Adaptive bluetooth indoor positioning system based on greedy strategy

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Abstract. In order to solve the problem that current bluetooth indoor positioning system has low positioning accuracy in dynamic environment and can’t unable to adapt to dealing with complex situation of anchor circle, this paper proposes an adaptive bluetooth indoor positioning system based on greedy strategy. The system uses the deployed bluetooth to intelligently sense the real-time environment and measure the ibeacon signal attenuation model to reduce the ranging error caused by dynamic change of environment. In addition, the three anchor circles of the weighted centroid positioning into three groups and two different anchor circles are one group, and greedy strategy is used for getting the better weighted objects when each group of circles are intersected, or separated, or contained. Finally, the sum of the reciprocal radius of each group of anchor circles is used as the weight to obtain the estimated coordinates of unknown nodes. To verify the effectiveness of the positioning system by case study, the results show that the average error value is 0.60m. Compared with the centroid localization algorithm and weighted centroid algorithm, the system has the advantages of intelligent environment perception, higher positioning accuracy, and adaptive algorithm for dealing with various situations of anchor circle.

1. Introduction
Based on Receiveed Signal Strength (RSSI) positioning theory is that using a certain number of wireless sensors laid out in the target’s pending location area in advance, the information of the pending object in the signal coverage area is sensed and collected, and the target’s location information is processed through the relevant algorithm. With the advantages of low cost and simple equipment, RSSI positioning is the hot spot of indoor positioning research at present.

Literature [1] proposes an accurate positioning scheme by offline RSSI location fingerprint database and fingerprint matching algorithm, but to bulid the fingerprint database needs onerous workload and RSSI datas are influenced by the environment, this way can only be applied to small relatively stable environment. Literature [2] puts forward to while taking the reciprocal error of coordinate obtained by substituting normal equation as weights, to distinguish the influence of the difference anchor nodes on the unknown node RSSI data improve the positioning accuracy. Literature [3] takes the sum of the reciprocal Nth power of the distance as the weight, the weight is larger when the anchor node is closer, and discusses the influence of N value on the positioning accuracy [3]. However, because the weighted object is the anchor node coordinates, the included area is too large, and the promotion effect is limited. Literature [4] takes the intersection of three anchor circles as the weighted object to reduce the weighted area and the positioning error[4].Literature [5] is not limited to
trilateral positioning, and proposes to take the quadrilateral intersected by four anchor circles as the weighted area to improve the accuracy by multiple weighting [5]. However, the algorithm is limited by the beacon density and must exist quadrilateral formed by four circles, so it is difficult to be widely applied to indoor complex environment.

The paper considers that the ibeacon signal attenuation model is variable in dynamic environment and the inevitability of RSSI ranging error caused by the interference of wireless signal propagation[6], two of the three anchor circles may intersect, or separate, or include, and it may lead to that three circles do not intersect at one point, or even have no intersection area. The optimization algorithm of literature [4] and [5] taking the anchor circle intersection point as weighted object is no longer applicable. To solve the problem, the system measures the ibeacon real-time signal attenuation model and apply the RSSI weighted positioning algorithm integrating greedy strategy. According to the difference of intersection, separation and inclusion, greedy strategy is used to determine three better weighted objects. Then, the sum of reciprocal radius of anchor circle is used as weights to obtain the estimated position of unknown nodes.

2. Intelligently sense the Real-Time environment
In the positioning system, a certain number of monitoring Bluetooth will be deployed in different areas to search for the surrounding ibeacons, and the RSSI value will be filtered to reduce noise error through filtering algorithm and be uploaded to the server with the help of wireless communication module. The server will fit the path signal attenuation model in real time according to the RSSI under different distance values between the ibeacon and the monitoring Bluetooth.

