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Improved Localization Algorithm Based on RSSI in Low Power Bluetooth Network

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***Abstract*—Due to the low power feature of Bluetooth, network based on Bluetooth has been considered as one of the promising positioning technology candidates by the research and industry communities. In order to reduce the positioning error being introduced by the Received Signal Strength Indication (RSSI) algorithm, an optimized RSSI ranging and positioning algorithm is proposed, which is fully based on the low power Bluetooth positioning technology. First, this algorithm uses the trilateral algorithm to get the rough region estimation which covers all the unknown nodes. Second, by breaking down the area, the algorithm forms the RSSI value for the beacon nodes at the centroid of each region, and also forms the RSSI value at the unknown nodes. Thirdly, the RSSI values that are formed by the beacon node at the unknown node and at the centroid of each region are compared against each other to determine the unknown node's location. Experiments and simulation results show that this algorithm can increase accuracy of distance estimation by 63.3% compared to the traditional centroid localization algorithm.**

Keywords*—low energy blue tooth; centroid localization algorithm; RSSI; node localization

I. INTRODUCTION

Recently, the low power Bluetooth technology based positioning has attracted a lot of attentions. There are mainly two ways to do location by using the Bluetooth wireless sensor network. One is range-based and the other is range-free [1]. The representative positioning algorithms, which don't need distance measurement, include triangle centroid location algorithm, distance vector hop algorithm, amorphous algorithm and approximate point in triangulation algorithm, etc. These algorithms are range-free algorithms which don't require distance measurement in real time, and are only used to estimate the location of the unknown node. Correspondingly the position is not accurate enough. And distance based localization algorithms mainly includes three side location algorithm, Time Difference Of Arrival algorithm (TDOA), Time Of Arrival algorithm(TOA) and Received Signal Strength Indication(RSSI). Among them, the TOA and TDOA algorithms generally require higher hardware resources [2]. However, the location algorithm based on RSSI does not have high demand of hardware resources [3]. In this algorithm, transmitter transmits the signal and the receiver takes the received signal strength value as input and further denoises it. Then the RSSI value is put into the equation to calculate the distance between the two nodes. Due to its simplicity, the RSSI based algorithm is usually used to locate the wireless network nodes [4].

Although RSSI based positioning algorithm is relatively simple, it still has some issues in terms of measurement error and positioning accuracy [5], which are mainly caused by the complex situation of the indoor environment, such as the flow of personnel and all kinds of obstacles occlusion. These indoor situations introduce the multipath and diffraction phenomenon of the signal during the propagation, which in turn seriously affect the positioning accuracy [6].

Through the above analysis of the existing centroid localization algorithm, the idea of combining the range-based location method and the range-free location method is needed [7]. In this paper, an improved centroid localization algorithm is proposed which is based on the three side location algorithm with combined impacts from RSSI value distribution. This algorithm dynamically divides the region where the unknown nodes exist. First, the approximate one region of the unknown node is determined by the three side location algorithm. Second, the algorithm further divides the region according to the nodes' RSSI value distribution. Thus a plurality of beacon nodes will form a RSSI value at the unknown node and a RSSI value at all the centroid area. By comparing these two RSSI value, the algorithm dynamically determines the location of each of the unknown node.

II. LOCATION ALGORITHM MODEL OF RSSI

A. Signal Attenuation Model

Usually, the signal intensity of the Bluetooth is gradually weakened with the increase of the transmission distance [8]. Commonly used signal propagation models are free space propagation model, two-ray propagation model and logarithm normal distribution model. The free space propagation model is an ideal model, which does not require human intervention [9]. The two-ray propagation model is a model of the signal which is assumed to be evenly spread to all around [10]. In practice, the signal of Bluetooth may be affected by the mobility of people. Therefore, the two propagation models are not suitable for precise positioning. According to a large number of experiments, the log normal distribution model is usually used for accurate positioning. The equation for calculation is as follows:

$$Pr(d) = d * Pr(d_0) - 10nlg\left(\frac{d}{d_0}\right) * X_\sigma \qquad (1)$$

In the above equation, d means the transmission distance. $Pr(d)$ represents the signal strength with distance d. Similarly, $Pr(d_0)$ represents the signal strength with distance d_0. In contrast, d_0 is the reference distance. Usually, d_0 is set to 1 meter. $X\sigma$ is a zero-mean normal distribution. When the d is less than 8 meters, the above equation can be simplified to the following expression:

$$RSSI = P_t - 40.2 - 10 * 2 * lgd \tag{2}$$

In order to make the RSSI value more accurate, this paper chooses Gaussian curve fitting technique and Gaussian smooth technique to process signal. The calculation equation is as follows:

$$\begin{cases} \mu = \frac{1}{m}\sum_{i=1}^{m} RSSI_i \\ \delta^2 = \frac{1}{m-1}\sum_i^m (RSSI_i - \mu)^2 \\ f(RSSI) = \frac{1}{\sigma\sqrt{2*\pi}} e^{-(\frac{(RSSI-\mu)^2}{2*\delta^2})} \end{cases} \tag{3}$$

According to the equation (1) to (3), the distance between the unknown node and the beacon nodes can be obtained. Then the triangle centroid algorithm can be used for positioning.

