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Accuracy Enhancement of RSSI-based Distance Estimation by Applying Gaussian Filter

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Abstract

RSSI values of Bluetooth Low Energy (BLE) beacon are unreliable to use localization. To cope with this problem, we propose a new localization algorithm that enhances the accuracy of RSSI value. The proposed algorithm applies Gaussian filter to RSSI values from BLE Beacons, and then uses weight value based on filtered RSSI quality. **Background/Objectives:** Friis formula is used to calculate distance between a BLE beacon and BLE scanners using triangulation scheme. Finally, Gaussian filtering is applied twice to the location values for accuracy improvement. **Findings:** Experiments are performed in indoor environment, and experiment data is calculated by MATLAB to make graph and chart for easily comparing location result. Experiment result shows that DGF algorithm shows more accurate and reliable localization result than commonly used Kalman filter algorithm. Furthermore, DGF algorithm is very effective to calculate not only distance but also location. **Improvements:** DGF algorithm indicates excellent performance when we adapt weight value. The proposed system can be used to tracking the location of BLE beacon in real-time.

Keywords: Bluetooth, Beacon, DGF, Localization, RSSI

1. Introduction

Recently, the rapid growth of wireless network technology leads to increased interests in services and applications based on location. For outdoor environment, there is several location tracking systems. However, each of these systems has own limitations which make it hard for indoor environment: Global Positioning System (GPS) is inappropriate for indoor use because it cannot obtain satellite signals in indoor. RFID also can be used for indoor localization; however, it covers short range. Wi-Fi is widely used in indoor for communication and solution for localization. The main limitation of Wi-Fi indoor localization is in determining the position of client devices with respect to access points. As an alternative to these systems, Bluetooth Low Energy (BLE) is widely studied for indoor location tracking system because of its low cost and easy deployment. It can be used over a range of 80m without obstacles and two years maximum. However, it also has shortcomings: battery replacement, difference in range and battery life depending on transmits power and so on. In addition, a Received Signal Strength Indicator (RSSI) value is easily affected by environment. Even at the fixed location, RSSI values vary according to errors and noise[1,2]. To cope with this problem, filtering algorithm is applied after triangulation or least square method is performed with inaccurate RSSI values[3-5]. The typical examples include recursive Bayesian filtering, Kalman filtering, and weights[6-11].

There are many algorithms for localization without RSSI scheme: Time of Arrival (TOA), Time Difference Of Arrival (TDOA) and Angle Of Arrival (AOA). However, the requirements for these systems are not supported in Bluetooth specification so that they are not applicable to Bluetooth: clock synchronization for TOA and TDOA and directional antennas for AOA. In this paper, we

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propose an indoor location tracking system with RSSI of a BLE beacon. To overcome the limitation of RSSI problem mentioned above, we propose a localization system with a weight based on its quality and double Gaussian filtering method for equalization of RSSI values, distances and locations in the system, one for RSSI values and the other for calculated locations. The proposed system adapts RSSI values considering following properties. First, it does not require device discovery scheme which is time-consuming work. Second, its output power is not affected by its location. We show through the experiment that the proposed method provides more accurate results on distance and location.

The rest of this paper is organized as follows. In Section 2, we describe the system design and implementation details. In Section 3, we show performance evaluation result of the proposed system and we conclude and discuss future research plan in Section 4.

2. System Design and Implementation

2.1 System Design

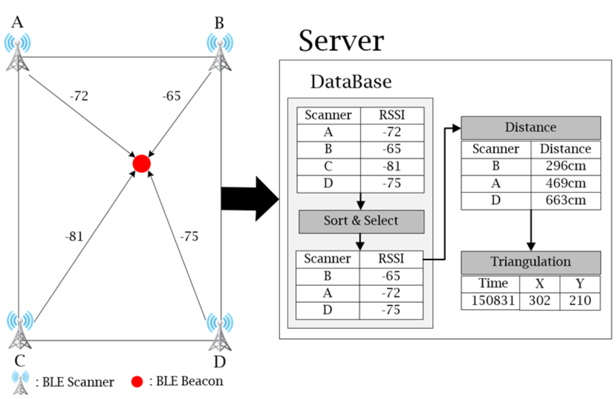

Figure 1. System layout and processing steps.