3. RSSI weighted centroid localization algorithm based on greedy strategy
In view of the problem of low positioning accuracy when the weighted object contains too large area and low anchor node density in the weighted centroid localization algorithm, although the point intersected by three anchor circles is proposed as the weighted object in literature [3], the possible area of unknown nodes can be reduced and the number of anchor nodes required is small, but due to the inevitability of RSSI ranging error, in the actual environment, there are many situations in which any two circles are included, or intersected or separated. Therefore, the three circles may not perfectly intersect at one point (such as (a) in Figure 1), but may intersect in one area (such as (c) in Figure 1), three areas (such as (b) in Figure 1), or even no intersection ((e) in Figure 1). The method of taking the intersection point of anchor circle as the weighted object will be invalid, while taking the coordinates of adjacent anchor nodes as the weighted object can not achieve the purpose of improving the accuracy of the algorithm by reducing the surrounding area of the weighted object. Therefore, the centroid weighting algorithm based on the intersection point of three anchor circles is limited and can not be applied to all general situations. The paper proposes an indoor weighted centroid localization algorithm based on greedy strategy which can adaptively deal with complex situations of three circles. The algorithm has the advantages of high positioning accuracy and good adaptability.
3.1. Algorithm theory

The basic idea of RSSI adaptive centroid localization algorithm based on greedy strategy is proposed in this paper: After preprocessing the collected original RSSI data, the distance value from the corresponding anchor node to the unknown node is calculated by using the logarithmic distance path loss model; The first three smaller distance values are taken out, and r1, r2 and r3 are recorded, and the three anchor circles are drawn; considering the complex position of three anchor circles may intersect, separate, or include, it should be discussed according to the specific situation:

1) For example, two circles intersect as shown in Figure 2-a. In theory, intersection point A and B of circle 1 and circle 2 exist the value of |dAO1−r1|+|dAO2−r2|=|dBO1−r1|+|dBO2−r2|=0. The greedy strategy of weighted object is the sum of error to two circles is the lowest, and the error to the remaining circle is relatively low. Obviously, A and B have a point closer to circle 3, which is used as the weighted centroid to locate new weighted points with high positioning accuracy.

2) In the same way, for example, two circles are separated as shown in Figure 2-b. In theory, circle 1 and circle 2 are separated without intersection, any point C in the line from A to B satisfies the minimum value of |dCO1−r1|+|dCO2−r2|. The greedy strategy of weighted object is the sum of error to two circles is the lowest, and the error to the remaining circle is relatively low. There must be a point on line AB that is closer to circle 3. As a new weighted point, it has high positioning accuracy.

3) Similarly, for example, two circles are included as shown in Figure 2-c. In theory, circles 1 and 2 don’t exist no intersection point, the extension line connecting the centers of the two circles intersects point A of the small circle and point B of the large circle, any point C in the line from A to B satisfies the minimum value of |dCO1−r1|+|dCO2−r2|. The greedy strategy of weighted object is the sum of error to two circles is the lowest, and the error to the remaining circle is relatively low. There must be the shortest distance between a point on line AB and circle 3. As a new weighted point located by weighted centroid, it has high positioning accuracy.
It can be seen from the above that any two circles can get better weighted points under the greedy strategy decision. In this way, three better weighted objects can be obtained by combining three circles in pairs. Then these weighted objects are weighted by the reciprocal sum of the selected anchor circle distance, and the result is the estimated position of the unknown nodes. The calculation method is as follows:

\[ X_O = \frac{X_E \times \left( \frac{1}{d_A} + \frac{1}{d_B} \right) + X_F \times \left( \frac{1}{d_A} + \frac{1}{d_C} \right) + X_G \times \left( \frac{1}{d_B} + \frac{1}{d_C} \right)}{2 \times \left( \frac{1}{d_A} + \frac{1}{d_B} + \frac{1}{d_C} \right)} \]

\[ Y_O = \frac{Y_E \times \left( \frac{1}{d_A} + \frac{1}{d_B} \right) + Y_F \times \left( \frac{1}{d_A} + \frac{1}{d_C} \right) + Y_G \times \left( \frac{1}{d_B} + \frac{1}{d_C} \right)}{2 \times \left( \frac{1}{d_A} + \frac{1}{d_B} + \frac{1}{d_C} \right)} \]  

In the formula (2), \( d_A, d_B \) and \( d_C \) are the distances from unknown nodes to anchor nodes A, B and C; \( E(X_E, Y_E) \) is the weighted object calculated by the combination of circle A and circle B, \( F(X_F, Y_F) \) is the weighted object calculated by the combination of circle A and circle C, \( G(X_G, Y_G) \) is the weighted object calculated by the combination of circle B and circle C; the weights of E, F and G are \( (1/d_A+1/d_B), (1/d_A+1/d_C), (1/d_B+1/d_C) \); the estimated position of the point to be measured \( (X_O, Y_O) \).