B. Traditional Centroid Location Algorithm Model

Centroid location algorithm only needs to know three or more beacon nodes coordinates in order to position an unknown node. It is a connectivity algorithm, which does not require distance information [11], and is relatively simple to achieve the results. The algorithm works as follows: beacon nodes periodically transmit theirs location information and their own identifier to the sides and the unknown node is constantly searching for the different beacon nodes. When unknown node receives the signal from different beacon nodes and the number of different beacon node reaches a certain threshold K, then the unknown node's position is determined by the K beacon nodes. Suppose the unknown node's coordinate is (x, y), and these K beacon nodes coordinates are (x_1, y_1), (x_2, y_2)…And (x_k, y_k). Assuming K = 3(Fig. 1), the centroid algorithm can calculate the coordinates of the unknown node.

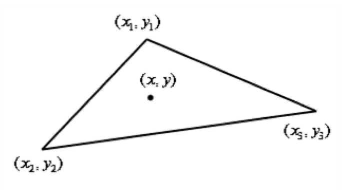

Fig. 1. Traditional centroid localization algorithm

This algorithm is relatively simple. However, this algorithm has accuracy issue. The reasons are as follows: this algorithm does not consider the true distribution of the RSSI value in the unknown nodes' area. In fact, the location information of each vertex is not equal, and each vertex causes different influence on the positioning accuracy. The unknown node transmits the signal forming different RSSI values at the beacon nodes, and the distance is not necessarily the same between each beacon node and the unknown node. As a result, the algorithm cannot calculate the beacon nodes coordinate by averaging.

C. Model of Centroid Localization Algorithm Based on RSSI

Through the analysis based on the above traditional centroid location algorithm, now more commonly used solution is to take the RSSI data into account, and combines the range-based and range-free location algorithm. The specific process is to set three beacon nodes as $O_1(x_1, y_1)$, $O_2(x_2, y_2)$, $O_3(x_3, y_3)$, then the distance between the beacon nodes and the unknown node is calculated according to the equation (1) to (3). Assume that the distance is d_1, d_2 and d_3. Suppose O_1, O_2, O_3 are the center, by using d_1, d_2 and d_3 as the radius, three circles are drawn and the intersection of the three circles is the unknown node's location (x_1, y_1).

$$\begin{cases} \sqrt{(x - x_a)^2 + (y - y_a)^2} = d1 \\ \sqrt{(x - x_b)^2 + (y - y_b)^2} = d2 \\ \sqrt{(x - x_c)^2 + (y - y_c)^2} = d3 \end{cases} \tag{4}$$

Ideally, the coordinate of the unknown node can be obtained by the equation (4). In practice, due to the complexity of the indoor environment, the distance calculated by equation is not exactly equal to the true distance between unknown node and beacon nodes. Therefore, according to the equation (4) it will get more than one intersection. These intersections form an overlapping area, as shown in Fig. 2.

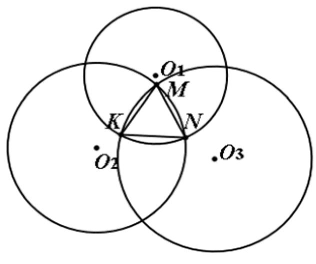

Fig. 2. Three-sided measurement

According to the equation (5), it calculates the intersecting point coordinate (x_m, y_m) formed by the three circles. Similarly, assume N point's coordinate is (x_n, y_n). K point's coordinate is (x_k, y_k). Finally, use the centroid localization algorithm to solve the problem.

$$\begin{cases} \sqrt{(x_m - x_1)^2 + (y_m - y_1)^2} \le d1 \\ \sqrt{(x_m - x_2)^2 + (y_m - y_2)^2} = d2 \\ \sqrt{(x_m - x_3)^2 + (y_m - y_3)^2} = d3 \end{cases} \tag{5}$$

The literature [12], introduced the modified weighted centroid location algorithm for positioning. Compared to the traditional positioning method, the positioning accuracy is improved, but it does not take into account that the complicated environmental factors influenced the positioning accuracy. The literature [13] used the preferred beacon nodes and the weighted centroid localization. However it does not consider the signal distribution model. In the literature [14], it proposed a ranging compensation idea, processing the RSSI value by mean filtering. However it depends on the specific environmental information and has a slow processing time.

