Scalable Computing: Practice and Experience, ISSN 1895-1767, http://www.scpe.org

Volume 25, Issues 6, pp. 5218–5226, DOI 10.12694/scpe.v25i6.3302

INTELLIGENT POSITIONING ALGORITHM FOR URBAN SUBSTATION PERSONNEL BASED ON WIRELESS SENSOR NETWORKS

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Abstract. In order to solve the problem of accurate and low-cost location of substation personnel in digital cities, a substation personnel location system based on wireless sensor cloud computing network is proposed. ZigBee wireless sensor cloud computing network is introduced into the substation to improve the direct location algorithm of substation personnel, and a fuzzy reasoning algorithm is proposed. The algorithm takes the signal strength received by each reference node and the relative distance between the reference nodes as input. After fuzzy, fuzzy reasoning and deblurring, the reliability of the received signal strength of each reference node is obtained, and then three reference nodes with high reliability are selected for trilateral positioning calculation. The experimental results show that the positioning error after improvement is more stable than that before improvement, and the maximum error before improvement is 1.4115m. Practice has proved that the algorithm can significantly improve the positioning accuracy of substation personnel without adding any hardware and using fewer nodes.

Key words: wireless sensor network, Substation, Fuzzy inference, Signal strength, positioning accuracy

1. Introduction. As the "intelligent information sensing terminal", the Internet of things, with its unique advantages, can meet the needs of real-time, accuracy and comprehensiveness of smart grid information acquisition in many occasions, and play a great advantage in the generation, transmission, transformation, distribution, use and dispatching of smart grid [1].Wireless sensor network (WSN) technology is one of the core technologies of the Internet of things, as shown in Figure 1.1.

Wireless sensor network is a network composed of a large number of wireless sensor nodes, which is used to monitor, collect and transmit information in the physical environment, such as temperature, humidity, light, sound, pressure, and so on. These nodes can collaborate autonomously to achieve task allocation and data sharing, in order to execute tasks more effectively. As a new technology, wireless sensor network integrates sensor technology, self-organizing network technology, data fusion technology, target positioning technology, etc., effectively realizing the highly intelligent data collection, transmission and processing.

As a new technology means, wireless sensor network integrates sensor technology, self-organizing network technology, data fusion technology, target positioning technology, etc., and effectively realizes the high intelligence of data collection, transmission and processing. Wireless sensor network (WSN) is a multi hop, self-organized network system formed by wireless communication and composed of a large number of inexpensive micro sensor nodes deployed in the monitoring area. It can be widely used in environmental monitoring, border protection, space detection, target tracking and other fields [2]. With the occurrence of various disasters and accidents and the further improvement of people's requirements for safety protection, there is an urgent need for more timely and accurate field data to strengthen management. Similarly, in some production management links, in order to further improve production efficiency and strengthen safety supervision, it is also necessary to timely feed back various personnel information on the site, understand the basic situation of the site, and conduct accurate guidance and control [3].The substation is a high-risk operation environment, and illegal operations such as entering the interval by mistake and patrol inspection are not in place occur from time to time. The substation personnel positioning and tracking system can locate the current position of the operators in real time, track their movement track in the station, automatically sense the behaviors such as

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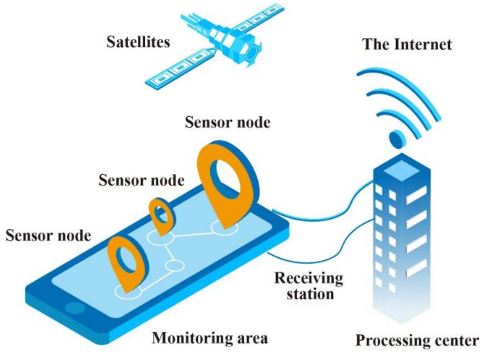

Fig. 1.1: Wireless sensor network

entering the work area by mistake, automatically record the patrol track of the inspectors, effectively monitor the illegal operation behaviors such as insufficient patrol, missing patrol or even non patrol, and remind the operators by mistake in the form of sound and light alarm. At the same time of the on-site alarm, the relevant information is transmitted to the monitoring center. The background management department can take corresponding measures to prevent accidents.

The substation personnel positioning system based on wireless sensor network is a real-time positioning and monitoring system for substation personnel using wireless sensor network technology. The basic principle of this system is to arrange multiple wireless sensor nodes inside the substation, which transmit data to the central node through wireless communication protocols. The central node processes and analyzes the transmitted data to determine the location information of personnel inside the substation.

