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Multi-barycenter Nodes Localization Method in Wireless Sensor Network Based on Improved RSSI

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Abstract: In order to improve the accuracy of nodes in wireless sensor networks (WSNs). An multi-barycenter localization algorithm based on improved received signal strength indication (RSSI) ranging is proposed. The algorithm first optimizes the RSSI values by the iterative filtering, the distance values of WSNs nodes could be more accurately calculated. And then a multi-barycenter algorithm is introduced to optimize the trilateral localization. The simulation results show that the algorithm can improve the positioning accuracy by 30% compared with the traditional trilateral localization algorithm. Finally, through the localization test of 5 WSN nodes, the measured localization deviation of the WSN nodes is controlled at about 2 m when the distance of sensor node is 80 m. The proposed method could improve localization accuracy effectively without increasing computing resources.

Key words: wireless sensor networks (WSNs); received signal strength indication (RSSI); iterative filtering; multi-barycenter localization

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Wireless sensor networks (WSNs) are the networks of massively deployed tiny, inexpensive and autonomous motes[1-2]. The WSNs nodes are deployed in a mission field randomly. Each node is aware of its location in the deployment field for successful self-organization. The location information is useful in recognizing and correlating[3].

At present, the localization technology of WSNs nodes mainly uses range-based algorithms[4-8]. The ranging-based location algorithm obtains the relative positional relationship between nodes by means of RSSI, time of arrival (TOA), time difference of arrival (TDOA) or angle of arrival (AOA)[9–13]. Yu[14] used an improved weight-based triangular centroid location algorithm to locate four sensor nodes which laid out on a distance of 8 m. Zhu[9] proposed an equilateral triangle location with a side length of 5 m and the beacon node is located at the apex of the triangle. Wang[15] focused on the location of traditional equilateral triangles and proposed a method of adding anchor nodes. Wang[16] proposed an equal-arc trilateral localization algorithm based on received signal strength indication (RSSI). The algorithm adopts Kalman filter to collected from the best communication range, thus the disturbance problem of RSSI value can be tackled easily.

In this paper, an optimized multi-barycenter localization algorithm based on RSSI is proposed. The values of multiple RSSIRs are optimized and transformed the parameters into dis-

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tance values by the iterative filtering algorithm firstly, and then the positions of the WSNs nodes are calculated by the multi-barycenter localization. A simulation calculation for the WSNs was set up, the deployment area was 100 m×100 m and the number of sensor nodes was 100. The node localization accuracy is improved 30% compared with that before the improvement. Finally, through the localization test of 5 sensor nodes, the localization deviation of the sensor nodes measured is controlled at about 2 m when the distance of WSNs is 80 m, which is much better than the traditional node localization deviation of 6 m. This method could improve localization accuracy effectively without increasing computing resources.

1 Theory/Calculation

According to the free space transmission equation[17], RSSI is the distance function of the range-free (RF) signal strength, which detected between the transmitting device and the receiving device, as shown in the following equation

$$P_{\mathrm{RX}} = P_{\mathrm{TX}} G_{\mathrm{TX}} G_{\mathrm{RX}} \left(\frac{\lambda}{4\pi d} \right)^{n} \tag{1}$$

where P_{RX} is the received signal power, P_{TX} is the transmitted signal power, λ is the wavelength of the RF signal, G_{TX} is the antenna gain of the transmitting device, G_{RX} is the antenna gain of the receiving device, d is the distance between transmitting and receiving device, n is the attenuation index of the propagation path, and its value depends on the environment in which the signal propagates.

The antenna gains G_{TX}, G_{RX} of the transmitting and receiving devices, the wavelengths λ and π of the signals are all known. These parameters are all set to X, and Eq. (1) is rewritten as

$$\lg P_{\mathrm{RX}} = -n \lg d + \lg X + \lg P_{\mathrm{TX}} \tag{2}$$

An expression that converts the received signal power into a dBm value, that is

$$\mathrm{RSSI} = -n \lg d + \lg X + \lg P_{\mathrm{TX}} \tag{3}$$

The RSSI value is greatly affected by the surrounding environment. The iterative filtering algorithm was introduced to improve solution accuracy and algorithm execution efficiency.

