

BLE-BASED ACCURATE INDOOR LOCATION TRACKING FOR HOME AND OFFICE

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ABSTRACT

Nowadays the use of smart mobile devices and the accompanying needs for emerging services relying on indoor location-based services (LBS) for mobile devices are rapidly increasing. For more accurate location tracking using Bluetooth Low Energy (BLE), this paper proposes a novel trilateration-based algorithm and presents experimental results that demonstrate its effectiveness.

KEYWORDS

Indoor location tracking, Indoor positioning, Distance-based filtering algorithm, Trilateration algorithm, Location-based services (LBS)

1. INTRODUCTION

Nowadays the use of smart mobile devices, such as smartphones, has increased explosively and the needs for emerging services relying on indoor location-based services (LBS) for mobile devices are also rapidly increasing.

For indoor location tracking, WiFi has been used most widely. Recently, the Bluetooth technology has introduced an energy efficient Bluetooth Low Energy (BLE) version [1]. Because of its lower transmitter power usage and its simpler receiver architecture without any sophisticated techniques for dealing with multipath such as MIMO or RAKE, BLE has been found to be a more suitable technology for indoor location tracking with respect to both accuracy and energy efficiency [2].

For computing distances, the BLE AP just broadcasts a short packet periodically with an advertising interval. After receiving this short packet, the BLE receiver can compute an approximate distance by comparing the Received Signal Strength Indication (RSSI) and the

broadcasting power of the BLE AP [3, 4]. If there are 3 or more distance information from the installed BLE APs in the given indoor area, the current location can be calculated through the Trilateration algorithm [5, 6].

Not only WiFi but also BLE uses the same 2.4 GHz Industrial Scientific Medical (ISM) radio band, and because of the license free characteristics of the ISM band, they can easily have interferences of signals, which cause signal strength fluctuations [7]. Due to this interference, RSSI value is not always accurate as the result of calculating distance values changes in every advertising interval. To make location tracking more accurate, many studies were conducted such as using numerous BLE APs or using the fingerprint pattern matching instead of the Trilateration algorithm [7, 8]. Beyond a threshold, increasing the number of BLE APs does not improve and may even deteriorate the location tracking accuracy [7]. In the case of the method using the fingerprint pattern matching, a pre-processing is required that creates a database of signal strength values for all sampling locations [8].

In this paper, we propose a novel Trilateration-based location tracking solution that uses the algorithms that are designed based on the result of analyzing BLE signal characteristics. Then we verify the effectiveness of the proposed solution through several experimental results in a realistic environment.

2. THE PROPOSED ALGORITHM

Figure 1 is the flow chart for our proposed algorithm. Once the receiver receives signals from BLE APs, the receiver extracts RSSI values and calculates distances through the RSSI values. In the following, we explain our proposed algorithm in detail by presenting each of its core component algorithms, which are shown in blue in Figure 1, in a sub-section. The proposed method of reducing distance errors is presented in Section 2.1 (Applying the Kalman filter for the first time). Section 2.2 explains the steps from removing error distances to removing error locations in Figure 1. The proposed distance-based filtering algorithm, which dramatically minimizes location tracking error, is presented in Section 2.3. And the method for getting a more accurate location point is presented in Section 2.4 (Applying the Kalman filter for the second time).

2.1. Applying the Kalman filter for the first time

A distance value of a BLE AP is calculated from RSSI in every advertising interval and the calculated distance values can fluctuate due to other signals in the ISM band [7].

There are many ways for reducing fluctuation. We considered both the moving average method and the Kalman filter [9] that is an effective and the most common noise filtering algorithm. We tested them to compare their performances. Testing checked location fluctuations in a small area (3.9m * 3.9m). Testing results from our testing application are shown in Figure 2, in which dots are calculated locations and lines are differences between the current locations and the previous locations. To compare performance the following methods are used:

(F1) Raw - without any filter

(F2) 3 moving average method – calculates the average result of the recent 3 calculated locations.

(F3) 5 moving average method – calculates the average result of the recent 5 calculated locations.

(F4) Kalman filter – calculates the result of the Kalman filter.