2. Literature review. With the expansion of power grid scale and the increase of equipment, the complexity of substation operation increases. In order to standardize and simplify the work of substation staff and improve their enthusiasm, a personnel positioning system is required to be applied to the substation [4]. Introducing automation technology, strengthening training and skill enhancement, establishing standardized workflow, and strengthening team collaboration and communication can help standardize and simplify the work of substation staff, increase their enthusiasm, and improve the efficiency and reliability of substation operation.

At present, ultra wideband (UWB) positioning method is used for personnel positioning in digital substation, which has the advantages of low power consumption, good anti multipath effect and high positioning accuracy [5]. However, due to its high cost, it is not suitable for promotion and use, so it is urgent to find a new positioning method. Among them, the personnel positioning technology based on ZigBee wireless sensor network has attracted wide attention in the world because of its low complexity, low power consumption and low cost [6]. In the wireless positioning technology based on ZigBee, the received signal strength indication (RSSI) positioning principle is applied to the wireless communication network. However, the RSSI direct ranging algorithm adopted at present is easily affected by the environment, with large error, unstable error and low positioning accuracy. Zahedmanesh, A. et al. Proposed several positioning methods for obstacles, but there is still little research on the precise positioning method of ZigBee positioning system based on RSSI in the space with large obstacles such as substation. It can provide real-time and accurate personnel positioning information for the above occasions, provide guarantee for various safety, and further improve production efficiency [7].In order to realize real-time and accurate personnel positioning, the whole positioning system can adjust the placement position of anchor nodes at any time according to the needs; The background map can be changed in time with the change of the site; Edit and manage the personnel information to be located; Personnel can be associated with mobile nodes; The current positions of all mobile nodes and the names of associated personnel can be marked in real time through the map displayed on the screen. And the positioning system can also provide a systematic environment for the positioning algorithm, routing mechanism, network survival time, personnel positioning accuracy, distribution of anchor nodes, wireless network security and related research and application of wireless sensor networks [8]. The implementation of the positioning system has strong expansibility with the hardware and database used. In this, a positioning method of ZigBee system based on fuzzy inference is proposed with reference to the location parameters of obstacle free space [9]. In this method, the reference node with the largest RSSI value is taken as the control. Firstly, the RSSI value of the reference node adjacent to the reference node and the relative distance between the reference node and the adjacent reference node are taken as the input. Then, after fuzzification, fuzzy reasoning and defuzzification, the RSSI credibility of each adjacent reference node is obtained. Finally, the reference nodes corresponding to the two RSSI values with the highest reliability were selected, and the trilateral positioning calculation was carried out together with the reference node with the largest RSSI to obtain the location information of the station staff. The positioning method of ZigBee system based on fuzzy inference effectively avoids the ranging error of directly taking three maximum RSSI, and can accurately locate the mobile personnel in the substation with large obstacles. Moreover, it does not need to do a lot of experiments like deterministic positioning, and only needs to obtain appropriate positioning parameters in the space without obstacles through a few experiments. However, it is more accurate than the traditional empirical positioning method [10].

3. Methods.

3.1. ZigBee positioning system structure. Zigbee is based on IEEE standard 802.15.4 wireless standard research and development. ZigBee positioning system is a visual wireless positioning monitoring system composed of positioning monitoring center and wireless sensor network. The wireless positioning network system is mainly composed of ZigBee gateway, reference node and positioning node [11]. In order to ensure the accuracy and reliability of the positioning system, it is necessary to design and optimize the layout of sensor nodes and signal acquisition. At the same time, it is also necessary to consider factors such as the security and real-time performance of data transmission. This system can provide important support for safety management and emergency rescue work in substations, effectively improving the operational efficiency and safety of substations.

Since each positioning node in the network (i.e. the staff in the station) has its own network address, the ZigBee positioning system can achieve multi-person positioning without interference at the same time.

ZigBee Gateway: Network coordinator of wireless positioning system, consisting of a HFZ-CC2430EM module and HFZ-SmartrF07EB, connected to PC through RS232 serial extension cable. It plays a vital role in the whole system. First, it needs to receive the configuration data of each reference node and positioning node provided by the monitoring software and send it to the corresponding node. Secondly, the effective data (such as coordinates Bx and By of positioning nodes) fed back By each node should be received and transmitted to the monitoring software [12].