Filtering the signal of the target node receiving the reference node as follows

$$\mathrm{RSSI}_i = \alpha \mathrm{RSSI}_i + (1-\alpha)\,\mathrm{RSSI}_{i-1} \tag{4}$$

The RSSI value is used to calculate the distance between the target node and the reference node. In addition, introducing two reference nodes to correct the obtained distance, as shown in Fig. 1. Node A is defined as the target node to be located, and nodes B and C are reference nodes with known locations. Let the signal strength of the node A to node B is RSSI_1, the distance between the two nodes is d_1, and the received signal strength of the node B to the node C is RSSI_2, and the distance is d_2.

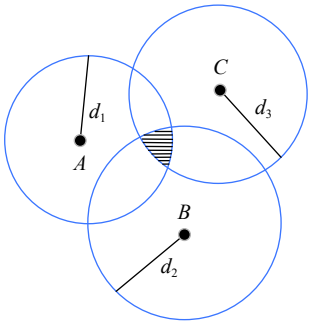

Fig. 1 Structure of RSSIR correction

The distance calculation based on log-distance distribution[18] as follows

$$10n \lg d = -(\mathrm{RSSI} + A) \tag{5}$$

where n is the path fading index, A is the RF parameter. The values of RSSI, n and A are all known, and the relationship between d_1 and d_2 can be derived from the above formula, as follows

$$d_1 = \left(10^{\frac{\mathrm{RSSI}_2 - \mathrm{RSSI}_1}{10n}} \right) \times d_2 \tag{6}$$

Fig. 1 shows that the traditional trilateral positioning method is not necessarily intersect at one point, due to the measurement error of the RSSI value.

Therefore, a barycenter assisted trilateral localization was introduced. As shown in Fig. 2, the position coordinates of the reference nodes A, B, and C are (x_1, y_1), (x_2, y_2), (x_3, y_3), respectively. The target node can get the RSSI value of the

reference nodes. The distance from the target node to the three reference nodes is d_1, d_2 and d_3, and the common overlapping part has three intersections of D, E and F. The coordinates of the three intersection points are (x_d, y_d), (x_e, y_e), (x_f, y_f). Therefore, the coordinates of D can be obtained as follows. Similarly, the coordinates of E and F can be obtained.

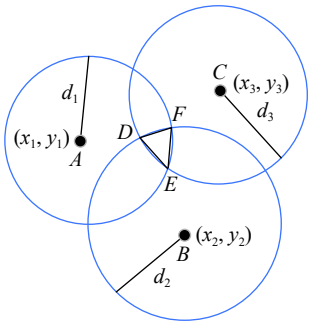

Fig. 2 Structure of proposed localization algorithm

$$\begin{cases} (x_d - x_1)^2 + (y_d - y_1)^2 \leqslant d_1^2 \\ (x_d - x_2)^2 + (y_d - y_2)^2 = d_2^2 \\ (x_d - x_3)^2 + (y_d - y_3)^2 = d_3^2 \end{cases} \tag{7}$$

The barycenter coordinate of ΔDEF is defined as $G\ (x_g, y_g)$, and it is obtained according to the mathematical definition of the center of gravity of the triangle:

$$\begin{cases} x_g = (x_d + x_e + x_f)/3 \\ y_g = (y_d + y_e + y_f)/3 \end{cases} \tag{8}$$

In addition, in order to improve the localization accuracy of the target node, introducing a reference node H based on the known nodes A, B, and C. Therefore, the target node can get the RSSI value of the four reference nodes. Three reference nodes are randomly selected from the four nodes for multi-barycenter trilateral localization algorithm. There are total of C_4^3 groups, and each group can form a triangle to obtain the barycentric coordinates.

$$\begin{cases} x_g = (x_{g1} + x_{g2} + x_{g3} + x_{g4})/4 \\ y_g = (y_{g1} + y_{g2} + y_{g3} + y_{g4})/4 \end{cases} \tag{9}$$

Therefore, this method optimizes the RSSI values firstly, and transforms the parameters into distance values, and then calculates the position of the WSN node by the proposed multi-barycenter localization. The algorithm structure is shown in Fig. 3.