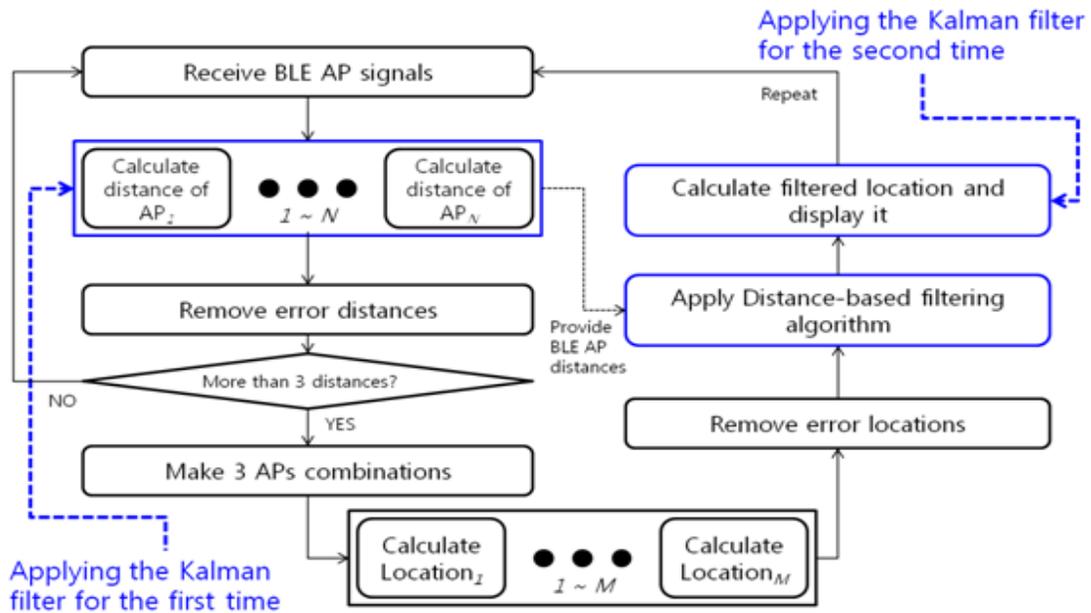


Figure1. Flow chart for the proposed algorithm

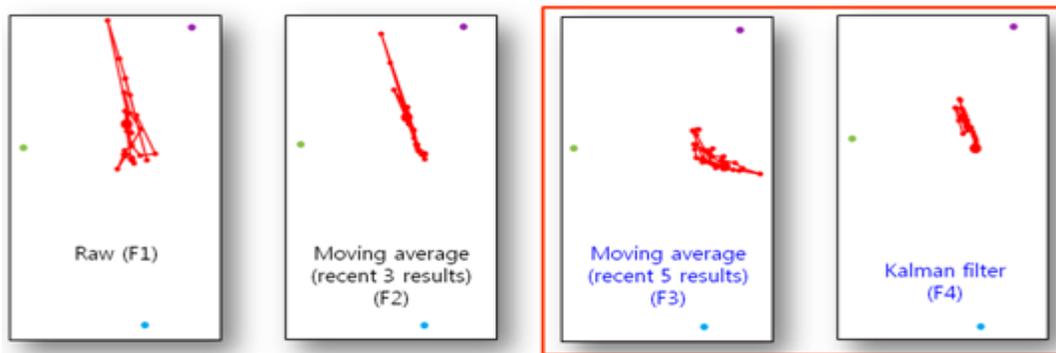


Figure 2. Filter comparison results

Figure 2 shows that both the 5 moving average method (F3) and the Kalman filter (F4) are superior to the others. To get the first location result in the case of the 5 moving average method (F3), however, waiting a minimum of 5 times of the advertising interval time is required. For instance, 5 seconds is required when the advertising interval is 1 second. This is a critical problem when the user moves repeatedly in a short time interval. So we decided to use the Kalman filter to reduce fluctuations in both distance and location.

Based on the above filter comparison results, we apply the Kalman filter to each distance value to reduce fluctuation effectively.

2.2. Removing error distances and locations

The most important thing for calculating accurate locations is the accurate distance information and, even though we apply the powerful Kalman filter, it may not be enough to get the accurate distance because of the inherent limitation of the BLE signal characteristics. Due to the fluctuation of the results, some distances should be discarded if they are out of the actual maximum distance.

If there are only three BLE APs, we can calculate only one location point through the Trilateration algorithm [5, 6]. If we use more than three BLE APs, however, any combinations of the three BLE APs can be selected for calculating location points. For example, if we use 6 BLE APs, a total of 20 combinations for calculating location points can be selected. Then each combination can be used to calculate a location point. However, because signals propagate making a circle without direction, calculated location points should be discarded if they are out of the boundary of the actual space. To get one accurate location, we can consider different choices of algorithms that calculate it by using the location points that remain after discarding the out-of-boundary location points.