Through the analysis based on the above, this paper has put forward an improved centroid localization algorithm. The ΔMNK region is further divided into *n!* small areas. The number of beacon nodes is *n*. Suppose n is equal to 3, according to the equation (5), the intersecting point coordinate (*M*, *N*, *K*) can be obtained. In the equation (4), for each equation, by taking square on each side, a new equation is formed. Further, by subtracting any two new equations, a linear function is achieved as shown in the following equation:

$$\begin{cases} L_1: 2(x_2-x_1)x+2(y_2-y_1)y = {d_1}^2-{d_2}^2-{x_1}^2 \\ \qquad +{x_2}^2-{y_1}^2+{y_2}^2 \\ L_2: 2(x_3-x_2)x+2(y_3-y_2)y = {d_2}^2-{d_3}^2-{x_2}^2 \\ \qquad +{x_3}^2-{y_2}^2+{y_3}^2 \\ L_3: 2(x_3-x_1)x+2(y_3-y_1)y = {d_1}^2-{d_3}^2-{x_1}^2 \\ \qquad +{x_3}^2-{y_1}^2+{y_3}^2 \end{cases} \tag{6}$$

According to the equation(6), it gets three straight lines L_1, L_2 and L_3, the three lines intersect at point *O*, and *O* is treated as the center of ΔMNK, as shown in Fig. 3.

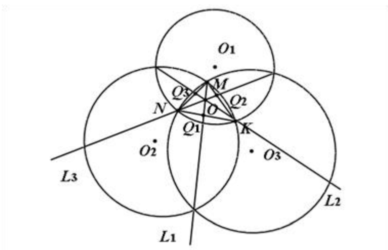

Fig. 3. The schematic of division

In the Fig. 3, *MO*, *KO* and *NO* divide the triangle into 6 parts. The six small regions' centroid is calculated respectively and the RSSI values that are formed by the beacon nodes at the centroid of each region are calculated. Take ΔMOQ_2 as an example, as can be seen from the ΔMOQ_2 area, three beacon nodes transmit signal in the ΔMOQ_2 region to form the following signal strength value relationship:

$$\begin{cases} RSSIO_1 > RSSIO_3 \\ RSSIO_3 > RSSIO_2 \\ RSSIO_1 > RSSIO_2 \end{cases} \tag{7}$$

Similarly, the beacon nodes can form a RSSI value at the other triangle centroid and at the unknown node. the RSSI values that are formed by the beacon nodes at the centroid of each region are recorded respectively in set R_i_SET(*i*=1,2…6). At the same time, the RSSI values between beacon nodes to the unknown node are recorded in set R_SET. The R_SET and R*i*_SET(*i*=1,2…6) are compared respectively to determine the location of the unknown node.

III. ALGORITHM FLOW

From the above description of the improved centroid location algorithm, the algorithm flow can be divided into two steps, as shown in Fig. 4.

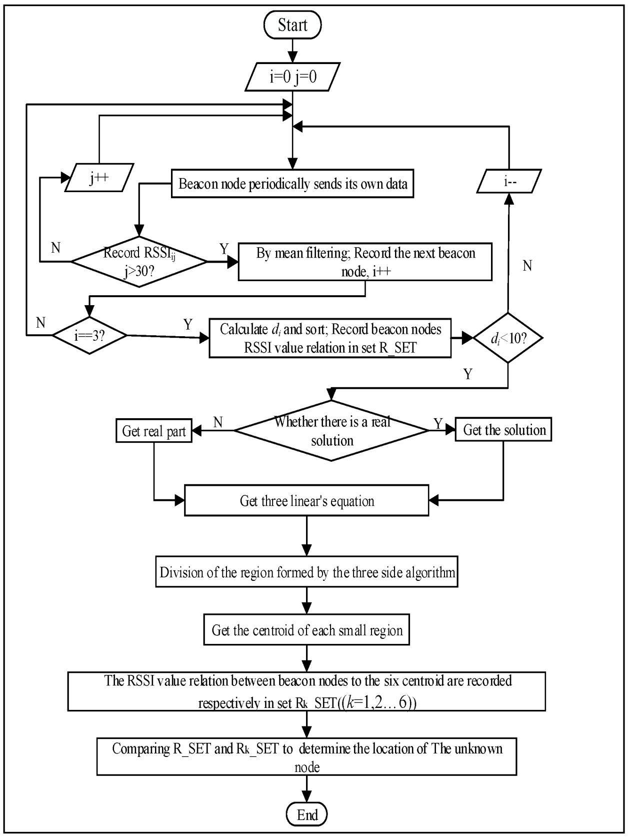

Fig. 4. Algorithm flowchart

Step one, beacon node periodically sends its own data; the unknown node receives and records the RSSI values. When unknown node receives the signal from different beacon nodes and the number of different beacon node reaches 3, the algorithm is beginning to location. Step two, the algorithm records the R*i*_SET(*i*=1,2…6) and R_SET set. Finally, the R_SET and R*i*_SET(*i*=1,2…6) are compared respectively to determine the location of the unknown node.