Reference node (Rn): a static node with known coordinates in the wireless positioning system, which is a router in ZigBee network and consists of a panel and a CC2430 module. This node must be correctly configured in the location region. Its task is to provide a packet containing its coordinate position Rx, Ry and RSSI values to the locating node. Such nodes are fixed on the support of the substation.

Positioning node (B): mobile node in the wireless positioning system, which is composed of a panel and a CC2431 module [13]. It calculates its coordinates by processing information packets sent by reference nodes, and is a router in ZigBee network. The positioning node can communicate with the reference node, collect the coordinate Rx, Ry and RSSI values of the reference node, calculate its own coordinate information based on these information and input parameters A and N, and then send its own position information Bx and By to the gateway, and finally to the positioning monitoring center through RS232[14]. This node is installed on the safety hat of the mobile personnel in the substation. Therefore, when substation workers wearing such helmets enter the substation, the monitoring center can monitor their real-time location in the station.

3.2. Fuzzy inference algorithm for ZigBee system positioning. The positioning principle of ZigBee positioning system is to select the first three largest RSSI from the information packet sent to the positioning node by the reference node, and then calculate the distance from the corresponding reference node to the positioning node, and then calculate the position coordinates of the positioning node by the three-sided positioning method. Specifically, the ZigBee positioning system first needs to deploy some wireless sensor nodes indoors, which can communicate with each other through the ZigBee wireless network and broadcast signals regularly.

When it is necessary to locate an object or person, the ZigBee device on the object or person can be used as the positioning target to send a request signal to the surrounding ZigBee nodes. Once the surrounding ZigBee nodes receive a request signal, they will reply with a response signal and send back the RSSI value of the response signal. Due to the influence of indoor environment on the propagation of wireless signals, the signal strength received by different nodes may vary. By using these different RSSI values, the distance difference between the positioning target and different nodes can be calculated, thus achieving triangular positioning. However, in the substation, due to the existence of obstacles, the obtained RSSI values of reference nodes are not all credible, so positioning errors may occur [15]. In order to overcome the defect of direct ranging algorithm, a ZigBee positioning method based on fuzzy inference algorithm is proposed in this . The working mechanism of the fuzzy inference system is as follows: Firstly, the input exact quantity is fuzzified by the fuzzification module and converted into the fuzzy set in the given domain. Then the corresponding fuzzy rules in the rule base are activated, the appropriate fuzzy inference method is selected, and the inference result is obtained according to the known fuzzy facts. Finally, the fuzzy result is defuzzified to get the final accurate output.

Fuzzy algorithm used in ZigBee system positioning can be divided into the following steps:

1. The reference node waits for the positioning node to send signals.
2. The positioning node sends signals to the reference node.
3. The reference node obtains RSSI and sends it to the positioning node together with its own position information [16].
4. The positioning node receives the information packet sent by the reference node, and then executes the fuzzy operation. Finally, according to the output of the fuzzy operation, the positioning calculation is carried out by the three-sided method.
5. The positioning node sends its position information to the gateway, and then the gateway sends it to the monitoring software of the monitoring center to monitor the position of the staff in the station in real time [17].

Fuzzy inference algorithms can be used for the localization of ZigBee systems, which can improve the accuracy and robustness of localization. Specifically, in ZigBee system positioning, the triangulation method is usually used, which calculates the position of nodes by measuring the time of arrival (TOA) of the signal.

3.2.1. Fuzzy system input. Due to the complex working environment of the substation, in order to ensure the reliability of RSSI value of each reference node, in this , 8 RSSI values of each reference node are averaged as its RSSI value. For all the RSSI values after taking the mean value, the one with the largest RSSI value is extracted as the reference of credibility, and the corresponding reference node is called the trust node. The RSSI value of the neighboring reference nodes around the fetching node and the relative distance from each neighboring node to the signal node are used as input. The two inputs are fuzzified by setting membership functions.

As shown in Figure 3.1, the fuzzy distribution of low RSSI is trapezoidal. When the RSSI value of the neighboring reference node is the smallest among all the neighboring reference nodes ($RSSI_{min}$), the membership degree is the largest. With the increase of RSSI, the membership degree linearly decreases until it becomes 0 when the RSSI is the median RSSI ($RSSI_{med}$). In, the fuzzy distribution of RSSI is triangular; The fuzzy distribution of high RSSI is trapezoidal, and the membership degree reaches the maximum when the RSSI reaches the RSSI($RSSI_{max}$) of the signal node[18]. For example, when $RSSI_{min}$ is -65dbm, $RSSI_{med}$ is -63dbm and $RSSI_{max}$ is -57dbm, and if the input RSSI is -62dbm, the membership calculated by the membership function is 0.167, 0.833 and 0 respectively in the fuzzy distribution of high, medium and low RSSI.