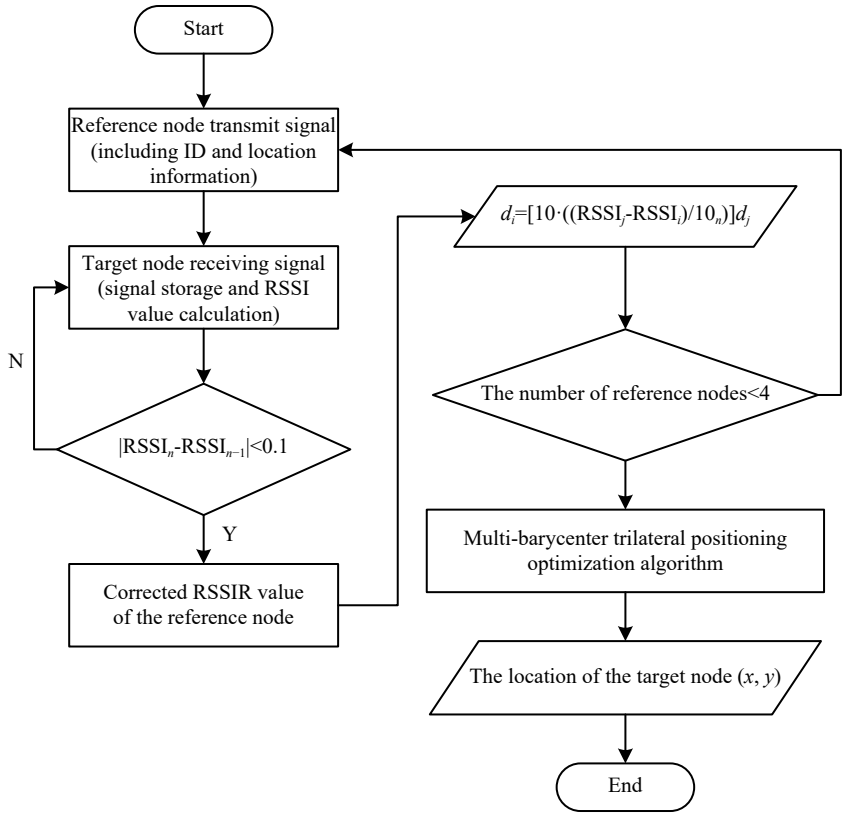

Fig. 3 Structure of proposed localization method

2 Simulation Calculation

The deployment area of the WSNs is 100 m× 100 m, and the number of WSN nodes is 100 in simulation. The ratio of reference nodes to the total WSN nodes is set to 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50% respectively. Considering the error in the RSSI measurement, the distance between the target node and the reference node is increased by 20% with a Gaussian white noise. The coordinates of all sensor nodes are randomly generated and stored, as shown in Fig. 4.