Figure 1 shows the proposed system flowchart. There are several BLE scanners which receive RSSI from the BLE beacon and send them to a database server. At the server, a Gaussian filter and a weight algorithm are applied to the obtained RSSI values to produce W_G_RSSI (Weight_Gaussian_RSSI) values. Friis equation is applied to the W_G_RSSI to calculate the distance between the beacon and the BLE scanners. If three or more scanners receive a beacon with an identical MAC address at the same time, triangulation is carried out to calculate the location of the beacon. If there are more than three scanners in this case, three scanners with the shortest distance from the beacon are chosen for more accurate localization. To calculate location of the beacon, the triangulation uses distances between the beacon and the scanners, and the known locations of the scanners from the database. Finally, another Gaussian filter is applied to the coordinates, X and Y, of the beacon to make them more accurate.

2.2 DGF (Double Gaussian Filter) Algorithm

DGF algorithm is a method to produce the exact localization result by making the values as averaging RSSI value which including the noise and the error value.

Require: Input $RSSI$, RSSI values received by scanners

1: **for** each scanner SC received beacon signals **do**
2: **for** mac, a MAC address of a beacon signal at s **do**
3: $RSSIs \leftarrow$ a set of previous RSSI values from SC with mac
4: **if** $|RSSIs|$ is enough to apply a Gaussisn filter **then**
5: $G\_RSSI \leftarrow$ Gaussian($RSSI$, $RSSIs$)
6: **else**
7: $G\_RSSI \leftarrow RSSI$
8: $W_G_RSSI \leftarrow$ApplyWeight(G_RSSI)
9: $Dist_s^m \leftarrow$ Friis(W_G_RSSI)
10: **for** each MAC address mac of beacons **do**
11: $D^m \leftarrow$ a set of $Dist_i^m$ for $1 \leq i \leq n$
12: **if** $|D^m| \geq 3$ **then**
13: $(x, y) \leftarrow$ Triangulation(D^m)
14: $PLoc \leftarrow$ a set of previous coordinatres (x, y) with mac
15: $(x', y') \leftarrow$ Gaussian((x, y), $PLoc$)
16: **function** ApplyWeight(G_RSSI)
17: $Quality \leftarrow 2 \cdot (G\_RSSI + 100)$
18: $Weight\_ST \leftarrow$ Weight strength based on $Quality$
19: $result \leftarrow Quality/Weight\_ST + G\_RSSI$
20: **return** $result$

Figure 2. DGF algorithm.

Figure 2 explain how to apply DGF algorithms sequentially. There are n scanners and more than one beacon to localize. Line 1-9 is executed for each scanner that received beacons. First of all, a Gaussian filter is applied to the received RSSI value and a set of previous values with the same MAC in Line 5. A Gaussian filter modifies the inputted signal by convolution with a Gaussian function, which smooths the inputted values. The one-dimensional Gaussian filter can be expressed with the standard deviation as parameter.

$$g(x) = \frac{1}{\sqrt{2\pi \cdot \sigma}} \cdot e^{-\frac{x^2}{2\sigma^2}} \quad (1)$$

By Equation (1), we can obtain filtered results, G_

RSSIs, of observed RSSIs. To apply a Gaussian filter, there should be enough number of previous RSSI values. Then, a weight based on the quality of the filtered value is applied to improve its accuracy. If a quality value is far form 100 percentages, then Weight_ST will be increased. Weight_ST is based on 50 percentage of Quality Weight_ST value will be increased 10 as follow the every 10 percentage increased. To improve the reliability of G_RSSI, DGF algorithm addition weight value which is calculated by divide Quality to Weight_ST. The obtained value is given to Friis equation to calculate the distance from the scanner to the beacon.