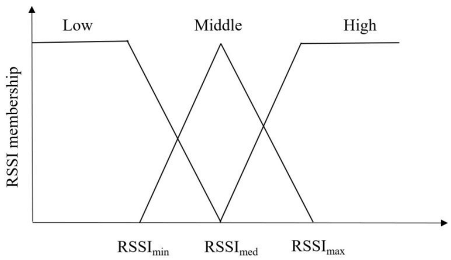

Fig. 3.1: RSSI distribution

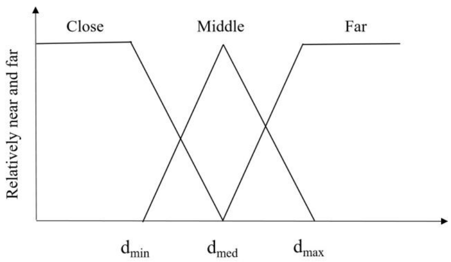

Fig. 3.2: Relative distance distribution

As shown in Figure 3.2, the fuzzy distribution of near-relative distance is trapezoidal. When the reference node is the shortest distance from the signal node (d_{min}), the membership degree is the maximum. With the increase of relative distance, the membership degree linearly decreases until it becomes 0 when the relative distance is the median (d_{med}). The fuzzy distribution of relative distance is triangle. The distant relative distance fuzzy distribution is trapezoidal, and the membership degree is maximum when the reference node is farthest from the signal node (d_{max}). For example, when Dmin is 2m, DMED is 4M and DMAX is 5m, if the input D is 3m, the membership degree calculated by the membership function is 0, 0.5 and 0.5 respectively in the fuzzy distribution of far, middle and near distance.

By setting the two input membership functions in this way, the membership functions can be modified online according to the actual situation of the RSSI of the reference node and the relative distance between the information node and its neighboring nodes to adapt to positioning in different environments.

3.2.2. Fuzzy inference. The fuzzy inference system in this adopts Mamdani inference method to carry out fuzzy inference [19].The signal node is set as high RSSI, and the membership degree is 1. According to the signal propagation theory: the farther away from the transmitting point, the weaker the signal strength received by the receiving point. Since the RSSI of the signal node is the largest, it is the closest to the transmitting point. The formulation of fuzzy rules is shown in Table 3.1.

The examples in Section 3.2.1 are used to blur the data. The fuzzy input activates rules ①,②,④ and ⑤ in the fuzzy rule base. Inactive rule confidence output is 0. The fuzzy inference process is shown in Figure 3.3. Take AND operation on the two inputs according to each rule, and then perform OR operation on the output result of each rule to obtain the credibility of each rule.

3.2.3. Fuzzy system output. The output of a fuzzy system is a specific numerical value or set of numerical values obtained through fuzzy reasoning and fuzzy processing, which represents the degree of influence of input variables on output variables. In fuzzy systems, the output is usually expressed in the form of fuzzy set, that is, the value of the output variable is divided into multiple fuzzy set with non-zero membership, and each fuzzy set represents a possible value of the output variable. In order to get a certain output value, these fuzzy set need to be de blurred and transformed into a specific value or a group of values. After the central method is used to defuzzification, the fuzzy system will output a value for each neighboring reference node,

Table 3.1: Fuzzy inference rules

Neighboring node RSSI		Relative distance	Confidence of output
High	①	Close	High
	②	Middle	Middle
	③	Far	Low
Middle	④	Close	Middle
	⑤	Middle	High
	⑥	Far	Middle
Low	⑦	Close	Low
	⑧	Middle	Middle
	⑨	Far	High

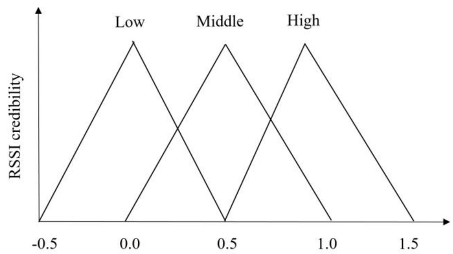

Fig. 3.3: RSSI reliability distribution

which represents the RSSI credibility of the reference node. The value ranges from 0,1. The closer it is to 1, the more trusted the RSSI is, that is, the more suitable the corresponding reference node is for positioning calculation. As shown in Figure 3.3, the low, medium and high trust degrees are all triangular distribution, with the midpoints 0, 0.5 and 1, respectively.