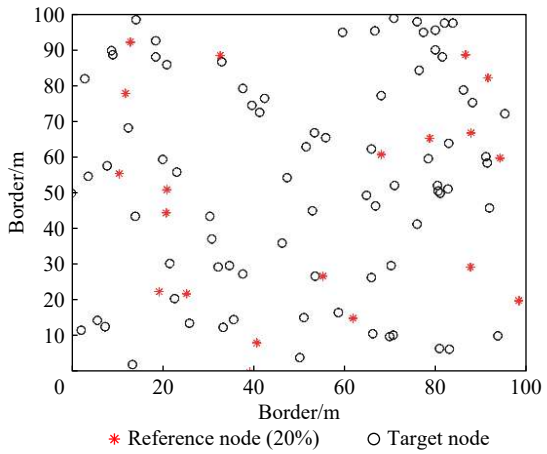

Fig. 4 Random distribution of WSN nodes

Eq. (5) is indicated that the values of the constants A and n determine the relation between the RSSI and the transmission distance d. The path fading index n value depends on the transmission environment of the RF signal, and there are usually interferences such as attenuation and obstacle reflection in the uneven transmission medium. When the RF parameter A (set A=35) is unchanged and n takes a different value, the relation between RSSI and d is shown in Fig. 5. It is concluded that the value of n is proportional to the signal transmission distance in the same space.

When the path fading index n (set n=3) is unchanged and the RF parameter A takes different values, the relation between RSSI and d is shown in Fig. 6. It can be seen that the attenuation of the signal strength in the short-distance transmission is relatively large, and the linear attenuation is approximated at a long distance. The value of A is inversely proportional to the transmission power of the transmitting device, and the attenuation margin of the signal in the transmission process.

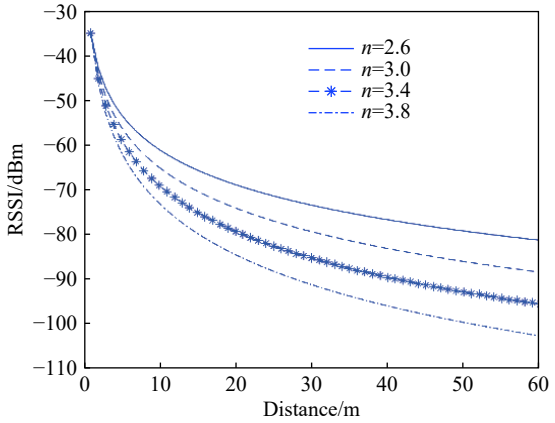

Fig. 5 Relation between RSSI and transmission distance d

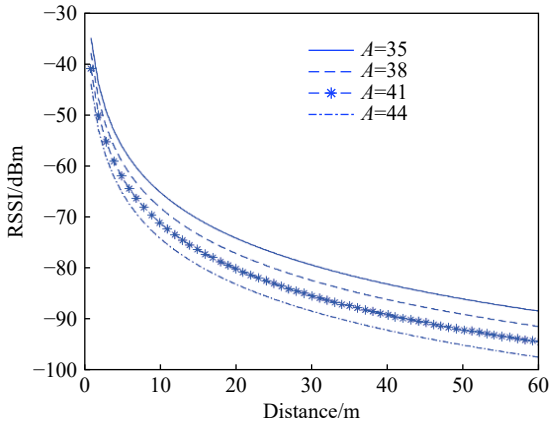

Fig. 6 Relation between RSSI and transmission distance d

The performance evaluation of the improved algorithm is considered from the localization error of the target node. The specific implementation is to continuously increase the proportion of the reference node in the WSN. The localization error (δ) refers to the distance between the localization coordinates and the actual coordinates based on the RSSI. Meanwhile, the noise and the reliable communication radius R of the sensor node are added. The localization error (δ) is calculated as follows

$$\delta = \frac{\sqrt{(x_q - x_p)^2 + (y_q - y_p)^2}}{R} \times 100\% \qquad (10)$$

The simulation results are shown in Fig. 7. The horizontal axis represents the ratio of the reference nodes to the total number of sensor nodes, which ranging from 10% to 50%. The vertical axis represents the node localization error. It can be seen that the multi-barycenter trilateral localization algorithm based on improved RSSI has a 30% improvement in the localization accuracy compared with the traditional trilateral localization.