Therefore, no matter what the anchor circle position is, the weighted centroid localization algorithm with greedy strategy has the corresponding weighted object solving method, rather than purely taking anchor nodes or anchor circle intersection points as weighted objects. So the algorithm has good adaptability and can handle all kinds of complex situations of anchor circle. It can be seen from the analysis that the algorithms in literature [4] and [5] which take the intersection point of anchor circle as the weighted objects, such as Figure 1-b and Figure 1-c, which is only a special case when three anchor circles intersect each other. In addition, in essence, the algorithm only needs to combine the distance and the center coordinates to judge the relationship between the three anchor circles, and further combine with the specific situation to get the corresponding weighted object. Because of the greedy strategy, the weighted area is effectively reduced. The algorithm takes into account the positioning accuracy and adaptability.

3.2. Algorithm process
The technical process of the algorithm is shown in Figure 3.
Figure 3. Technical Flow Chart

1) The monitoring blue tooth acquires multiple RSSI data at different distance values, and a better logarithmic distance path loss model is fitted;

2) Through the logarithmic distance path loss model fitted in step 1), the RSSI value of the unknown node receiving the adjacent anchor node is replaced to obtain the distance value from the unknown node to the corresponding anchor node;

3) The distance values in step 2) are sorted, and the first three smaller distance values are taken as anchor circles for calculation;

4) The anchor node coordinates and distance values corresponding to the distance value are selected from 3). By analyzing the relationship between two groups of anchor circles, three weighted points are calculated by greedy strategy;

5) The centroid coordinates of the area surrounded by the three weighted points in step 4) are calculated with the sum of the reciprocal radii of each anchor circle as the weight.

4. Experimental results and analysis

4.1. Experimental environment
Taking the 10m long and 7m wide classroom as the experimental area, and considering the complexity of the real environment, the desks and chairs are placed in the classroom and the personnel are arranged to walk around. IBEACON ONE, IBEACON TWO, IBEACON THREE, IBEACON Four as anchor nodes are deployed in the experimental area to verify the effectiveness of the proposed algorithm. Those name, MAC address, transmit power and other configuration information are shown in Table 1. The plane coordinate system was established in the experimental area. The deployment position of anchor node ibeacon and nine node positions P1, P2 ..., P9 as the check points in the quadrilateral region was recorded.

| Table 1. IBEACON Configuration Information Table |
|-----------------|-----------------|-----------------|
| Name            | MAC             | TX_POWER        |
| IBEACON ONE     | 9c:a5:25:12:bc:9c | +8dbm          |
4.2. Analysis of experimental results

Through the fitting path loss attenuation model, the distances from each check point to different anchor nodes are calculated by using the collected RSSI data. According to the distance value and anchor node coordinates, the centroid positioning algorithm, the weighted centroid positioning algorithm and the improved weighted centroid positioning algorithm are used to calculate the estimated positions of each check point. The estimated positions calculated by the three methods are shown in Figure 4, and the coordinate values are shown in Table.2.