Friis transmission equation gives the power received by one antenna under idealized condition when another antenna transmits a known amount of power at some distance. The power received Pr can be expressed with transmitting power Pt, wavelength λ, distance d, and antenna gains Gt, Gr

$$\frac{p_r}{p_t} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (2)$$

Antenna gains *Gt* and *Gr* are usually expressed in dB and in free space they are power ratio of 1.0 or 0 dB. The inverse of the third factor of Equation 3 is so-called free-space path loss and can be expressed in dB

$$L_{FS} = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (3)$$

$$L_{FS}(dB) 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) = 20\log_{10}\left(\frac{4\pi df}{c}\right) \qquad (4)$$

From Equation 5 we can calculate distance d.

$$d = \frac{c}{4\pi f} \cdot 10 \frac{L}{20} \qquad (5)$$

If there are more than three distances with the same MAC, triangulation is applied to them in Line 13. In the procedure Triangulation, the shortest here distances are used for accuracy. Triangulation is a process to calculate the locations of a point by coordinates of three known points. On a two-dimensional plane, if we know the coordinates of known points and distances from those points to unknown location, we can determine the coordinate of the unknown location from following equations.

$$\begin{aligned} d_1^2 &= (x - x_1)^2 - (y - y_1)^2 \\ d_2^2 &= (x - x_2)^2 - (y - y_2)^2 \\ d_3^2 &= (x - x_3)^2 - (y - y_3)^2 \end{aligned} \qquad (6)$$

To make the location more accurate, another Gaussian filter is applied to the result with the previous coordinates (Line 15). The algorithm is carried out at the server because it needs all the received beacons and computed values.

3. Experiment Results

For experiments, we used a Raspberry PI Model B as BLE scanners which has a Broadcom BCM2835, 512MB RAM, and NEXT-104BT USB (Bluetooth 4.0). For each experiment, we collected RSSI values for different locations and applied the proposed procedure to calculate locations of the beacon. MATLAB was used to compare and analyze the results.

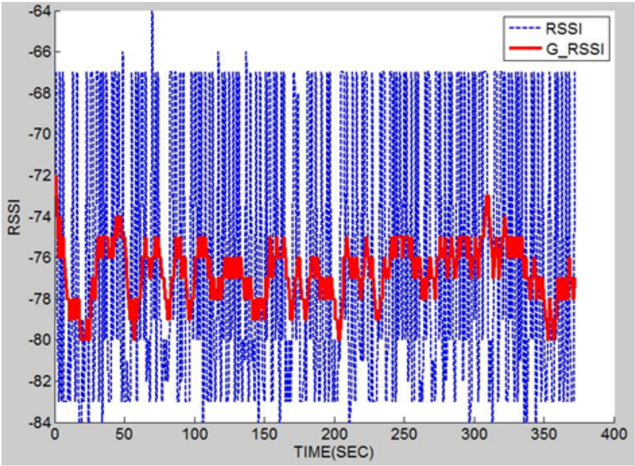

Figure 3. Effects of Gaussian filter to RSSI.

The horizontal axis represents elapsed time and the vertical axis represents RSSI values. We collected RSSI values and applied a Gaussian filter to them to see the effect of the filter. Figure 3 depicts RSSI and G_RSSI values of the beacon for six minutes which is six meters apart from the scanner. The blue dotted line shows RSSI and the red solid line shows G_RSSI, the filtered values. The results are summarized in Table 1.

Table 1. Summary of Gaussian filtered RSSI

Case	Count	Min	Max	Mode	Average
Actual	372	-84	-64	-67	-76.17
G_RSSI	372	-80	-72	-76	-76.72

It shows that difference between the maximum and the minimum of the filtered values is smaller than that of raw values and the mode of the filtered values are closer to the average. From these results, it is obvious that applying a Gaussian filter to RSSI values is very effective in reducing noise.