2.3. The distance-based filtering algorithm

We developed the distance-based filtering algorithm by analyzing the characteristics of RSSI-distance variations. According to the path loss model [10], attenuation of RSSI becomes larger as the distance becomes longer. We picked the BLE AP closest from the current location as the reference point. Compared to the distances of the other BLE APs, the distance of this reference point is probabilistically more accurate.

As explained in Section 2.2, there are remaining location points calculated from a three BLE AP's combination. We can calculate distances between the reference point and the remaining location points and then choose N location points by sorting the distances where N is the value pre-defined by the environment. Now we can calculate an average location point through N location points as a candidate for the current location.

2.4. Applying the Kalman filter for the second time

Candidates of the current location are calculated in every advertising interval of BLE AP, for example in every 250ms. Still there may be some location tracking error in each candidate. So we apply the Kalman filter for the second time to each candidate location point to minimize location tracking error.

3. IMPLEMENTATION

To develop the solution, we implemented the receiver and configured the parameters of the BLE AP. The following sub-sections present configuring the BLE AP in Section 3.1, and implementation of the receiver in Section 3.2.

3.1. The BLE AP

The BLE AP periodically broadcasts a short packet to all receivers in every pre-defined advertising interval. Then the receiver approximates the proximity by converting the RSSI of this packet to distance depending on the broadcasting power of the BLE AP. When calculating a

location using BLE, the role of the BLE AP is just advertising packets periodically. For the BLE AP we just need to adjust two parameters “the advertising interval” and “the broadcasting power”, and most of the BLE products support these two parameters. So we decided to use Estimote products as the BLE APs.

3.2. The receiver

We used Android phone to implement the receiver, and Figure 3 shows the software architecture of the receiver. The implemented Android application includes the following modules:

- (D1) The BLE AP manager
- (D2) The movement detector
- (D3) The accuracy algorithm module
- (D4) UI

We used the following public libraries:

- (D5) The Kalman filter
- (D6) The Trilateration algorithm

Because we used Estimote product, we also used the following library:

- (D7) Estimote SDK/ service

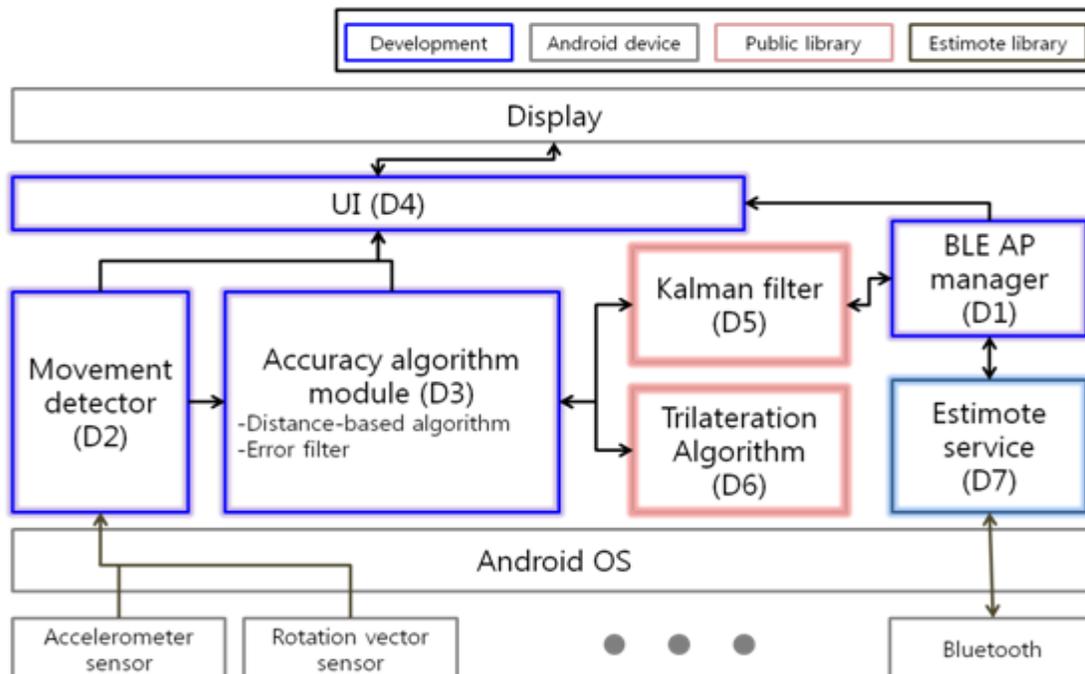


Figure 3. The software architecture of the receiver

The BLE AP manager (D1) maintains information of each BLE AP including its MAC address, location, and distance. The Estimote service (D7) notifies distance through event listener in the BLE AP manager in every advertising interval. Some distances are discarded because they are out of the boundary of actual space, and the Kalman filter (D5) is applied to get more accurate distances as explained in Section 2.1.