| Checkpoints | Actual location (m) | Centroid Localization algorithm (m) | Weighted Centroid Localization algorithm (m) | Optimized weighted Centroid Localization algorithm (m) |
|-------------|---------------------|------------------------------------|---------------------------------------------|-----------------------------------------------------|
| P1          | (1.3,0.2)           | (1.77,1.43)                        | (1.48,0.93)                                 | (1.77,0.65)                                         |
| P2          | (1.7,1.7)           | (1.77,1.43)                        | (1.98,1.53)                                 | (1.86,1.90)                                         |
| P3          | (1.3,3.2)           | (1.77,2.77)                        | (1.60,2.80)                                 | (1.75,3.03)                                         |
| P4          | (2.8,0.1)           | (1.77,1.43)                        | (2.37,1.06)                                 | (2.32,0.73)                                         |
| P5          | (2.8,1.4)           | (3.43,1.43)                        | (3.34,1.31)                                 | (3.19,1.67)                                         |
| P6          | (2.8,2.8)           | (3.43,2.77)                        | (3.35,2.92)                                 | (3.07,3.22)                                         |
| P7          | (4.4,0.1)           | (3.43,1.43)                        | (3.71,0.92)                                 | (3.87,0.69)                                         |
| P8          | (4.4,1.8)           | (3.43,1.43)                        | (3.72,1.47)                                 | (3.79,2.03)                                         |
| P9          | (4.4,2.8)           | (3.43,2.77)                        | (3.68,2.98)                                 | (3.69,2.55)                                         |
The actual position $P_i(X_i, Y_i)$, the centroid localization algorithm estimates the position $A_{P_i}(A X_i, A Y_i)$, the weighted centroid localization algorithm estimates the position $B_{P_i}(B X_i, B Y_i)$, and the improved weighted centroid localization algorithm estimates the position $C_{P_i}(C X_i, C Y_i)$. The distance between the two points of the estimated position and the actual position is taken as the evaluation standard of the positioning accuracy, which is recorded as $\Delta$ and the error value of the centroid positioning algorithm is taken as an example,

$$\Delta = \sqrt{(A X_i - X_i)^2 + (A Y_i - Y_i)^2}$$  \hspace{1cm} (2)

Therefore, the errors of the three positioning algorithms are shown in Fig. 6.

![Figure 5. Comparison of Errors in Experimental Measurements of Three Algorithms](image)

According to Figure 5, the maximum error is 1.68m, the minimum error is 0.28m, and the average error is 0.98m; the maximum error of weighted centroid localization algorithm is 1.07m, the minimum error is 0.33m, and the average error is 0.71m; the maximum error of the improved weighted centroid localization algorithm is 0.79m, the minimum positioning accuracy is 0.26m, and the average error is 0.60m. Compared with the center of mass algorithm indoor positioning accuracy, the maximum increase of 89cm, the minimum increase of 2cm, the average increase of 38cm, compared with the weighted centroid algorithm indoor positioning accuracy, the maximum increase of 28cm, the minimum increase of 2cm, the average increase of 11cm.

It can be seen from Figure 4 that the final estimated position of the RSSI based centroid localization algorithm is located at the centroid position of the area surrounded by the three anchor nodes receiving the signal. When the unknown node is near the centroid, the error is small, otherwise the error is large, so the positioning effect is unstable, especially when the unknown node is located at the edge of the area surrounded by the anchor node; the weighted centroid localization algorithm is loop bound environmental impact based on RSSI ranging error is bound to exist and anchor nodes surrounded by polygon as a weighted area is too large, some check points positioning effect improvement is limited.

In this paper, the system fits the path signal attenuation model in real time and the optimized weighted centroid algorithm fully considers the geometric relationship, combines the distance and anchor node coordinate information, adaptively processes a variety of three circle positions, and combines greedy strategy to obtain better weighted points, which can reduce the possible area of unknown nodes. Because the error sum from the weighted point to two circles is the lowest, and the error to the remaining circle is relatively low. In addition, the reciprocal sum of distance is used as the weight, so the deviation between the calculated check point coordinate and the real check point coordinate is small, the positioning accuracy is high, and the requirements for the number of adjacent anchor nodes are not high, and the algorithm is simple and easy to understand.
5. Concussion

In this paper, the existing weighted centroid localization algorithm based on RSSI is optimized. The weighted object is no longer limited to anchor nodes or anchor circle intersections, and according to the position relationship of three anchor circles, the greedy strategy is adopted to select new better weighted points, which not only meets the minimum error to two circles, but also reduces the possible area of unknown nodes. Compared with the centroid localization algorithm and the weighted centroid localization algorithm, the accuracy of the optimized algorithm is improved by 38.7% and 15.5% respectively, and the positioning error is significantly reduced. Moreover, the algorithm has good adaptability and can flexibly handle various complex situations of the three anchor circle in the actual environment. In addition, the algorithm is simple and can be applied in the case that the number of adjacent anchor nodes is small and the deployment density of anchor nodes is small.

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