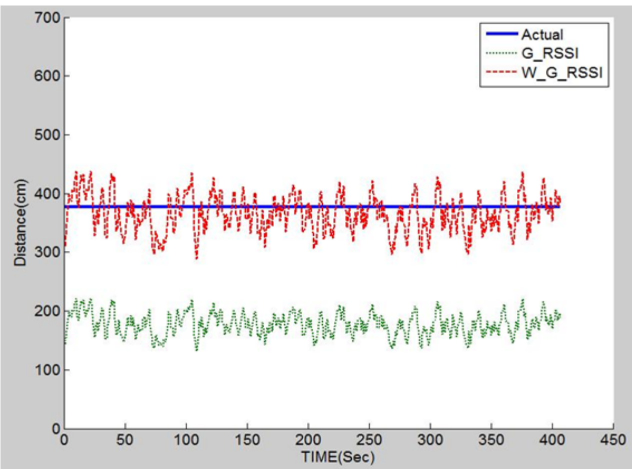

Figure 4. Effects of a Gaussian filter and a weight to RSSI.

We applied a weight based on its quality to G_RSSI to see its effect on the calculated distance. Figure 4 presents calculated distances with the filtered RSSI values, G_RSSI (green dotted line), from a beacon 377m apart from the scanner and the values after applying a weight to the filtered values, W_G_RSSI (red dotted line). It shows that we can obtain more accurate distances by applying a weight to the filtered values of RSSI. However, it also shows that the modified values also contain errors which are shown by the differences between the actual distance (blue horizontal line) and the computed distances. These errors affect accuracy of location, which can be reduced by applying another Gaussian filter at later step of the proposed procedure. Figure 3 is summarized in Table 2.

Table 2. Summary of weighted Gaussian filtered RSSI

Case	Count	Min	Max	Mode	Average
Actual	407	377.49	377.49	377.49	377.49
G_RSSI	407	131.65	222.30	173.60	177.87
W_G_RSSI	407	288.31	438.40	359.72	366.45

It shows that W_G_RSSI provides more accurate values for localization: 366.45m of the computed distance compared to the actual 377.49m. The mode and the average with W_G_RSSI are also much closer to the actual distance. These results confirm that applying a weight to G_RSSI based on its quality is an effective step toward more accurate localization.

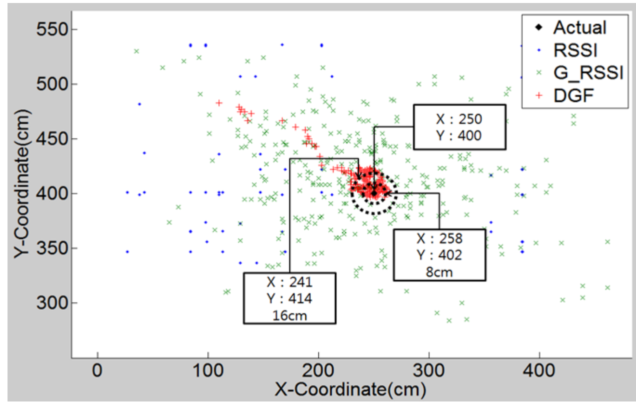

Figure 5. Effects of a Gaussian filter to distance.

Figure 5 shows effect of DGF algorithm by compare with RSSI and G_RSSIs location result. Black dots (250, 400) indicate exact locations and others show computed locations. It shows that applying a DGF algorithm to the calculated coordinates improved accuracy of the locations than other values, received RSSI values or the filtered values: red dots are located closer to black dots than green or blue dots.

4. Conclusions

We proposed a new algorithm that uses double Gaussian filtering and a weight based on its quality for accurate localization. By reducing signal noise and errors by applying a real time Gaussian filter to received RSSI values from a BLE beacon, we can obtain the distance between the BLE beacon and scanners more accurately. Finally, to calculate more accurate location, we applied a Gaussian filter once more to the results of triangulation. The proposed system provides distances and locations of the BLE beacon with high accuracy. In this way, we can estimate indoor location efficiently with BLE technology. The results show that BLE can be used as an efficient tool for indoor localization system.

5. Acknowledgment

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