The movement detector (D2) is developed using the Android accelerometer sensor for detecting user movement. When moving such as walking or running occurs, the acceleration of gravity in the Android device changes. Android accelerometer sensor provides X, Y, Z values [11]. X value indicates left or right movement, Y value indicates up or down movement, and Z value indicates forward or backward movement. Through these values we can get the amount of change of the device acceleration of gravity. This information is passed to the accuracy algorithm module (D3) to make it detect user location changes.

The accuracy algorithm module (D3) was developed to get an accurate user location based on the Trilateration algorithm (D6) and includes the distance-based filtering algorithm explained in Section 2.3 and applies the Kalman filter (D5) for the second time as explained in Section 2.4.

4. EVALUATION

The testbed consists of 6 Estimote BLE APs in a polygonal living room (8.5m × 13m) of a real house and 1 Android phone (Samsung Galaxy Note 3 with Android 5.0) as the receiver. Figure 4 shows the installed BLE APs in the living room.

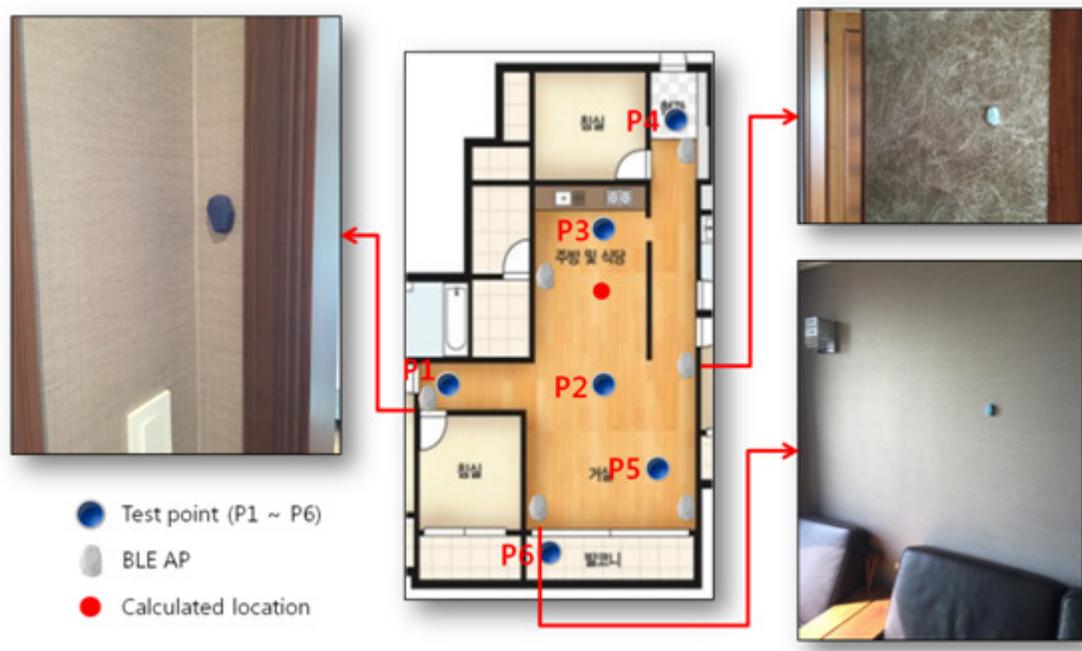


Figure 4. BLE APs and test points in the testbed

4.1. Evaluation scenario and method

We set 6 test points as in Figure 4 to measure accuracy by checking distance differences, called *location tracking errors*, between test points and calculated locations. For measuring accuracy the measurer moves from test point 1 (P1) to test point 6 (P6) sequentially.

When approaching each test point the measurer touches the test point button in the testing application, which was developed especially for evaluation, the testing application automatically calculates the location tracking error and displays its value next to the test point button. To evaluate performance, the following algorithms are considered:

- (A1) The raw algorithm – calculates the average result from all calculated locations without the Kalman filter
- (A2) The average algorithm – calculates the average result from all calculated locations using the Kalman filter
- (A3) The proposed algorithm – calculates the average result from distance-based filtered locations using the Kalman filter

In the case of the raw algorithm (A1), only the minimal filter that excludes values outside the boundaries of the actual distance and the actual location is used. The result is the average value of all calculated locations from the BLE AP combinations.

In the case of the average algorithm (A2), the minimal filter and the Kalman filter are used. The result is the average value of all calculated locations from the BLE AP combinations.