It should be noted that if the three beacon nodes form an equal RSSI value at the unknown node, then the algorithm takes the point *O* as the unknown node estimated position. If the beacon nodes O_1 and O_3 have the same RSSI value at the unknown node, then O_1 and O_3 have the equal radius, and L_3 is perpendicular bisector of O_1O_3. The unknown node is estimated to be on the straight line L_3. And if O_1 and O_3 beacon nodes form higher RSSI value than O_2 beacon node at the unknown node, the unknown node is considered to be in the OQ_2 section. OQ_2's midpoint is taken to estimate the unknown node's location. Similarly, it can analyze the situation on the other lines.

IV. RESULTS

The algorithm above is verified by Matlab simulation. The simulated area is 20m*20m. For a more realistic simulation environment, it can randomly distribute the beacon nodes and unknown nodes in this region. The reference distance is 1 meter. At the same time, in order to simulate the effects of multipath effect and humans activities the Gauss noise with zero mean and seven variances is added.

This new proposed algorithm is compared against the tradition centroid localization algorithm. This work mainly evaluates the performance of the algorithm from two aspects: the errors distribution and the node localization accuracy. For the first aspect, the number of beacon nodes is set as 20. These two algorithms are simulated and the results are as shown in Fig. 5 and Fig. 6.

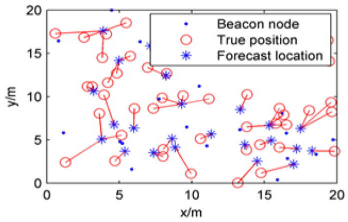

Fig. 5. Simulation results for traditional centroid method

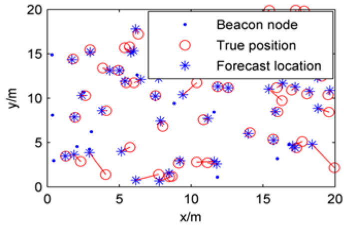

Fig. 6. Simulation results for improved centroid method

In Fig. 5 and Fig. 6, the length of the line represents the magnitude of error. It can be seen that the improved centroid algorithm error has been significantly reduced. These two algorithms are run multiple times to obtain the average error statistics, as shown in Table 1 and Fig. 7.

TABLE I POSITIONING ERROR STATISTICS

Algorithm	Avg error	Max error	Accuracy improvement	Beacon number
Traditional centroid	2.4637	4.8102	NA	20
Improved centroid	0.90188	3.3145	63.3%	20

As can be seen from the table 1 and Fig. 7, the centroid localization method of improved has a significant improvement in positioning accuracy.

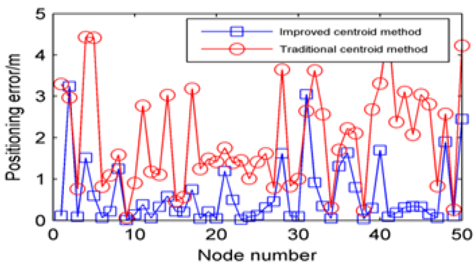

Fig. 7. Error comparison of the two algorithms

For the second aspect, the error distribution was analyzed. 50 test points were calculated, and the results are shown in Fig. 8. In the Fig. 8, it can be seen 62% of the positioning error of the improved centroid method is less than 1 meter, while most of the traditional centroid algorithm's positioning error is in the range of 2 to 3 meters.

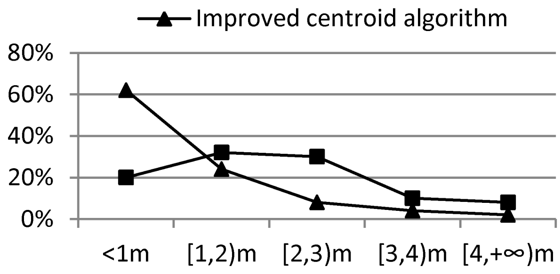

Fig. 8. Error distribution of the two algorithms

V. CONCLUSION

In this paper, it uses the region division algorithm to improve the traditional centroid localization algorithm. This algorithm differs from the traditional weighted centroid localization algorithm which only considers the 3 beacon nodes RSSI value. The improved centroid location algorithm calculates the RSSI value in the cell field after subdivision of the estimated region which gives more accurate estimation. Results show that this algorithm can improve the average position error by 63.3%.

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