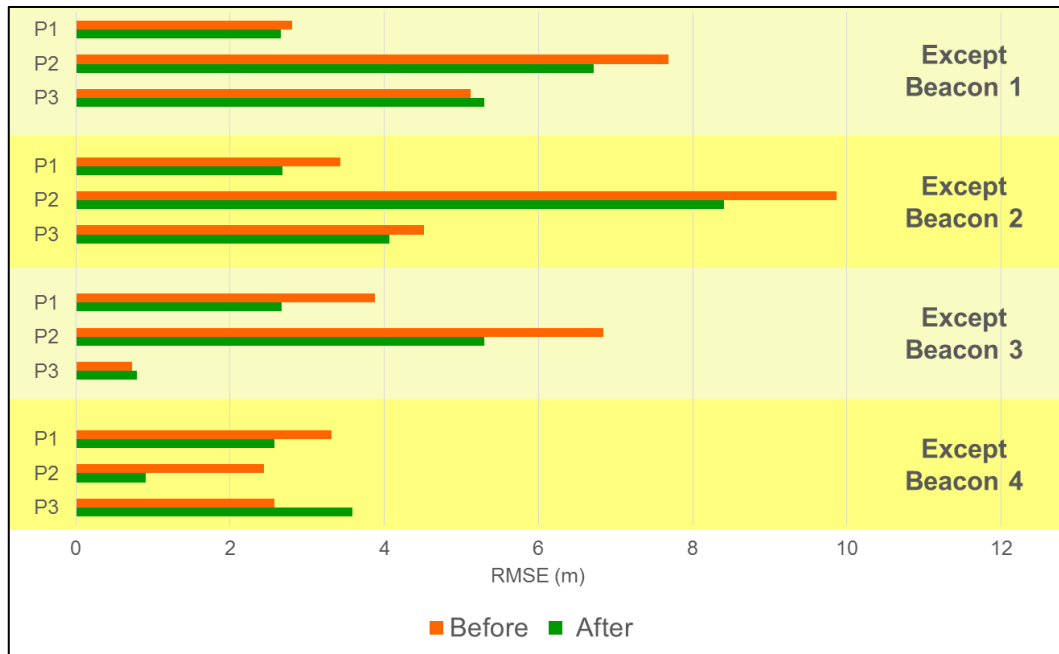
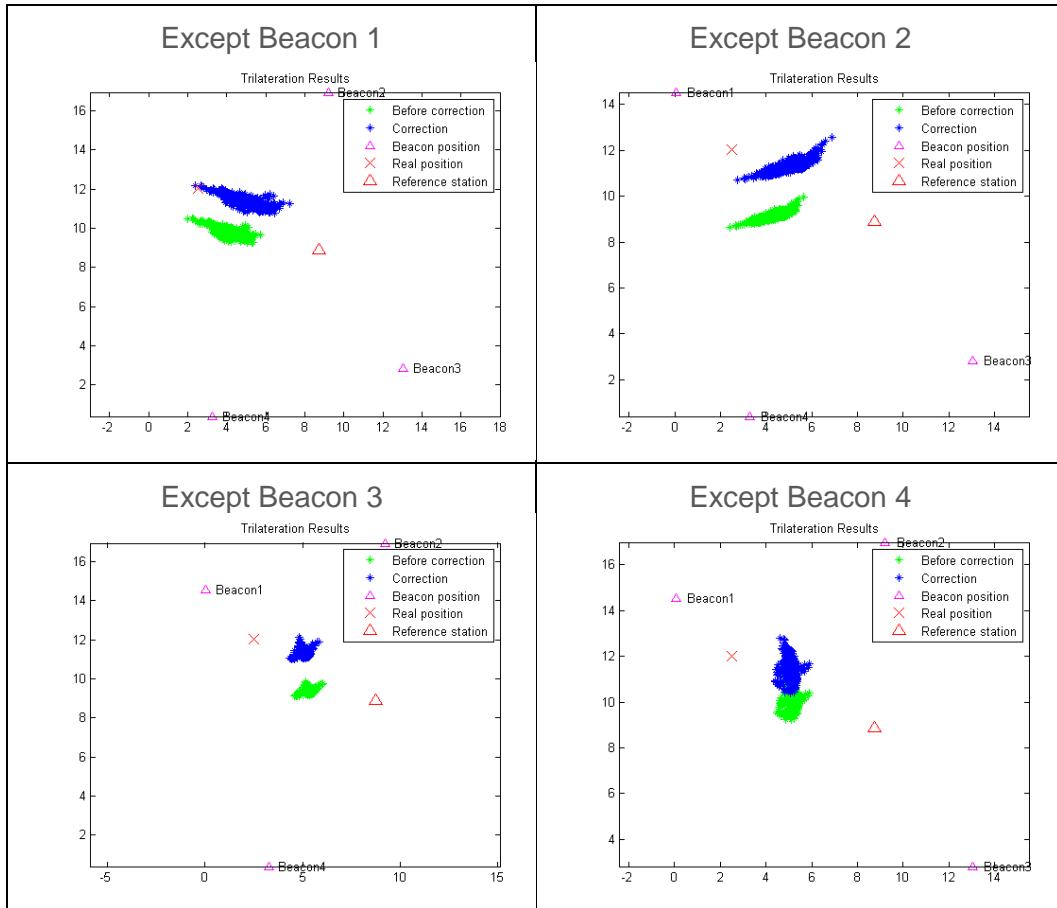