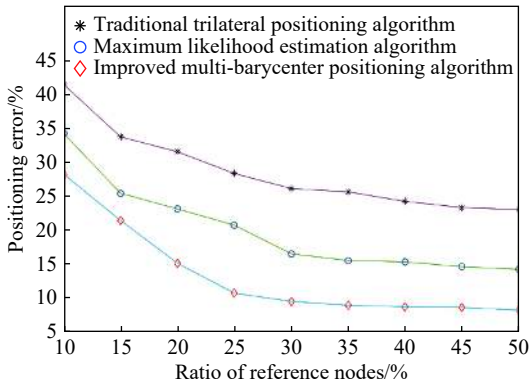

Fig. 7 Localization error analysis

3 Experimental Verification

The five wireless sensor devices (WSD) were used to WSNs localization test, where four sensors are set as reference nodes and one is set as the target node to be located. The layout of the five wireless sensor devices at the test is shown in Fig. 8. The reference coordinate system is established with the location of the WSD2 node as the origin, as shown in Fig. 9. The coordinates of WSD 1, 2, 4, and 5 are (0, 50), (0, 0), (80, 0), (80, 50), respectively.

The two WSN are divided into transmitting and receiving devices, and the transmitting device transmits data with maximum transmit power is set to 0 dBm, and the recording communication distance is 1 m, 10 m, 40 m, 80 m, 100 m respectively. The RSSI value is measured by the device at 200 m.

The data processing is performed using the filtering algorithm used in Eq. (4), where $\alpha = 0.85$ is taken. The received signal strength of WSD is –38.1 dBm when the communication distance is 1 m, as show in Fig. 10.

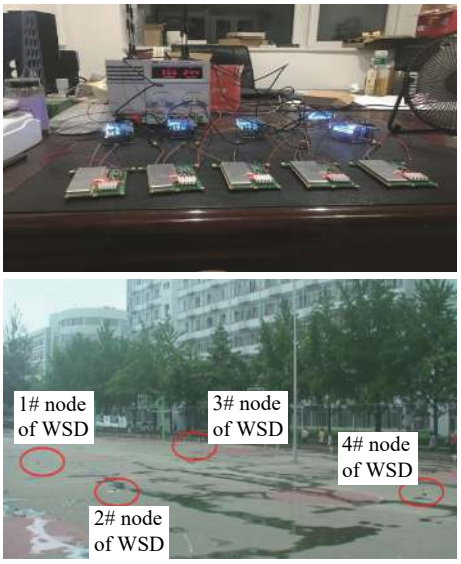

Fig. 8 Test layout diagram of node localization

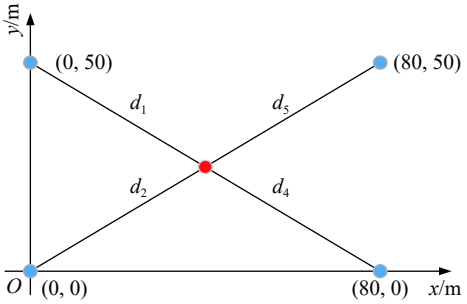

Fig. 9 Reference coordinate system of node localization

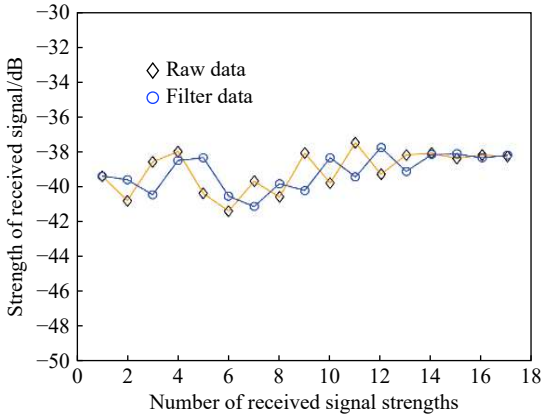

Fig. 10 Received signal strength of WSD (d=1 m)

Fig. 11 shows the received signal strength of WSN when the communication distance is 10 m. The original measurement range is between –70.5 dBm and –66.4 dBm. After the iterative processing by the filtering algorithm, it is –68.2 dBm.