In the case of the proposed algorithm (A3), in addition to the minimal filter and the Kalman filter, the distance-based filtering algorithm explained in Section 2.3 is used. The result is the average value of locations selected by the distance-based filtering algorithm.

4.2. Experimental results

We performed testing 10 times for each of the algorithms A1, A2 and A3. The advertising interval of the BLE AP is 250ms, and its broadcasting power is 4dBm.

Table 1 shows the average result from each test point, and Figure 5 shows the result graph when using the raw algorithm (A1). The average location tracking error was about 3.01m.

Table 2 includes average result from each test point and Figure 6 shows the result graph when using the average algorithm (A2). The average location tracking error was about 2.93m. The location tracking error was slightly decreased due to the use of the Kalman filter.

Table 1. Result of the raw algorithm

	Point1	Point2	Point3	Point4	Point5	Point6	Average
Average of 10 tests	1.94	1.51	2.61	5.57	2.63	3.79	3.01

Table 2. Result of the average algorithm

	Point1	Point2	Point3	Point4	Point5	Point6	Average
Average of 10 tests	2.37	1.05	2.62	5.43	2.46	3.65	2.93

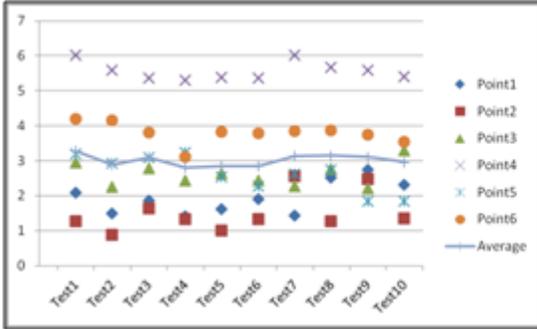


Figure 5. Result of the raw algorithm

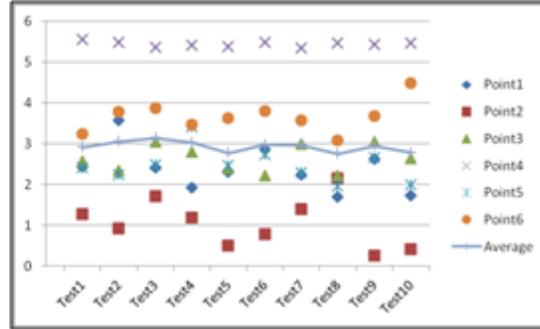


Figure 6. Result of the average algorithm

As Table 3 and Figure 7 show, the location tracking error dramatically decreased when using the proposed algorithm. The average location tracking error was about 1.77m and the reduction ratios are about 41% from the raw algorithm and about 39% from the average algorithm.

Table 3. Result of the proposed algorithm

	Point1	Point2	Point3	Point4	Point5	Point6	Average
Average of 10 tests	1.21	1.70	2.33	2.46	1.17	1.75	1.77

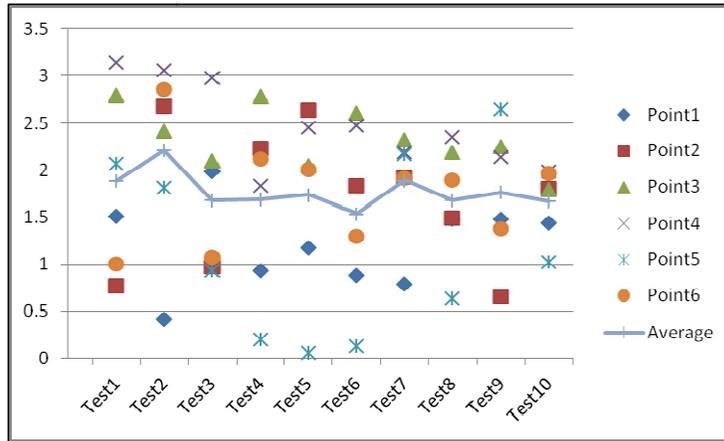


Figure 7. Result of the proposed algorithm

5. CONCLUSION

An indoor location tracking technology is necessary for emerging services or applications. In this paper we proposed a novel distance-based filtering algorithm and a solution, which are based on the Trilateration method that does not require any pre-processing such as creating a database of signal strength values at all sampling locations.

Through several experimental results, we demonstrated the effectiveness of the solution in significantly reducing location tracking errors. We are convinced that our indoor location tracking technology using the proposed algorithm and solution can further contribute to making more convenient the emerging services such as the Online to Offline (O2O) service and to creating new services in the IoT environment.

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