The central method defuzzification is shown in Equation 3.1.

$$y^* = \frac{\sum_{i=1}^{N}(y_i \mu_{max}^i(y))}{\sum_{i=1}^{N} \mu_{max}^i(y)} \tag{3.1}$$

where: N is the number of elements in the domain, namely the number of rules in the rule base; y_i refers to the fuzzy value of the ith central point in the theoretical domain, that is, the output central point obtained by operation according to the ith rule; $\mu_{max}^i(y)$ is the maximum membership degree obtained by the ith rule operation.

According to Equation 3.1, the examples in Section 3.2.2 are defuzzified

$$y^* = \frac{0.75 \times 0.167 + 0.5 \times 0.167 + 0.5 \times 0.5 + 0.75 \times 0.5}{0.167 + 0.167 + 0.5 + 0.5} = 0.625 \tag{3.2}$$

That is, when the RSSI of the neighboring reference node is -62dbm and it is 3m away from the information node, the output reliability is 0.625 after defuzzification.

3.2.4. Positioning Calculation. According to the three-side localization method, at least three reference nodes are needed for localization calculation. Therefore, firstly, according to the RSSI reliability of all neighboring nodes output by the fuzzy system, the reference nodes corresponding to the two RSSI values with the highest reliability are selected, and together with the information nodes, the three reference nodes required for positioning are composed. Then, the distance d between the three reference nodes and the positioning node can be calculated according to Equation 3.3. Finally, according to the position information of the three reference nodes, the coordinates of the positioning nodes are obtained by the three-sided positioning method, namely

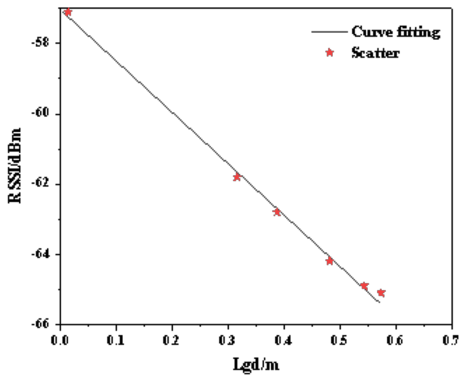

Fig. 3.4: Fitting curve of barrier-free space

Equation 3.4 [20].

$$d = 10^{\frac{A+RSSI}{-10N}} \tag{3.3}$$

where: A and N are positioning parameters, which are related to the actual environment such as weather. According to the barrier-free space experiment, different A and N are measured under different weather conditions. In actual positioning, parameters A and N are input according to the weather conditions. d is the distance from the reference node to the positioning node (unit: m); RSSI unit in dBm.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_1 - x_3) & 2(y_1 - y_3) \\ 2(x_2 - x_3) & 2(y_2 - y_3) \end{bmatrix}^{-1} \cdot \begin{bmatrix} x_1^2 - x_3^2 + y_1^2 - y_3^2 + d_3^2 - d_1^2 \\ x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_3^2 - d_2^2 \end{bmatrix} \tag{3.4}$$

where: x is the abscissa of the positioning node; y is the ordinate of the positioning node. $x_1, x_2, x_3, y_1, y_2, y_3$ are the position coordinates of the selected three reference nodes; d_1, d_2 and d_3 are the distances from the positioning nodes calculated by the RSSI of the selected three reference nodes.

3.3. The simulation positioning. According to Equation 3.3, if the distance between the reference node and the positioning node is to be determined, the values of the positioning parameters A and N must be known. Therefore, this first carries out simulation operation on the barrier-free space. Firstly, a positioning node is fixed, and then six reference nodes with different distances from the positioning node are randomly selected to obtain its RSSI by simulation, and the distance d from each reference node to the positioning node is calculated, so a set of data (RSSI, lgd) can be obtained for each reference node. 6 groups of data (RSSI, lgd) were fitted according to Equation (5), and A=57, N=1.47 were obtained. This is shown in Figure 3.4.

$$RSSI = -(A + 10 \times N \times lg(d)) \tag{3.5}$$

Then, the area where the six towers are located in the substation is taken. Set the distance between the poles and towers of the substation as 2m. According to the fuzzy inference algorithm proposed in this , the personnel location in the substation is also simulated. Among them, the position of the staff can be arbitrarily changed. In this , four typical positions are selected for analysis.