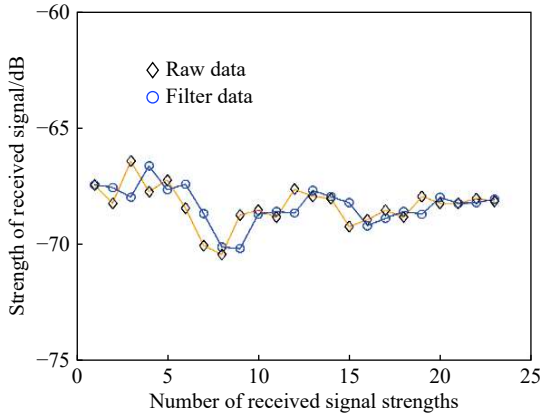

Fig. 11 Received signal strength of WSN (d=10 m)

Fig. 12 shows the received signal strength of WSN when the communication distance is 40 m. The original measurement range is between –80.7 dBm and –83.3 dBm, which is 82.5 dBm after iterative processing by the filtering algorithm. And Fig. 13 shows the received signal strength of WSN when the communication distance is 80 m. The original measurement range is between –92.0 dBm and –91.3 dBm. After the iterative processing by the filtering algorithm, it is 91.7 dBm.

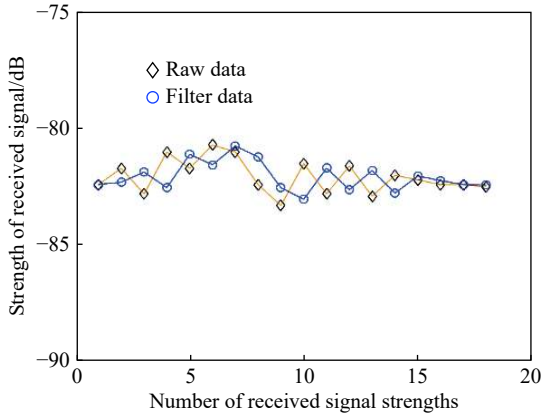

Fig. 12 Received signal strength of WSD (d=40 m)

Substituting d=40 m and d=80 m into Eq. (4), the theoretical RSSI values are –82.96 dBm and –91.39 dBm, respectively, which are basically consistent with the measured values of –82.5 dBm and –91.7 dBm. It is indicated that the distance model has a certain practicability. The received signal strength measured at different communication distances from 1 m to 80 m is summarized in Tab. 1.

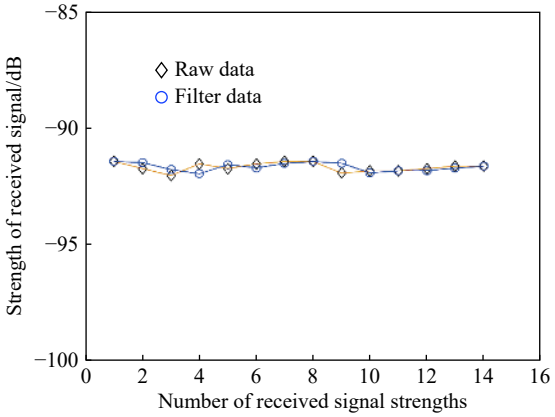

Fig. 13 Received signal strength of WSN (d=80 m)

Tab. 1 RSSI measurements at different distances

Communication distance d/m	RSSI/dBm
1	–38.1
10	–68.2
40	–82.5
60	–87.7
62	–88.4
64	–88.8
66	–89.2
68	–89.3
70	–89.6
72	–90.2
74	–90.4
76	–90.5
78	–91.3
80	–91.7

The correction of the parameters n and A is performed by the measured data according to the distribution model. The values of n and A are 2.765 and 38.8. The fitting curve is shown in Fig. 14. n and A fall into the 95% confidence interval (2.696, 2.834), (37.63, 39.98), respectively.