Table 4: RMSE of the horizontal positioning result without P4

Improvement	Except Beacon 1		Except Beacon 2		Except Beacon 3		Except Beacon 4	
	meter	%	meter	%	meter	%	meter	%
P1	0.14	5.00	0.75	21.87	1.21	31.19	0.75	22.59
P2	0.96	12.5	1.46	14.79	1.54	22.51	1.53	62.70
P3	-0.18	-3.52	0.45	9.96	-0.06	-8.22	-1.01	-39.14
Mean	0.31	4.66	0.87	15.54	0.90	15.16	0.42	15.38

From Figure 8, most of the RMSE values are lower than the uncorrected value and enhance the accuracy of different three check points. Table 4 which shows the improvements of various situation also describes the same trend. The improvements are recorded in the form of meter and percentage so as to understand fully at a glance. The advancement of the RMSE can be up to 62.70%; however, the accuracy may deteriorate in some case. The RMSE values of P3 are larger when Beacon 2 is included; in other words, the accuracy of P3 is reduced if using Beacon 2 signals and enhanced if Beacon 2 is excluded. Beacon 2 is set beside the stairway which the signals are often blocked and become feeble in the view of P3; receiver at P3 receives weak signals from Beacon 2 that lead to poor positioning result. Note that the surrounding environments of P3 and reference station are similar, but the stairway block more Beacon 2 signals in respect to P3 rather than the reference station. So, the accuracy only improves when not using Beacon 2. Moreover, the RMSE values of P2 are often larger than the other check points. P2 is set on the stairway which is higher than the floor. Because of height and handrails, poor accuracy of P2 is caused by the multipath effect which the receiver at P2 receives beacon signals reflected by other objects. As a result, the calculated distance exists error and brings about bad positioning result. Even so, differential distance correction still can make the positioning result of P2 close to the real position, same as P1. The accuracy of P1 also improves after exploiting the differential distance correction. Figure 9 compares trilateration results of uncorrected and corrected distance at P1 in different kinds of beacon combination. It is clear that the horizontal positioning result of P1 is closer to the real position. The last but not the least, the experimental results show that the positions after differential distance correction are closer to real position in terms of overall accuracy and the improvement is about 0.6 m.

Figure 9: Trilateration results of uncorrected and corrected distance at P1



6. CONCLUSIONS

This research proposes a novel method to improve the performance of the positioning method utilizing Bluetooth Low Energy technology, which corrects the distance derived from the RSSI attenuation model. The proposed differential distance correction is based on the differential method which is similar to the principle of GPS/GNSS. In order to obtain better positioning accuracy, it exploits reference station which is a known point to compute the residual of distance so as to correct the distance observation from receiving station at the check point. Once the distance of receiving station to each beacon is revised, the positioning result calculated by trilateration will be closer to the real position after differential distance correction. Finally, this study uses Root Mean Square Error (RMSE) to evaluate the accuracy of the check points which the true location is surveyed by the total station.

The experiment was performed at the relatively complicated field, so lots of factors influenced the experimental result. Positioning result of P4 is not considered for accuracy analysis due to dissimilar surrounding environment to reference station. The remaining check points verify that the purposed differential distance correction is truly able to make the positioning result more accurate when the surroundings of check points are similar to those of reference station. The improvement is about 0.6 m which shows that the differential distance correction can optimize positioning accuracy. The further research of this study will conduct another experiment in an empty room so as to compare the influence of the obstacles in the experimental space. To sum up, this research uses Bluetooth Low Energy technology for indoor positioning and the proposed method, differential distance correction, is indeed capable of improving the accuracy on the indoor positioning system.

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