To further ensure the accuracy of fuzzy operation, $RSSI_{med}$ is obtained by theoretical calculation. When the location of substation staff (positioning node) is in the middle of the whole positioning area, the distance d between the positioning node and reference node 1 is calculated, and then the $RSSI_{med}$ is calculated by Equation 3.3 according to the fitted function. The minimum RSSI value of all reference nodes is $RSSI_{min}$. There are 3 relative distances between the information node and its neighboring nodes, which are 2m, 4m and 4.472m respectively. The three distance values were set asd_{min},d_{med} and d_{max}.

Table 4.1: Positioning results

Locating Node Number	a	b	c	d	
	x/m	0	-0.5	0	0.5
Actual location	y/m	1.8	1.5	1	1
	x/m	-0.0053	-0.1255	0.076	0.4881
Fuzzy algorithm	y/m	1.7617	1.5199	1.007	1.0024
	x/m	0.0389	0.3755	0.076	0.0112
Direct ranging	y/m	0.8314	0.0838	1.4115	0.8069
algorithm	y/m	1.7616	1.5199	1.007	1.0025
	e/m	0.8323	0.5846	1.4113	0.3064

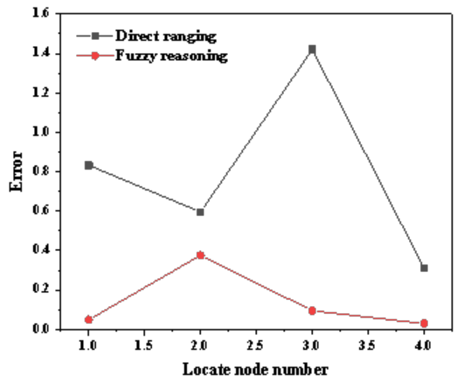

Fig. 4.1: Positioning error

4. Results and Discussion. In the simulation process of this paper, firstly, according to the fuzzy reasoning algorithm, the output credibility of all adjacent reference nodes is obtained. Then, two neighbor nodes with high reliability are extracted from each location node. Finally, the specific location of the staff in the substation is calculated by the trilateral method by combining the two adjacent reference nodes with high reliability with the signal nodes, as shown in Table 4.1. For comparison, for the direct ranging algorithm that directly selects the three largest RSSI values and their corresponding reference nodes for positioning, the trilateral method is also used to do the positioning calculation. The simulation results are shown in Table 4.1.

The positioning error is in formula 3.6

$$e = \sqrt{(x - x_0)^2 + (y - y_0)^2} \tag{4.1}$$

where: x,y is the staff coordinate obtained by simulation calculation; x_0,y_0 is the actual coordinate of the staff.

As can be seen from Table 4.1, the positioning accuracy after the algorithm improvement is significantly higher than that before the algorithm improvement. Fuzzy algorithm is an effective mathematical tool that can handle uncertainty and fuzziness problems in reality, and has advantages such as flexibility, adaptability, and interpretability. In addition, the improved positioning error is more stable than that before the algorithm is improved, and is stable within a small error range. As shown in Figure 4.1, the maximum is 0.3755m, and the maximum error before improvement is 1.4115m. It can be seen that compared with the positioning algorithm before the improvement, the improved positioning algorithm can locate substation personnel more accurately.

5. Conclusion. In this, the substation personnel location system based on wireless sensor network is proposed, and the substation personnel location method based on ZigBee wireless sensor network is adopted. Aiming at the shortcomings of low accuracy and unstable error of the direct ranging algorithm used in ZigBee, a fuzzy inference algorithm is proposed. Through simulation, it can be known that the fuzzy inference algorithm has the following advantages for substation personnel location: (1) low cost. Using fewer nodes to locate the station staff; (2) High accuracy. Compared with the direct ranging algorithm, the positioning accuracy of the fuzzy inference algorithm is greatly improved; (3) Good positioning stability. Through the fuzzy inference algorithm, the error can be controlled within a small range. (4) It has wide applicability and can accurately locate mobile personnel in substations with large obstacles, which is expected to be popularized and used in various substations and even other positioning fields. (5) Handling ambiguity: There are various interference factors in the positioning of substation personnel, such as multipath effects of signals, changes in signal strength, and target movement. These factors can lead to errors and uncertainties in the positioning results, and fuzzy inference algorithms can handle these uncertainties, making the positioning results more accurate and reliable.

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Edited by: Bradha Madhavan
Special issue on: High-performance Computing Algorithms for Material Sciences
Received: Feb 1, 2024
Accepted: Apr 17, 2024