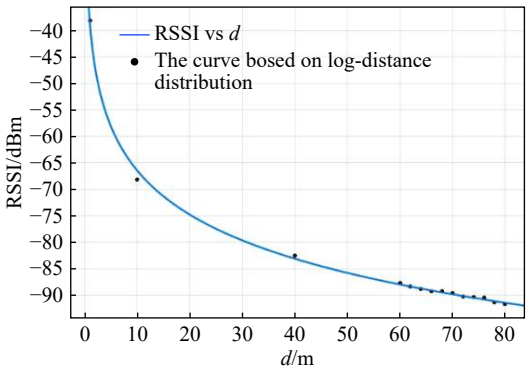

Fig. 14 Fitting curve based on log-normal distribution model

The measured data based on WSD3 is shown in Tab. 2. It is illustrated that the measured distance deviation is controlled at about 2 m based on improved RSSI, and the intersection coordinates of the three circles could be solved, which is (21.37, –16.55), (50.16, 52.86) and (66.63, 28.86), when the WSD1, WSD2 and WSD4 are regarded as the center of the circle, as shown in Fig. 15. The coordinates of the center of gravity of the triangle are (46.05, 21.72) by using Eq. (8).

Tab. 2 RSSI measurements based on WSD3

WSD	RSSI	Measured distance	Actual distance
WSD1	–89.8	62.46	64.03
WSD2	–90.3	62.87	64.03
WSD4	–88.2	63.18	64.03
WSD5	–90.5	63.10	64.03

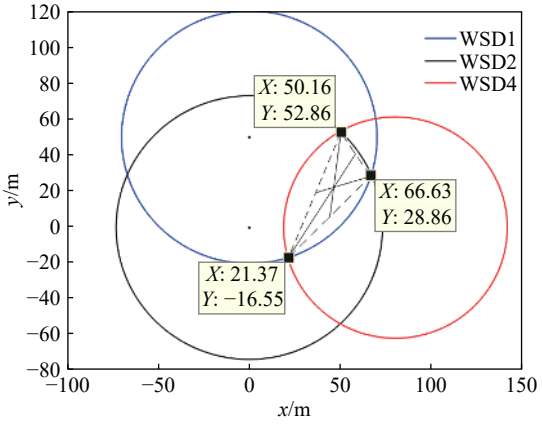

Fig. 15 Localization solution by the proposed method

Similarly, the coordinates of the center of gravity obtained by combining the other three reference nodes are (37.48, 30.56), (41.53, 19.42), (46.13, 12.47). The localization coordinates of the target node WSD3 could be calculated by Eq. (9), which the value is (42.80, 24.04). The calculated deviation is 1.85 m compared to actual coordinates (40, 25). The minimum distance deviation obtained by the traditional algorithm of RSSI is 5.69 m. Therefore, the proposed method in this paper could improves the localization accuracy of the nodes effectively.

4 Conclusions

In order to improve the localization accuracy and optimize the allocation of node resources in wireless sensor networks (WSNs), the proposed main method can be summarized as follows.

① The values of multiple RSSI is optimized and transforms the parameters into distance values by the iterative filtering algorithm. The relationship is analyzed between RSSI and distance by the test. It is indicated that the results have a better distance fault tolerance.

② A multi-barycenter localization algorithm is proposed. The simulation results show that the localization accuracy of the target sensor node has a 30% improvement compared with the traditional trilateral localization.

③ The test results show that the localization deviation of the sensor nodes is controlled at about 2 m when the distance of sensor node is 80 m, which is much better than the traditional node localization deviation of 6 m. This method could improve localization accuracy effectively without increasing computing resources.

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